This is to certify that the

thesis entitled

Rein Tension during Horse-back
riding activities

presented by

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has been accepted towards fulfillment
of the requirements for

MS degree in Animal Science

Christine Skelly
Major professor

Date 12/11/01

REIN TENSION DURING HORSE-BACK RIDING ACTIVITIES

By

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A Thesis

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

MASTER OF SCIENCE

ANIMAL SCIENCE

2001

ABSTRACT

REIN TENSION DURING HORSE-BACK RIDING ACTIVITIES

By

Wesley H. Singleton

Description of the rider's communication with the horse through the bit and reins, also known as rein aids, is based on subjective interpretation. The purposes of this study were to develop and test an objective system for measuring and displaying rein tension. A technique was developed in which force sensors, inserted between the bit and rein, were used to measure rein tension. Data were transmitted via a cable to a laptop computer, which gave a real time display of the rein tension output and stored this information on the hard drive. Video images were synchronized with the rein tension data, so that changes in the tension profile could be correlated with movements of the horse and rider. The system was tested using two riders on the same horse. In both cases, the rein tension data showed a spiky profile with characteristic patterns at the walk, trot and canter. Video evaluation indicated that rein tension spikes were related to the timing of the horse's footfalls and movement of the horse's neck and to the action of the rider with the hands and body posture. Rider experience appeared to influence the rein tension data. It was concluded that the equipment and technique are adequate for measuring dynamic rein tension and that the results obtained are far more precise and accurate than those perceived by the rider. The use of this technique provides objective measurement of the rein aids and offers a way to analyze, compare and understand the rein aids as a means of improving horse-rider communication.

Dedication

I dedicate this work to all horses for putting up with us, demanding and clueless humans.

Acknowledgements

♠ Thanks to Dr. Clayton for giving me the chance to work and study at The Mary Anne McPhail Equine Performance Center and for all the help and patience completing this work.

♠ Committee members Dr. Chris Skelly, Dr. Gary Cloud and Dr. John Shelle for advice, support and help with this manuscript.

♠ Joel Lanovaz for all the technical help in this project and for writing all the handy customized programs.

♠ Family for unconditional support.

♠ Friends for help and joy.

♠ No thanks to burrocratic institutions for hindering and minimizing this work

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Chapter 1 Introduction

As we enter the 21st Century, equestrian sports are a popular recreational activity that involves the interaction of a human and a horse. This interaction has existed for thousands of years and has in many ways shaped the history of mankind. In the beginning, wild horses represented a food source, then horses became domesticated as animals of burden following the example of oxen and onagers. But what separated the horse from other domesticated animals were its superior speed, strength and stamina, characteristics that made this species more suitable for providing transportation and as a vehicle in warfare. With the arrival of modern technology, tractors, trains, trucks and tanks replaced horses in the fields and on the roads and battlefields. More recently horses have become popular again, this time as leisure companions and as competition athletes.

In order to use the horse for transportation, warfare or sporting activities, mankind needs to control and direct the horse's movements and gaits. Many control or restriction devices have been developed, some of which are still in use today. The use of a mouthpiece or bits within the oral cavity of horses is probably one of the most universal and most successful control devices. Evidence of ancient bits and their widespread use in today's equitation indicates the importance of bits in horsemanship. However, the use of a mouthpiece alone does not assure the control of the horse during riding activities. There is also a need for a correct method for training and riding horses and teaching them to respond appropriately to the action of the bit.

Successful training and riding methods take into consideration the cyclic motion of the equine gaits to yield a better communication between horse and rider as well as optimal performance in equestrian sports. The rider influences the horse's movement using cues, also known as riding aids, to steer, control speed and impose rhythm in order to perform the chosen task. The riding aids are a progressive and refined language that has to be taught to the horse. Riding aids involve coordinated use of the different body segments of the rider in timely fashion at particular instants of the horse's cyclic motion, inducing the horse to alter his gait within the pressures and restraints of the rider. Through repetition and reward the aids given by the rider and the trained reactions of the horse become more automatic, efficient and elegant.

The correct use of rider's hands, also known as rein aids, is linked to fine performance in equestrian activities and therefore has received great attention in the equestrian literature. Many different training methods and many types of riding equipment are available giving the rider a great variety of tools to train the horse. The way the rein aids are used depends on many factors including the type of bit used, the activity performed, the level of training and temperament of horse and rider. The capability of each rider to perceive and alter the action of the rein aids and the resulting restriction in the horse's motion is only one of the many difficulties the rider may face. The rider is constantly receiving input regarding balance and motion of both horse and rider. The large amount of input received at once could limit the correct perception of specific actions (e.g. rein aids) by the rider. Therefore, the subjective information given by riders is probably somewhat imprecise.

Modern technology and science make use of objective tools to measure and quantify different physical phenomena. The study of horse motion, also known as equine biomechanics, offers valuable information that is not perceptible to the human eye. The equine biomechanical literature gives researchers detailed and precise information on the nature of horse movements that can be used to quantify normal movement as well as adaptations in horse gaits to different conditions, such as riding.

The riding aids transmitted by the rider to the horse are a key factor in equestrian sport performance since they are the primary means of communication between rider and horse. The rein tension developed between the rider's hands and the horse's mouth, probably the oldest of all riding aids, deserves objective evaluation in order to understand its effect on sport performance.

Although conventional training methods have proven successful in training horses and riders for different riding activities, the exact nature of the interaction between rider and horse is not known. Application of a more scientific approach to the study of equestrian activities will provide a better understanding of the problems that horses and riders may face during riding activities. Understanding such problems can, in turn, help trainers and riders to pursue better solutions and improve the art of riding and training horses.

1.1 Objectives of study

The primary objective of this study is to develop a valid system for objective measurement of rein tension between horse and rider and to provide visual correlation of the riding events with changes in rein tension to better explain this interaction. The secondary objective is to apply the system in studies of riding technique.

Chapter 2 Literature review

2.1 Ancient horsemanship

Horses have played an important role in the history of civilization. Ancestors of modern horses inhabited the area north of the mountain ranges that run from Mount Everest in the Himalayas to Mont Blanc in the French Alps. Two distinct types of horses existed, the Przewalski horse found in Central Asia and the Tarpan horse found in Europe. In ancient cave drawings horses were predominantly depicted since they constituted an abundant food source in the wild. In the Neolithic period (12,000-10,000 BC) mankind changed from hunter to farmer, domesticating animals for food, leather and as beasts of burden in transportation and agriculture.

Domestication of horses and their use for working and riding activities seems to be linked to the development of an adequate method of confinement and restriction. Horse skulls and teeth found on human camps in the Ukraine dating back to 3,500 BC have wear pattern on the second premolar tooth that are similar to teeth of modern horses that have been ridden with a bit (Anthony and Brown, 1991). The bridle is adjusted so that the mouthpiece of the bit is aligned with the diastema, a region that is devoid of teeth. Horses use their tongue to push the bit up and backward or they raise their heads so that the bit contacts the rostral edge of the second premolar tooth (Figure 2.1). When the horse closes its jaws with the bit between the teeth to resist the action of the rider's hands the rigid bit causes microscopic lines or fractures in the horse's teeth. Lesions of this type have been found in skulls dating back to 3,500 BC, which implies that horses were already being ridden with mouthpieces at that time (Anthony and Brown, 1991).

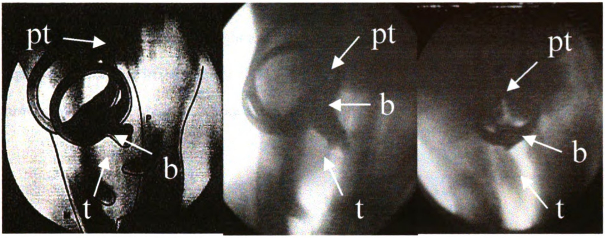


Figure 2.1: Fluoroscopic pictures of a jointed snaffle bit in the horse's mouth. pt (premolar teeth), b (bit) t (tongue). Normal position in horse's mouth (left), horse moves bit upward with tongue (center) and raises bit up further between the second premolars where horse can bite mouthpiece (right) Courtesy of Dr. H.M. Clayton

The use of the horse as draft animal to pull chariots rather than carry riders was the first military use of the horse recorded historically around 1,800 BC (Chenevix, 1970). Two men were needed, one to control the horse and drive the chariot and the other to fight the enemy by throwing spears or firing arrows. Charioteering began in the region between the Caspian Sea and the Black Sea and it had spread as far as Egypt and India by 1,500 BC (Chenevix, 1970). Since horses were growing larger and stronger as a result of consuming larger quantities of higher quality food, combined with selective breeding, their control became more difficult. For this reason the development and successful use of cavalry did not occur until 900 BC when better training methods for the horse were used.

Many restriction mechanisms were developed by mankind in order to facilitate the control of horses. The bit or mouthpiece dates at least to 3,500 BC (Anthony and Brown, 1991) and its use became widespread among horse handlers as the device of choice for controlling the horse. Many shapes of bits have been developed to provide adequate control to the rider. Straight and jointed snaffles (Figure 2.2 and Figure 2.3), equipped with spikes in the rings or cheeks at the side of the mouthpiece to facilitate turning were used for chariot driving dating back to 1,800 BC and 1,400 BC respectively.

Figure 2.2 Straight snaffle, 1,800 BC, used for chariot driving

Figure 2.3 Jointed snaffle, 1,400 BC, used for chariot driving

During the Roman Empire the Celts developed the curb bit (Figure 2.4), which uses a leverage action to give the rider more control over the horse. The leverage action of a curb bit increases the effect of tension applied by the rider to the reins so that higher pressures are transmitted to the horse's mouth compared to non-leverage bits.

It is important to keep in mind that the presence of a bit is of little use unless the horse is trained to respond to it in an appropriate manner. Since the development of the chariot to the present day, a large body of literature has been published which deals with training methods for different riding activities.

Figure 2.4 Modern curb bit. Notice length of leverage arms from mouthpiece to rings where reins are attached.

2.2 Equitation literature

Xenophon (430-354 BC), the Greek horse master wrote one of the first works on horsemanship and riding entitled *The Art of Horsemanship* (Xenophon, 1962). He addressed the most important aspects of horse care, riding and training. He specifically encouraged riders never to pull on the horse's mouth or misuse the bit, not to hit the horse with a whip or kick the horse with spurs. Xenophon stressed the use of the bit since during his time saddles and stirrups did not exist leaving the rider with little more than the bit to control the horse (Figure 2.5). In his view, it was important that each horse owner should have a minimum of two bits. One mild bit with big heavy rings and no spikes and a rougher bit with small rings and spikes. The appropriate bit was selected depending on the temperament of the horse or the activity being performed. He favored the use of flexible bits and the addition of small chains to the bit encouraging the horse to play with the mouth piece. This playing, also known as chewing the bit, prevented the horse from locking his mouth or jaws against the bit and resisting the rider's rein aids.

Figure 2.5 Greek riders without saddle or stirrups.

The saddle, stirrup, curb bit and horse shoes had been developed by the end of the Roman Empire (van Weeren, 2000). The availability of these additional methods of control allowed the evolution of heavy cavalry during the Middle Ages. The horses were expected to support the immense weight of the rider's armor and weaponry, which produced great discomfort causing horses to become resistant. Mechanisms for controlling the horses became more severe, particularly in their effect on the horse's mouth.

Little equestrian literature was written during the Middle Ages although horses became the backbone of military and economic power. It was during the Renaissance that the art of horsemanship regained momentum with the creation of riding schools. The first riding school was founded in Naples where the horse master Grisone published his book *Gli Ordini di Cavalcare* (Grisone, 1550). Grisone's method had a strong medieval influence, as shown by the fact that the bits used were always curb bits, with solid (straight) or jointed mouthpieces. In today's equitation these bits would be considered instruments of torture, since they were often equipped with spikes. Many other riding schools and horse masters appeared after the creation of Naples Riding School, which promoted more refined training methods and use of more reasonable types of bits. The most notable of these training methods are mentioned here in relation to subjective impressions of these master trainers regarding the rein tension.

The French trainer Baucher mentioned some aspects of the use of bits in his book *Method of Horsemanship* (Baucher, 1852). In this book, Baucher expressed the opinion that there was no difference between horses in sensitivity of the mouth to the bit and all horses presented the same lightness when in the position he called "ramener". Ramener is an upright position of the horse's neck with the front of the head perpendicular to the ground (Figure 2.6). The contact between rider's hands and horse's mouth was described as being like that of "cutting butter". Hardness in the horse's mouth to the rider's hands was thought to come from conformational defects of the horse, such as long or weak loins, narrow croup, short haunches, thin thighs, straight hocks or a disproportionate croup to withers height. Contraction of the neck muscles and closing of the jaws were thought to occur in response to such weaknesses. The use of exercises to supple the neck and the jaw caused this hardness to disappear.

Figure 2.6 Ramener position. Notice perpendicular position of horse's head

The book *Gymnasium of the Horses* (Steinbrecht, 1884) offers a different perspective. Steinbrecht argued with Baucher's idea of ramener or butter-like contact, saying that each horse established a different "working contact" depending on conformation, temperament and training level. Steinbrecht also stressed that the restraining aids (rein aids) were not necessarily better under soft hands, since they were the product of the correct carriage of the horse during motion. The rein aids were dependent on the correct use of all of the other riding aids and vice-versa. The length of the reins during different riding activities determined the rein tension or "contact" established with the horse's mouth. So riding with long reins produced a softer contact than riding with short reins. Excessive rein tension in turn stiffened the movement of the horse and was detrimental to the supple use of its joints. Steinbrecht speculated that the suspension phase was key to the horse's movement since muscle relaxation can occur as a result of no contact with the ground.

The book *Give Your Horse a Chance* (D'Endrody, 1976) described different types of rein commands that can be used by the rider and the purpose of using them. The rein for maintaining contact was described as an uninterrupted smooth connection between the bit and the horse's mouth, neither pulling nor being loose. The retarding rein is a soft taking action, which has not yet been completed when the pulling terminates and is used to prepare the horse for a new command. The directing or turning rein consists of a simple pull of the rein on the side to which the turn should be made. The counter balancing and lateral moving rein is used to make a lateral movement with the forehand or shoulders, or to prevent the horse from doing so of its own accord. The collecting rein is the same as the lateral moving rein but it is applied simultaneously with both hands in order to achieve collection. The loosening rein is to release the stiffness in the lateral muscles of the horse's neck (Figure 2.7). D'Endrody also argued that the horse's confidence can only be won if the contact established does not cause the horse any inconvenience in the mouth. Otherwise the horse may manifest this discomfort by altering his working posture and regularity in the movements performed.

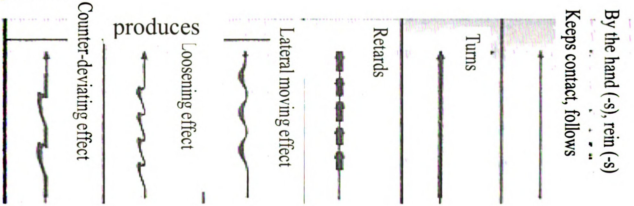


Figure 2.7 Illustration of rein action for different movements.
From D'Endrody (1976)

Another interesting work is *Das Dressur Pferd* (Boldt, 1978) which uses pictures and diagrams to explain the riding aids required to perform different dressage movements. The rein aids are presented in two different gradations of rein contact, loose contact (allowing rein) and maintaining contact (non-giving rein). Other riding aids are also described and illustrated by sequential pictures and diagrams that allow the reader to picture the sequence of aids needed to perform the movement (Figure 2.8).

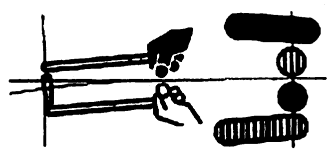


Figure 2.8 Diagram of the different riding aids applied during specific movements
From Boldt (1978)

2.3 Horse biomechanics

Kinematic (Buchner et al., 1996) and accelerometric (Barrey et al., 1994) studies performed on horses moving on the treadmill have shown that when the horse's body is viewed in a sagittal plane several of the segments show a sinusoidal movement pattern within each stride. The head/neck, withers and croup show such a pattern, but vary in the amounts of vertical displacement, velocity and acceleration. Each gait has its own characteristic pattern of displacement and rotation. At the walk two sinusoidal patterns are described in each complete walk stride (Buchner et al., 1996) while performing a four beat rhythm. At the trot two sinusoidal patterns are present within each stride, associated with the two beat rhythm of the diagonal limbs. The head, withers and croup are lowest around the time of diagonal midstance and highest during the short suspension (airborne) phases between the diagonal stance phases at the trot. The total vertical excursion of the head for horses trotting on a treadmill at 3.5 m/s was about 6-7 cm (Buchner et al., 1996). The trot also showed a high degree of symmetry between the left and right sides in sound horses moving at slow speed in a straight line with higher symmetry in the front limbs than in the hind limbs (Pourcelot et al., 1997).

At the canter the neck and trunk are lowest during the diagonal limb stance and are raised during the leading forelimb stance phase and suspension phase reaching their maximum height as the trailing hind limb contacts the ground. Thereafter the neck and trunk are lowered until the leading forelimb makes contact. The importance of this research to the work described in this thesis is the fact that the horse's body moves in a sinusoidal pattern under normal conditions.

The ground reaction forces expressed in Newtons (N) generated by horses depend on gait and speed (McLaughlin et al., 1996) ranging from 1-1.6 N/kg at the walk, 10-12 N/kg at the trot and considerably higher at the canter and gallop. When horses are ridden, ground reaction forces increase in the forelimb, but little change occurs in the hind limbs (Clayton et al., 1999). If the weight of the rider was added to the system (horse + rider) the combined weight-normalized ground reaction forces would be lower in ridden horses than in non-ridden horses (Clayton et al., 1999). The experience of the rider plays a role in determining the magnitudes of the forces, so an experienced rider is equivalent to an equal weight of sand-bags while an inexperienced rider increased the forces more than the equivalent weight in sand-bags (Sloet et al, 1997). For a horse moving on a treadmill the presence of a rider resulted in an increase in stance duration and fetlock extension (Sloet et al, 1997). This research shows that the presence of the rider alters the movement of the horse to a greater or lesser degree. A kinematic study of rider position measured shoulder, hip, trunk, thigh, and lower leg angle at the walk, posting trot and sitting trot for 78 riders clustered in 3 riding levels (beginner, intermediate, advanced). The results showed significant differences in all variables except knee angle. Experienced riders carry all their joint angles more open as a result of straighter body posture (Schils et al., 1993).

The balanced rider's position allows for what is described in equestrian terms as the "independent seat". The body of a rider who displays an independent seat moves in conjunction with the horse's body independent of the movements of other body segments and the use of other riding aids. A rider who does not display an independent seat is not able to maintain a smooth and consistent movement pattern that is in harmony with the horse, since the seat and weight aids are disturbed by use of the legs and hands of the rider (British Horse Society, 1982).

The rider's weight and hands (rein aids) can restrict freedom of the natural movement of the horse, in particular movements of the neck and poll, which in turn affect the horse's back. If constant incorrect posture and movement of the horse is caused by the rider, then temporary or permanent damage in the locomotive system may occur (Meyer, 1999). Regularity in movement may not be as constant as expected as shown in a study using an instrumented saddle pad equipped with pressure sensors (Jeffcott et al, 1999). With this technology it was observed that the pressure patterns occurring beneath the saddle as a result of the horse's movement and the rider's weight and seat aids did not follow a consistent pattern for more than 3 seconds (Jeffcott et al, 1999).

Fluoroscopic studies of the position and action of various bits relative to the horse's mandible have been performed with the horse trainer manipulating the reins and therefore the bit as if long lining the horse (Figure 2.1) (Clayton and Lee, 1984). The use of a bit that was too wide for the horse's mouth or a bit of the correct width that was positioned too low in relation to the horses lips, increased the range of movement of the bit within the oral cavity. The use of one rein did not produce an independent action on that side of the horse's mouth, since it also affected the other side due to the bit moving on both sides of the horse's mouth (Clayton and Lee, 1984). The study was repeated with different kinds of bits to give insight as to how different bits act on the horse's mouth (Clayton, 1985). Seven pressure points within the horse's mouth were observed depending on the bits used (Clayton, 1985).

2.4 Strain measurement technology

Selection of a suitable technology for measuring rein tension requires an understanding of the forces acting on the system. To visualize this we could imagine two individuals pulling on a rope, also known as tug of war (Figure 2.9)

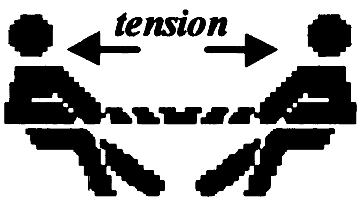


Figure 2.9 Tug of war

Rein tension is generated in a similar manner with the pull being created between rider's hands and horse's mouth. Force transducers have been used for many applications. For example, they have been applied to study the torque at the shoulder and hip joints in athletes performing a backward giant swing on the rings. One of the cables suspending the rings had a force transducer between the top of the rope and the ceiling. The measured tension was combined with the kinematic data to calculate joint torque and rate of energy generation and absorption using the inverse dynamics technique (Sprigings et al., 2000). This research showed that the use of force transducers is adequate for measuring dynamic tensions.

Another study investigated the restrictive effect of different types of head gear used in horses by means of a force transducer located in the rein (Preuschoft et al., 1999). Data for the walk, trot and canter of one rein were presented. The rein tension showed a sinusoidal like pattern with the maximum magnitudes generated ranging from 30 N at the walk to 80 N at the trot and 60 N at the canter. These magnitudes were relatively high considering that they are equivalent to approximately 3, 8 and 6 kg of weight for the mentioned gaits.

2.5 Perception

Assessment of rein tension is highly subjective and has not been determined accurately. In the field of psychophysics, Weber (1834) presented the results of experiments on the tactile senses. Regarding the discrimination of an object's weight, Weber concluded that different parts of the body sense the same weight differently and that there are differences between left and right hands in discriminating weights. The perception of an object's weight can be misleading to the human observer depending on its size, texture and rotational properties. Charpentier (1891) presented a theory known as the weight-size illusion. The weight of light objects with large volumes tends to be overestimated. The weight of an object with a smooth surface is also overestimated unless it is being held with the hand in the horizontal position. The tighter grip applied to prevent slipping of a smooth object compared to one with a rougher surface causes the overestimation of its weight (Flanagan et al, 1995; Flanagan,1997). The rotational properties of an object, determined by the distribution of its shape and density, also cause mis-leading perceptions of weight depending on the way the object is held (Amazeen et al, 1996). Fatigue can also hinder the perception of weight so that the observer assesses the same weight differently under rest or fatigue situations (Burguess et al., 1997).

No papers on perception issues have been written about horse-back riding activities, but it is assumed that many mis-perceptions may occur, since rein tension is only one of the many issues riders have to deal with while riding a horse.

Chapter 3 Pilot study

The objective of this research was to develop a system to study the riding aids using technology that would allow the data to be recorded, stored and reviewed in the future. The practical goal was to give riders and trainers a visual and graphical representation of the magnitude and timing of the rein aids.

The author was aware of some unpublished experimental trials performed by other research groups that tried to measure rein tension. In those studies strain gages were attached onto the leather reins, but as a result of the tension developed and the movement (stretching) of the rein, the strain gages broke and little or no data were recorded. This raised some concerns about choosing an appropriate type of measuring device and attaching it in an appropriate manner. It seemed difficult to install different strain gages on the reins, since the elastic properties of the leather would again stretch the thin strain gage beyond its capacity and break it. It seemed to be preferable to use sensors that could be attached independently from the reins, rather than on the rein itself.

A commercial sensor manufacturer called Transducer Technologies (Temecula, CA) produces a range of sensors of different capacities that seemed to fulfill the needs of this study in that they were light weight, had high resistance (to avoid overloading and breaking), and offered good accuracy. Therefore, the MLP sensor series seemed to be a good choice for the purpose of this study. Table 3.1, which has been taken from Transducer Technology's web page (www.ttloadcells.com), gives information describing the properties of the sensors.

The tension capacity of different sensor models ranges from 10 lb to 1000 lb. However the range of tension that could be developed in the reins was not known, so a pilot study was performed using a sensor with a tension capacity that exceeded our estimate of the maximal tension likely to be generated in the reins. The MLP 300 series was chosen for this pilot study. It accurately measures tension up to 300 lb (1,334 N) and can withstand 450 lb (2,002 N) tension before breaking and the sensor weighs only 85 g (3 oz).

MODEL	CAPACITY LBS.	NATURAL RINGING FREQUENCY HZ	DEFLECTION INCHES	WT. OZS.
MLP-10	10	2,175	.003	.5
MLP-25	25	2,200	.003	.7
MLP-50	50	2,500	.003	.7
MLP-75	75	2,800	.003	.8
MLP-100	100	4,500	.003	.8
MLP-150	150	4,500	.003	1.3
MLP-200	200	5,200	.003	1.4
MLP-300	300	5,200	.003	3.0
MLP-500	500	5,200	.003	3.0
MLP-750	750	5,200	.003	3.0
MLP-1K	1,000	5,200	.003	3.0

Table 3.1 Description and properties of sensors manufactured by Transducer Technologies

One MLP-300 sensor was purchased and attachments were made to insert the sensor between the rein and bit (Figure 3.1). The sensor recorded tension across two screws, so the screws had to be securely attached to the bit ring on one side and the rein on the other. A loop of braided wire was threaded through the hole in each sensor screw and looped through a clip that attached to the bit ring or the leather loop at the end of the left rein. The wire was secured using a hook clamp.

The wires carrying power to the sensor and the wires carrying the signal from the sensor were connected to a laptop computer using a long cable. The equipment used to transmit, process and store the signal will be described in detail in chapter 4. An assistant supported the cable manually as the horse was ridden in circles around the computer (Figure 3.2). A horse was selected that was known for its heaviness on the bit, since the objective of this pilot study was to estimate the maximum tension likely to be developed between the horse and rider. To this effect the rider was instructed to ride strongly with the hands to maximize tension on the horse's mouth. Recordings were made at the walk, trot and canter with each recording being 5 s in duration, as the horse was ridden in a circle on the left and the right reins (counter clockwise and clockwise direction), so the sensors recorded tension on the inside and the outside reins.

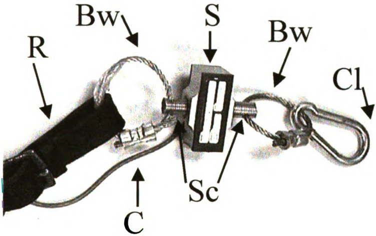


Figure 3.1: MLP 300 tension sensor (S) attached through hole in screws (Sc) by braided wire (Bw) attachments to rein (R)(at left side) and clip (Cl) that hooked onto the bit ring (at right side). Cable (C) carrying voltage and returning signal attached to reins.

A video camera was set up on a tripod outside the horse's circle of motion. The field of view was set to include the entire circular path followed by the horse. Synchronization was achieved by audio triggering (shouting) when the computer operator started recording rein tension. In this way, the audio track on the videotape was used to identify the initiation of the 5 s trials. This method of synchronization gave a rough estimate of events observed on the video tape as the rein data were collected.

Figure 3.2: Horse being ridden with MLP 300 sensor. Assistant walks beside the horse supporting a cable that connects the sensors to a power supply and a computer. The horse is ridden in circles around a laptop computer.

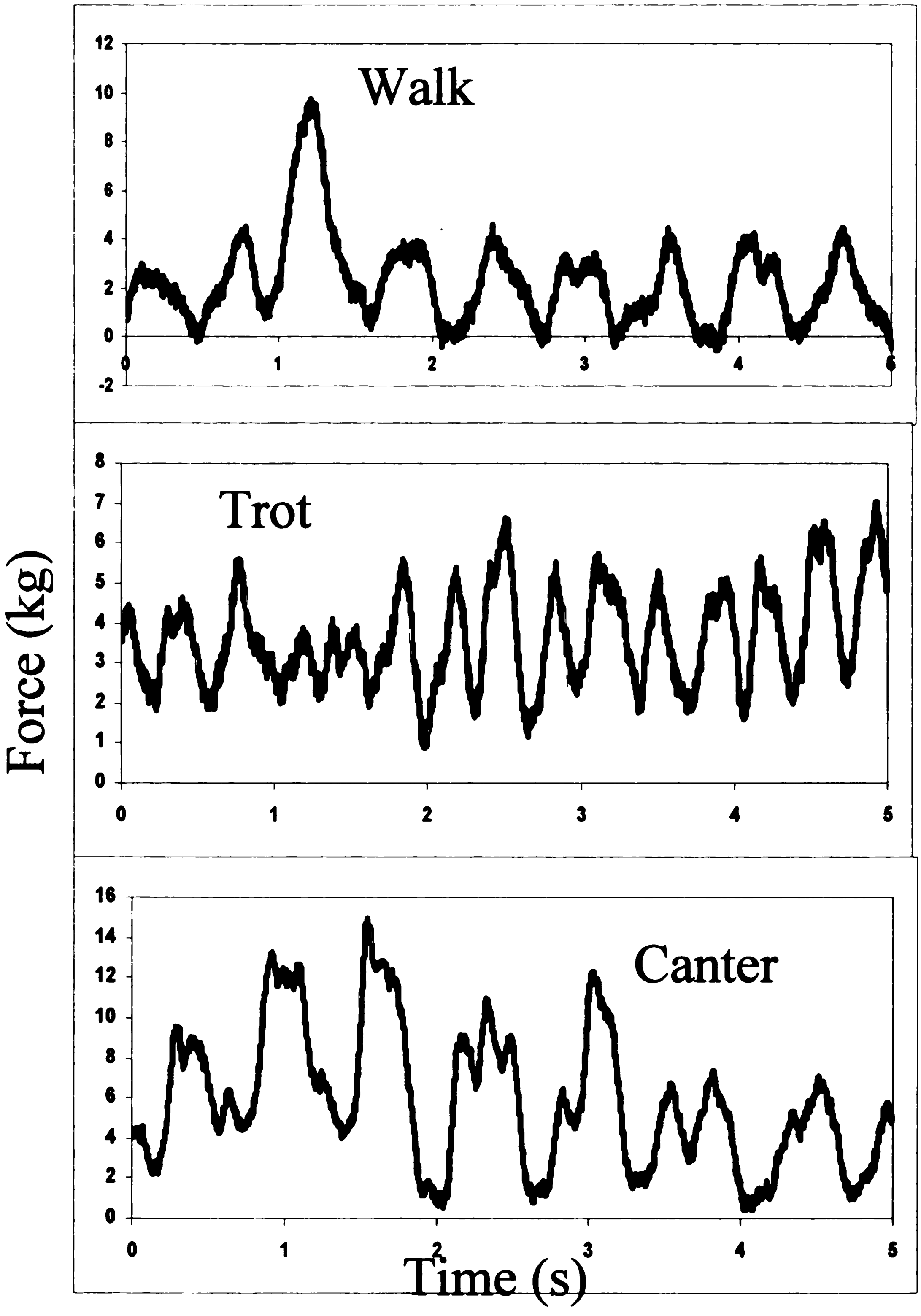
After completion of the data collection, the laptop computer was taken to the lab and the data were graphed using an Excel worksheet. The graphic output was rather surprising in that the profile of the rein tension graphs was quite different to what the rider and researchers expected. Although the rider perceived a high but consistent tension in the reins, the data showed repetitive patterns of spikes at the walk, at the trot and at the canter (Figure 3.3). Furthermore, rein tension was higher in magnitude then expected reaching maximal tension of 156 N, equivalent to 15.9 kg (35.1 lb).

There were questions as to whether the data collected were an accurate representation of rein tension, since the rider did not feel the spikes and valleys observed in the graphs. One possible source of error was the wire connectors used to attach the sensors to the reins and the bit, which had some elasticity that might change the rein tension signal by damping or retarding the actual rein tension. This possibility indicated the need for a more rigid bit-sensor-rein connection in future studies.

The videotapes were reviewed in an attempt to correlate the spikes with kinematic events in the stride. It was observed that the peaks of rein tension occurred around the time of limb contact with the ground, which seemed to indicate that the peaks and valleys observed in the data were a product of the horse and rider action and not of inaccuracies in the measuring system.

The results of this pilot study were used as a basis for selecting an appropriate sensor for future studies and for improving the method of intercalating the sensors between the bit and the rein. For the horse and rider used in this pilot study 156 N (15.9 kg, 35.1 lb) maximum tension was recorded. However, the rider was a small female and it was assumed that a larger, stronger person might generate more tension, so a margin of safety should be allowed. The MLP 50 and MLP 75 (50 lb and 75 lb, respectively) would have been reasonable choices for this horse-rider combination but may not be adequate for larger/stronger horses and riders. Since the difference in weight and size between the MLP 50, MLP 75 and MLP 100 were very small or non existent (Table 3.1), it was decided to use the MLP 100. This sensor can accurately measure 444.8 N (45.4 kg, 100 lb) and can withstand 667.3 N (68 kg, 150 lb) of tension before failure.

Another important finding from this pilot study was that the use of a synchronized video images of the riding events was of great importance in understanding and interpreting the rein tension developed between horse and rider. One of the challenges would be to develop a more precise method of synchronizing the video images with the rein tension data.



Figures 3.3 Rein tension recordings at the walk (top), trot (middle) and canter (below) for one rein.

In summary, the pilot study confirmed the feasibility of using the MLP sensor technology to measure rein tension in conjunction with video recordings during riding. The results indicated the MLP-100 sensor, which measures accurately up to 444.8 N (45.4 kg, 100 lb) and withstands 667.3 N (68 kg, 150 lb) before breaking, should be adequate for the purpose. A rigid connection between sensor and bit/rein is needed to avoid damping of the signal. It is highly desirable to correlate the rein tension recordings with the movements of horse and rider, so a more accurate method of synchronizing rein tension with video data is required. The use of a cable connecting the sensors to a power supply and recording device was inconvenient, since it restrained the movements to a circular path. A future development might include the use of a telemetry system to transmit data to the computer without the need for a cable, thus allowing more freedom of movement.

Chapter 4 Development of equipment and analysis techniques for the measurement of rein tension

4.1 Rein tension measuring system

The objective was to develop a measuring system that was relatively simple and inexpensive and that could be used in a practical setting to evaluate horse-rider interaction. The general plan was to use two tension sensors attached between the bit rings and the reins, one on the left side and one on the right side. The sensors would be tethered (connected through a cable) to individual signal processing units that provide voltages to the sensor and transfer the sensor output to a computer for display and storage. As a result of the need to tether the system, the horse and rider would be restricted to riding in a circle, around the computer, since the development or purchase of a telemetry system was beyond the scope of this thesis.

When the results of the pilot study were evaluated, there was some concern that any elasticity in the attachment would affect the tension recorded by the sensors. The twisted wire connectors used in the pilot study might show some movement, so a more rigid attachment system was sought. The system that was chosen consisted of double threaded ¼ inch diameter screws that joined the sensor to a rigid metal frame connecting to the bit ring on one side of the sensor and to the reins on the other side of the sensor (Figure 4.1). The connectors between rein-sensor-bit were purposely rigid, as opposed to elastic, in order to avoid damping or delay in the tension developed between the horse leaning on the bit and/or the rider pulling on the reins. Aluminum was used to build these connections with the objective of making them as light as possible. This was necessary to avoid changing the weight sensation on the horse's mouth when the reins were loose and to avoid contaminating the tension readings as a result of the added weight. The entire sensor and its attachment system on each side, consisting of two connectors, two screws and one sensor, had a total weight of 56.7 g (2 oz).

MLP-100 sensors (Transducer Technologies Inc. Temecula, CA) were used. These sensors measure tension up to 444.8 N (45.4 kg, 100 lb) linearly and that can withstand 667.3 N (68 kg, 150 lb) of tension as guarantied by the manufacturer. The MLP 100 sensor consists of bonded foil strain gages arranged in a balanced Wheatstone bridge configuration.

In the pilot study described in Chapter 3, the MLP-300 sensor was used which has an accurate tensile capacity of 1334 N (136.1 kg, 300 lb). The maximum tensile force generated between a horse with a hard mouth (heavy contact) and a small rider purposely pulling hard on the reins was 156 N (15.9 kg, 35.1 lb). This information was used to select the appropriate sensor. The MLP-100 was considered to have a large enough margin of safety, and the advantage over the MLP-300 was that the threshold gives a more accurate bit resolution. The MLP-100 sensors are low in weight 22.7 g (0.8 ounces) and small in size (length 4.2 cm, width 1.6 cm and height 1.9 cm). They are sturdy and reliable enough to be used around horses, but small and lightweight enough not to interfere with the riding activities.

An unshielded, eight strand, 30ft cable (Belden-M 9421 CMG 8C22 Las Vegas, NV) was used to connect the sensors to two signal processing units (Vishay Measurements Group P-3500 Strain Indicator, Raleigh, NC). Four strands were used for each sensor, two strands provided excitation voltage (2 VDC) from the signal processing units to the sensors. The sensors produced a voltage change (ΔV) in response to the load

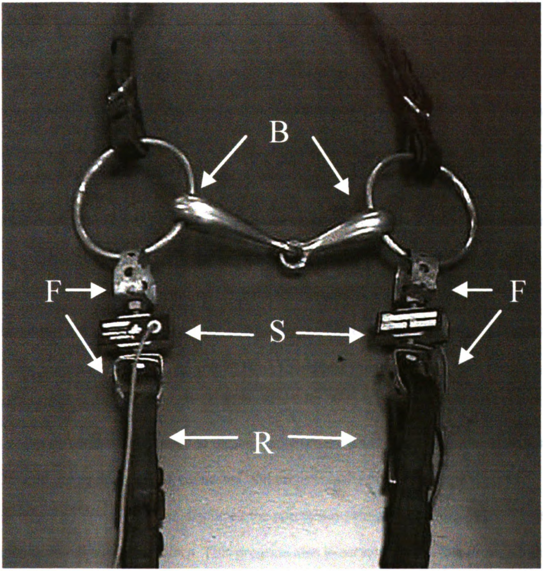


Figure 4.1 Sensor attachment to bit and reins. The cable attached to the reins is easily visible on the left of the figure. The sensor (S) is attached via an aluminum frame (F) to the bit ring (B) and to the rein (R).

acting on the reins, which was transmitted via the remaining two strands from the sensor back to the signal processing units. The signal processing units were set in a full bridge configuration with 1X amplification and connected to a 12 bit analog-digital (A/D) board

(National Instruments DAQ CARD™-700, Austin, TX) located inside a laptop computer (Toshiba Satellite 2535 CDS, New York, NY) using BNC cables (Figure 4.2). The laptop computer had Pentium I 300 MHz MMX technology with 32 MB of RAM and sampled data at 1,000 Hz. The A/D board converted the continuous analog force data from the sensors into discrete digital levels called bits. The resolution of the digital data was expressed in N/bit and is dependent on the A/D board and the amplification of the analog signal. Due to circuitry and power supply configurations the two signal processing units produced different levels of amplification. This resulted in a digital resolution of 0.78 N/bit for the left sensor and 0.34 N/bit for the right sensor. This difference affected only the step increments of tension, but not its real value. Since the magnitudes of tension occurring as a result of the interaction between horse and rider are many times larger than the bit resolution, the data were not affected by the bit resolution difference. For example, if rein tension is 10 N (~1 kg), at 0.78 N/bit resolution, the value of the data was 12.8 times the bit resolution.

The laptop computer was used to display and store the data using a customized program. Once all the equipment was connected, the program collected the voltage changes generated by the sensors and displayed the rein tension already transformed from volts to pounds on the computer screen. This program also generated a pulse that drove a light emitting diode (LED) counter device displaying numbers (Figure 4.3). On the left side of its readout, the LED counter displayed increasing numbers between 0 and 416 during the 5 second (83.2 Hz) period of data collection. The numbers on the counter began to advance at the same instant as the computer started to collect rein tension data. The counter also displayed the current trial number on the right side of its readout. The same numbers displayed by the counter were recorded and stored simultaneously with the corresponding rein tension data. This enabled synchronization between the rein tension recordings and the events occurring during the trials by means of a digital video camera (JVC GR-DVL 9800, Wayne, NJ) that recorded the LED counter numbers and the movement of the horse and riders during the trials. The numbers displayed by the counter on the video images were matched to the same numbers in the rein tension file recorded by the computer.

The same measuring system, but without the counter, was used as an interactive tool in the laboratory environment. The bit was held in place while people pulled the reins and watched the resulting changes in rein tension displayed on the computer screen.

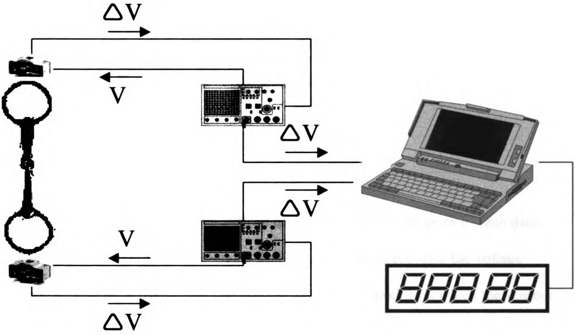


Figure 4.2 Recording instrumentation and setup. In center of the image are the two signal processing units providing voltage (V) to sensors attached to bit. As a result of pulling on the reins (not shown), a change in voltage (ΔV) is produced and transmitted from the sensors to the signal processing unit and then to an A/D board on the laptop computer. Simultaneously, the laptop computer generates a time sequence on an LED counter for synchronization with video recordings.

Figure 4.3 LED counter showing time sequence (3 digits on left side) and trial number (2 digits on right side).

4.2 Data collection

4.2.1 Equipment setup

The portable computer was positioned in the center of the riding arena on a cart, which also carried the two signal processing units and AD board. Power was supplied with an extension cord buried under the arena footing. A cable connecting the laptop to the LED counter was buried under the footing alongside the extension cord. The horse was tethered to the computer by a cable, and was ridden in circles approximately 20 m in diameter. The video camera captured the entire circle described by horse and rider using panning technique. The counter located outside the circle perimeter was visible on the video image throughout the recordings (Figure 4.4).

4.2.2 System calibration

The sensors were calibrated with all cables and attachments prior to each data collection by suspending known weights from the sensor and recording the voltage changes. A calibration device was constructed by using a tripod from which the sensors and weights could be suspended. The calibration was performed using ten weights that ranged between 0 and 22 kg. The regression calculation from the calibration was obtained and was used to establish accuracy and linearity of the system (Figure 4.5). The different slopes for the left and right sensors were due to the different bit resolutions. The regression equation was also used to convert the voltage readings into the actual tension in Newtons (N), pounds (lb) or kilograms (kg). The data stored in the computer were the raw voltage data and these were later transformed to the desired measuring unit.

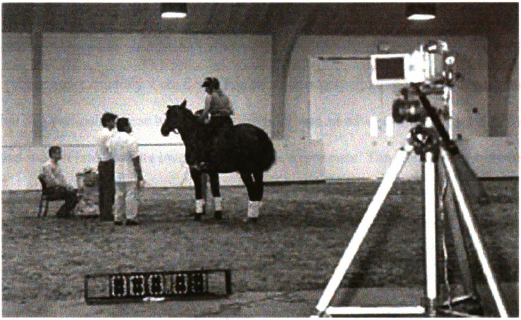


Figure 4.4 Data collection setup. Camera and counter located outside the arena perimeter. Cart with computer and signal processing units in middle of arena.

The same measuring system, but without the counter, was used as an interactive tool in the laboratory environment. The bit was held in place while people pulled the reins and watched the resulting changes in rein tension displayed on the computer screen.

4.2.3 Data collection schedule (rider and horse)

The horse used in the study was a well mannered, 20 year old Morgan gelding that had competed in 3rd level dressage competitions. The horse was exercised on a regular basis, about five times per week, and was used for dressage and trail riding. He was considered to be a good horse to carry the riders around the circle because he worked quietly around cables, machines and people. The horse's tack (riding equipment) used was the same for all trials and consisted of a loose ring, hollow mouth snaffle bit, which fitted the horse's mouth properly, and a bridle with flash nose band. The saddle used was the horse's regular working dressage saddle (Lauriche, Walsall, U.K.). The horse was transported to the Mary Anne McPhail Equine Performance Center, where data collections were performed in the indoor arena. The footing in the arena consisted of sand and rubber approximately 9 cm deep. The two riders participating in the study had never ridden this particular horse before. The first rider was an advanced dressage rider, the second was an intermediate level rider with less experience. Ten days passed between the first and second rider.

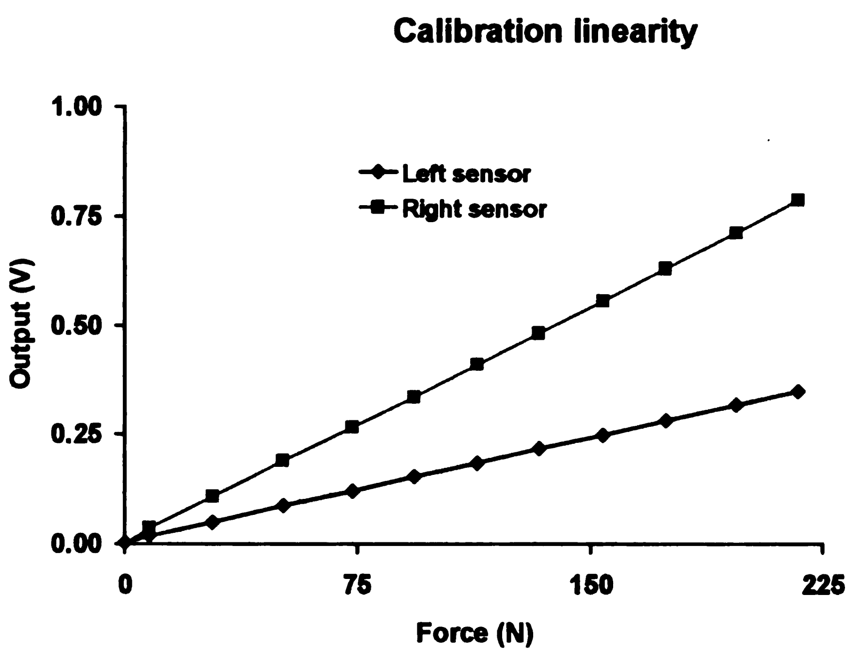


Figure 4.5 Calibration regression lines for left sensor (dark, diamonds) and right sensor (light, squares) showing linearity over the weight ranges used in calibration.

4.2.4 Riding activities and data collection

The rider and horse were allowed to acclimate and warm up using the entire arena for 10-20 min. After the warm up was completed the rider positioned the horse on the left rein (counter clockwise direction) and the tension sensors were attached to the reins and bit as described previously. The wires were taped to the portion of the rein not used by the rider (Figure 4.6), and stabilized using duct tape to attach them to the rider's waist. The cables extended from the rider's waist to the center of the arena where the computer was located.

Three volunteers assisted on the inside of the circle. One of them operated the computer, the second lifted the cable over the computer operator as the horse circled around them and the third accompanied the circling horse and rider supporting the cable and preventing it from dragging on the ground and upsetting the horse (Figure 4.7).

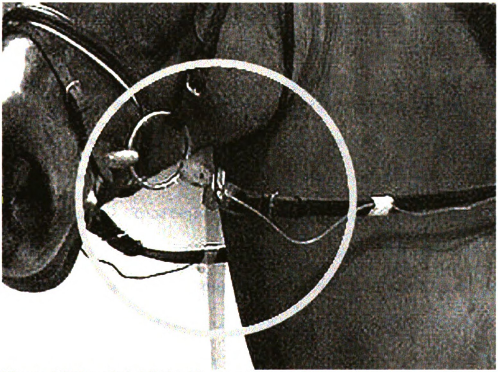


Figure 4.6 Horse's bridled with measuring equipment. Notice the cable carrying signal attached to the reins.

Figure 4.7 Image taken by digital camera. Horse circling around cart containing computer and signal processing units. Volunteers holding cable and lifting it over computer operator.

After the sensors, cables and connections had been attached, the horse and rider proceeded at walk, posting trot, sitting trot and at the canter in the left direction (counter clockwise) and then repeated the same gaits in the right direction (clockwise). Data were collected during 5 second periods as the horse and rider moved around the side of the circle closest to the camera. Because the speed of each gait was different the computer operator had to optimize the instant for initiating data collection. Storing the trial data and resetting the counter and system took some processing time by the computer so it was not always possible to record the next trial on the subsequent circle performed by horse and rider. At the canter every other circle was recorded. At the trot, recordings were made on every pass or every other pass depending on the speed and diameter of the circle. At the walk every pass was recorded.

For each gait and direction between 4-8 trials were collected, which resulted in a total of approximately 50 trials being recorded at the different gaits for each rider. Rest intervals were given to horse and rider as seen appropriate and when changing the direction from left circle to right circle. The entire process including warm up, sensor attachment, data collection and rest breaks took between 50-60 minutes.

4.3 Data processing and analysis techniques

4.3.1 Frequency analysis

The rein tension data were analyzed for frequency content in order to select an appropriate frequency to filter noise from the trials without losing real data. A Matlab routine was used to examine the data from the 5 second trials to evaluate the frequency power spectrum below half the sampling rate (500 Hz). The routine calculated the frequencies found in 95% of the data. Evidence for 60 Hz frequency spikes was found shown in the frequency power spectrum. This indicated some contamination of the signal by 60 Hz cycle noise from the power source or the fluorescent lights. Actually the 60Hz frequency was only detectable within the 95 % frequency power spectrum when the magnitude of the rein tension was very low, which resulted in a higher data to noise ratio (rider one at the walk). Therefore, a similar analysis was performed looking at the 95% frequencies below 55 Hz. The results enabled selection of an appropriate frequency to filter noise from the trials (8 Hz) without losing any relevant data.

4.3.2 Data conversion and smoothing

The rein tension data that were recorded and stored by the computer had to be processed through a series of steps before analysis could be performed. The raw data were collected and stored in volts, which is how the sensors output the data (Figure 4.8).

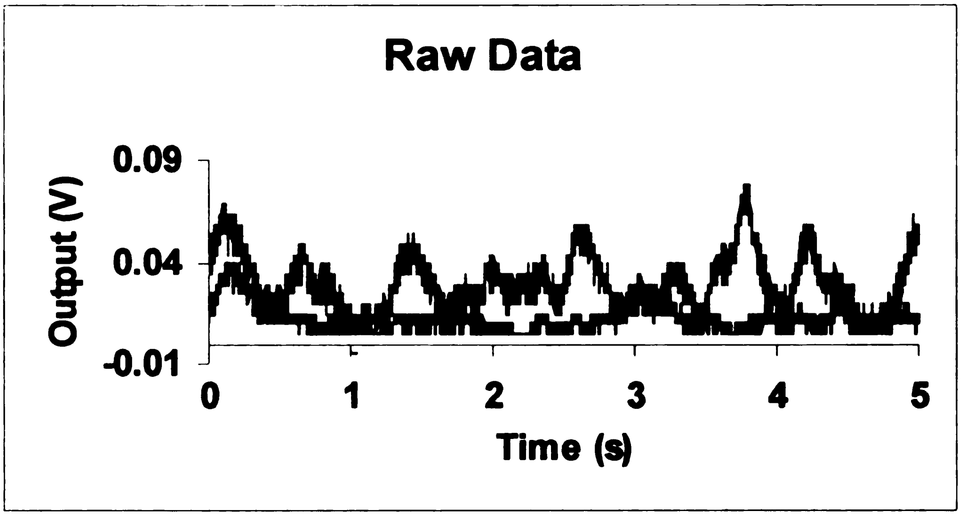


Figure 4.8 Raw rein tension data for 5 second recording in volts as generated by left sensor (dark line) and right sensor (light line) for trial 2 (rider two).

In order to view the data more clearly these voltage changes had to be converted to standard units of force. This was accomplished by multiplying the recorded voltages with the regression slope obtained from the calibration procedure to determine the actual tension measured (Figure 4.9).

Smoothing the data was necessary in order to eliminate the bit noise. The system had a resolution of 0.78 N/bit for the left sensor and 0.34 N/bit for the right sensor, which represents 79 g and 34 g respectively. This bit noise results in a fluctuation between the increments of tension data that the sensor outputs and it is responsible for the noise that makes the force tracings rather thick (Figures 4.8 and 4.9).

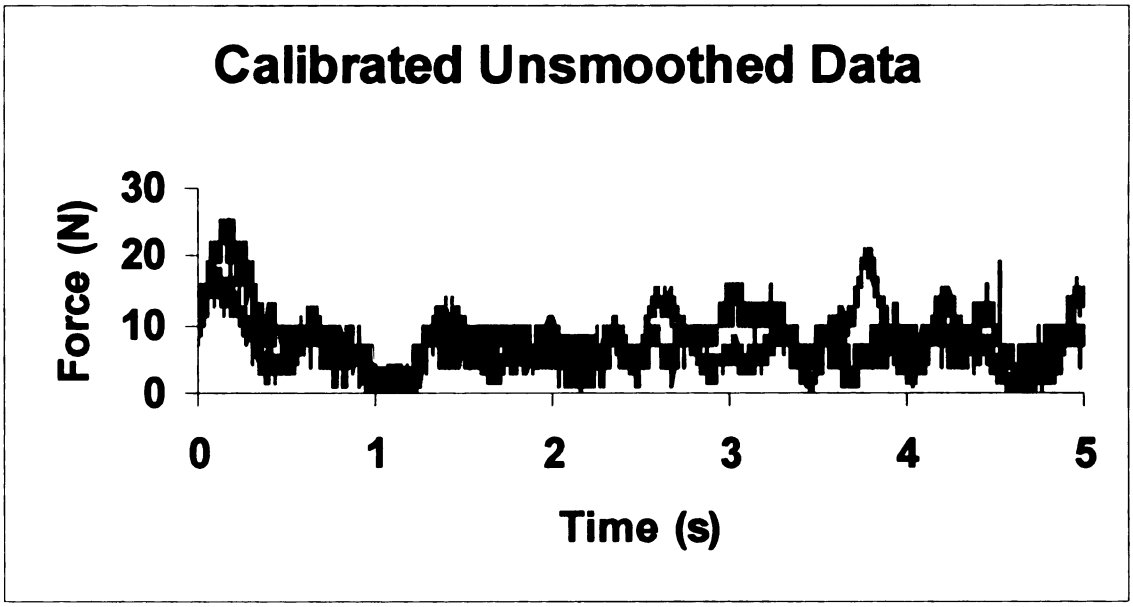


Figure 4.9 Raw rein tension data from trial 2 (rider two) transformed using regression values. Left sensor (dark line) and right sensor (light line)

After conversion from volts to standard measuring units, it becomes apparent that this bit level noise is really very small in comparison with the amount of tension recorded. Figure 4.10 illustrates the noise of the data more clearly when only the first second of the data is presented.

From Figure 4.10 it is apparent that the data seems to have more then a bit noise since it can be observed that the data jumps correspond to many times the bit noise. In table 4.1 we can observe the first 30 readings converted to Newtons. This accounts for 0.03 s of data since the data scanned at 1000 Hz.

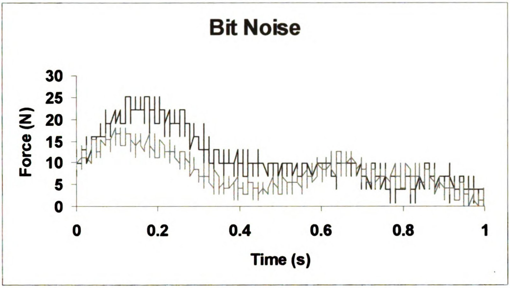


Figure 4.10 Bit noise shown in the first second of rein tension data from trial 2 (rider two).

Left rein	Right rein
9.930546	9.773041
6.887523	9.773041
9.930546	8.375567
9.930546	8.375567
9.930546	11.17052
9.930546	11.17052
12.97357	11.17052
9.930546	11.17052
12.97357	11.17052
9.930546	11.17052
9.930546	9.773041
9.930546	11.17052
12.97357	13.96546
12.97357	12.56799
12.97357	12.56799
12.97357	12.56799
9.930546	11.17052
9.930546	9.773041
9.930546	9.773041
9.930546	8.375567
9.930546	11.17052
9.930546	11.17052
12.97357	11.17052
12.97357	11.17052
12.97357	11.17052
12.97357	11.17052
12.97357	11.17052
12.97357	11.17052
16.01659	12.56799
16.01659	13.96546
[illegible]	[illegible]

Table 4.1 First 30 readings of rein tension data from trial 2 (rider two) accounting for 0.03 seconds for data was sampled at 1000 Hz.

One can clearly see repetitiveness in the data followed by a change in magnitude larger than the calculated bit resolution. This seems to indicate a data bottleneck in the acquisition, transmission or storage of data. This fluctuation falls within an acceptable error level since the data may not need such resolution nor high sampling rate.

As a result of this bit noise and in order to view and analyze the data for the various processing applications, different smoothing frequencies were used. The rein tension tracings shown on the videos have been smoothed at 30 Hz and can be seen in

(Figure 4.11). The graphs used for data extraction for detailed analysis were smoothed at 8 Hz (Figure 4.12).

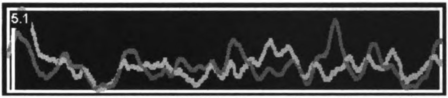


Figure 4.11 Rein tension data from trial 2 (rider 2) smoothed at 30 Hz and view as displayed in video data tool. Maximum value on the left side is indicated in pounds.

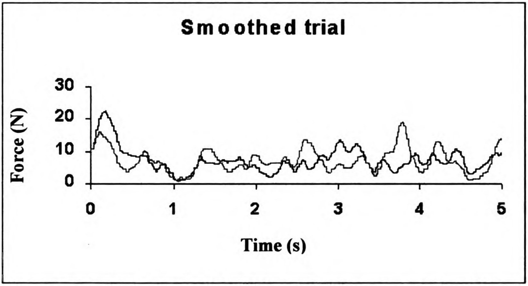


Figure 4.12 Rein tension data from trial 2 (rider two) smoothed at a frequency of 8 Hz. Left sensor (dark line) and right sensor (light line)

From the above figures we can see that a high similarity is present in the overall scheme of rein tension in the data smoothed at 8 Hz and 30 Hz.

4.3.3 Video-data tool

In order to interpret the rein tension data it was fundamental to correlate these data with the visual appearance of horse and rider at that specific moment in time. The video images for the trials of interest were captured to the computer, then combined with the corresponding rein tension data to generate a video image displaying the synchronized video and rein tension data together. This was achieved using a customized program that created a digital video (AVI) file in which the rein tension graphs for the left and right rein (filtered at 30 Hz) were superimposed over the original video at the top of the image (Figure 4.13). A vertical white line moves from left to right across the rein data indicating the moment on the graph that corresponded with the video frame displayed. Each graph was scaled according to the maximal tension recorded during the trial. On the top left part of the graph the maximum value for the graph (in pounds) is displayed. On the top right side of the image, adjacent to the line graphs of the rein tension are two bar graphs that indicate the tension in each rein at the instant in time that corresponds with the video image and the vertical line on the line graph. The amount of tension in each rein is displayed above the corresponding bar (in pounds).

Prior to generating each new AVI file, the video was synchronized to the force data by matching the counter number displayed in the video field to the force data containing the same counter number. After being synchronized with the force data, the AVI files were stored on CD's. In this format they provided a valuable tool for viewing the data and associating rein tension patterns to the riding events. The videos proved valuable in designing more processing tools for understanding and explaining the data that were collected.

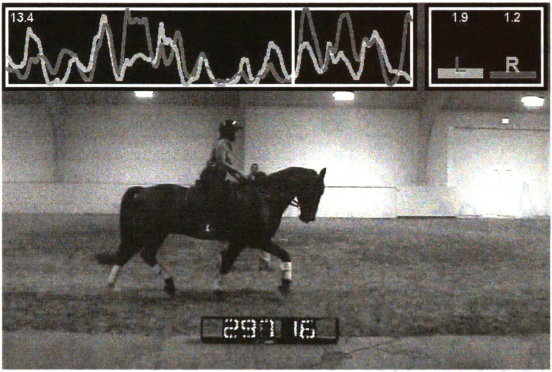


Figure 4.13 Video image with rein tension superimposed. On top left rein tension in the left rein (light line) and right rein (dark line) for a 5 second interval. White vertical line indicates time frame synchronized to video. At the top right of the picture left (L) and right (R) rein tension generated at that instant in pounds.

4.3.4 Forelimb contact analysis

The videos were also used to determine the timing of forelimb hoof impact for all gaits using a customized program. Impact times and time between impacts were saved and used to split the 5 second trials into one combined graph with all rein data superimposed by strides (Figure 4.12). Also the 5 second trials were marked with the corresponding impact times to allow for better data interpretation. All these data had been previously smoothed with an 8 Hz digital algorithm.

After the data were split and grouped, they could be used for correlation analysis between different strides. It is evident from Figure 4.14 and Figure 4.13 that the right rein shows a more distinct pattern than the left rein. This would yield a higher correlation between right rein stride data and lower correlation for left rein stride data. The experimental design and technology used in this study imposed limitations to interpreting rein patterns. The results will be presented in the format shown in Figure 4.15 in section 5.3.3.5.

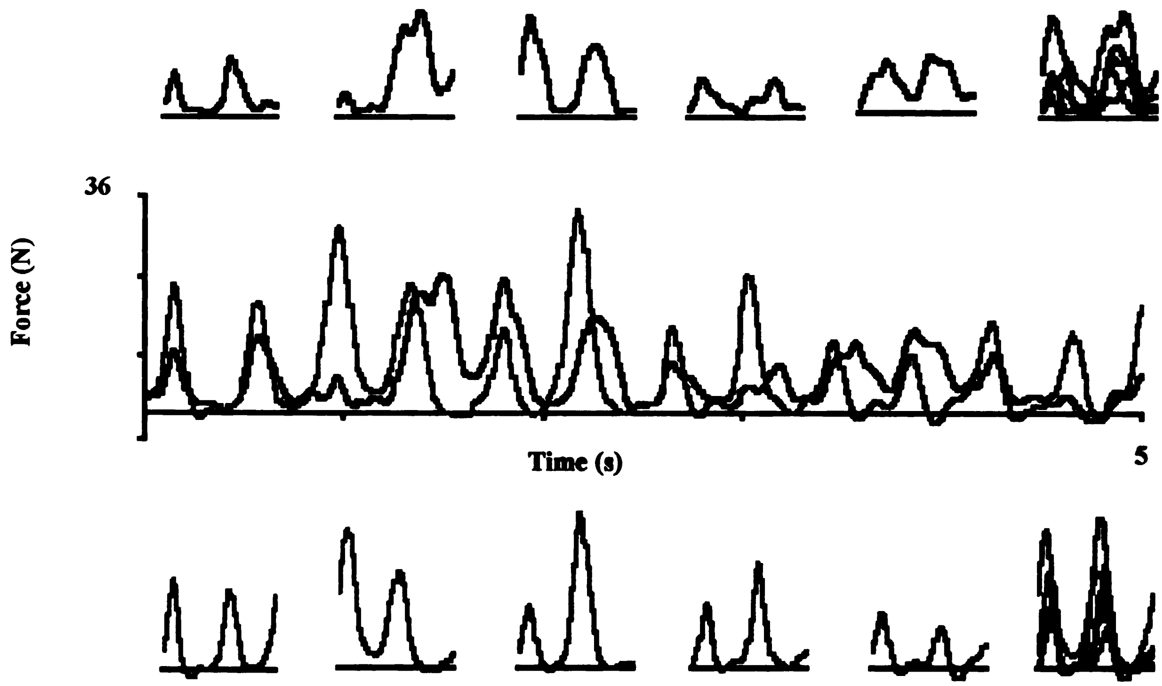


Figure 4.14 Middle graphs shows 5 second data for trial 19 by rider one for the left rein (dark line) and right rein (light line). Successive contacts of the same limb were used to split the data into single strides for the left rein (top) and right rein (bottom) graphs. Last graphs on top and bottom show all curves from the split section superimposed.

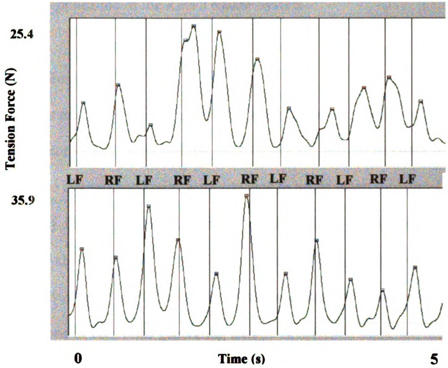


Figure 4.15 Rein tension graphs for left rein (above) and right rein (below) with forelimb contacts superimposed as vertical lines. This trial is the same as shown in Figure 4.14, trial 19 by rider one at the sitting trot, and can be compared in this graph by joining left fore contact to the subsequent left fore contact. LF: left forelimb contact. RF: right forelimb contact.

Chapter 5 Application of the Rein Tension System

5.1 Static Simulation

This tension measurement system was adapted for use in a laboratory environment to allow riders and trainers to develop a feel for different magnitudes of rein tension. The instrumented reins were attached to a half moon (unjointed) snaffle bit (Figure 5.1). One person held the bit with all the sensors and equipment while another person held the reins. Tension profiles for the left and right reins were displayed interactively on the computer screen. With this setting one or both people could apply tension to one or both reins generating tension between the reins and the bit. This tension was viewed in real time on the computer screen. If a consistent, prolonged pull was applied the tension could be observed on the screen as a steady line (Figure 5.1, top graph line on computer screen). When short intermittent pulls were applied to the reins the tension trace showed a series of peaks in the rein tension (Figure 5.1, bottom graph line on computer screen). These peaks could be generated by the person holding the bit (simulating the action of the horse), or by the person holding the reins or as a result of both people pulling at the same time.

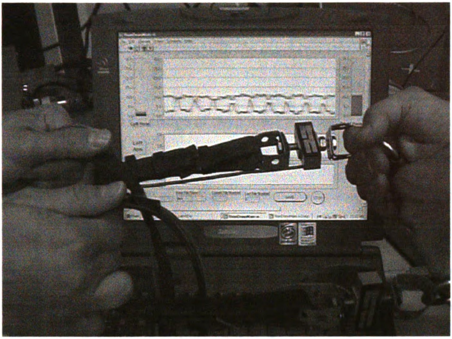


Figure 5.1 Laboratory setting showing one person holding the bit (right) and another pulling on the reins (left). In the background the computer screen shows the graphs of both rein tensions. The top line shows a constant pull while the bottom graph is the other rein acting intermittently. This was achieved by moving one side of the bit while holding the other side with constant tension.

5.2 In vivo measurements

Real time observations of rein tension were made as the horse was ridden in circles around the data collection cart. The system displayed rein tension on the computer screen and recorded the values on the hard drive. The rein tension displayed by the computer was constantly being refreshed on the computer screen allowing only the most recent data to be observed.

The rein tension data comprised a series of peaks (spikes), some of which appeared to be repeated with a regular frequency. In general the data were too complex for quick interpretation. A general idea of the regularity of the patterns and the magnitudes of the spikes could be appreciated by observing the results displayed on the screen. However it was difficult to interpret the data further without observing and correlating the horse and rider's motion with the exact rein tension displayed by the computer.

At the present time knowledge of the normal patterns of rein tension during riding is extremely limited. The data gathered in this study will form the beginning of a database that will eventually be applied to allow instantaneous evaluation of riding technique. Before this is possible, however, further research is needed to gain more background knowledge, also more customized software must be developed to automatically display the important and relevant variables that will make this technology into a useful real time training tool. For the data collected during this study, analysis is limited to post-processing in order to develop a better understanding and to form an explanation for the rein tension patterns that are generated.

5.3 Post processing results

5.3.1 Calibration similarity

Figure 5.2 shows the regression line obtained for both reins and both days. Four regression lines are plotted and are grouped in two pairs (left rein and right rein). The graph shows the calibration prior to data collection for rider one (day 1) and prior to data collection for rider two (day 2) 10 days after. Both reins had almost identical slopes, which makes the data obtained for both riders numerically comparable. This seems to allow the use of these sensors over time and obtain comparable data.

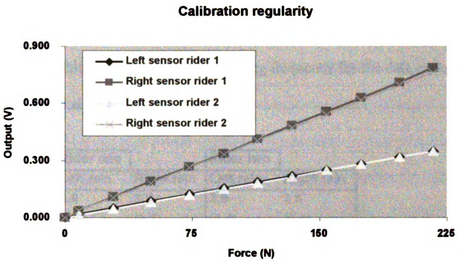


Figure 5.2 Calibration regression line for left and right sensors on two days. The top regression lines represent the right rein sensor for both riders (square: rider one, ex's: rider two), bottom regression lines represent the left rein sensor (spade: rider one, triangles: rider two).

5.3.2 Frequency content

As presented earlier during Chapter 4, frequency analysis was performed to study the frequency content of the force data between horse and rider through the reins. As a result of 60 Hz interference from AC current, frequencies below 55 Hz were studied. The resulting power spectrum, that is 95% of the frequency power found in the 5 s trials (frequencies < 55 Hz), is presented in Table 5.1 for each rider in the left and right rein at the different gaits. The results show that average frequencies are in the range of 4-5 Hz. The highest average frequencies are observed at the canter 4.7-5.2 Hz, but not so far from those observed at the trot. At the walk the mean frequencies for the riders was just below 4 Hz. The highest frequency found in a particular canter trial was 8 Hz, while the lowest frequency was 2 Hz at a walk trial.

This seems to indicate that in this data set comprising two riders and one horse, the frequencies observed between gaits are fairly similar. No frequencies were present above 8 Hz, which was the chosen smoothing frequency for the data except the video data smoothed at 30 Hz.

	Rider one		Rider two	
	Left rein	Right rein	Left rein	Right rein
Walk	3.9 (0.9)	3.9 (1.3)	3.9 (0.4)	3.8 (0.4)
Posting trot	4.6 (0.7)	4.5 (0.5)	4.0 (0.7)	4.1 (0.9)
Sitting trot	4.3 (0.8)	4.8 (0.4)	3.9 (0.7)	3.8 (0.7)
Canter	5.2 (1.2)	4.7 (0.8)	5.2 (0.8)	4.9 (1.1)
Avg all gaits	4.5 (1.0)	4.5 (0.9)	4.2 (0.8)	4.2 (1.1)

Table 5.1 Mean values and (standard deviation) in Hz for the frequency content of the 5 second trial for rider one and rider two circling at the left and right reins for different gaits.

5.3.3 Data description and interpretation

Based on the frequency content of the trials, the rein tension data of the 5 second trials were smoothed at a cutoff frequency of 8 Hz and plotted against time. The complete results for both riders at all three gaits are shown in Appendix A and discussed later in detail. Each page in the appendix shows one rider at one gait (walk, posting trot, sitting trot and canter). On the left side of the page are the trials corresponding to the left direction (counterclockwise), while on the right side of the page are the trials corresponding to the right (clockwise) direction. The same scale has been used for the equivalent gaits in both riders to facilitate comparisons between them.

The rein tension data show a wide variability within and between riders, as well as between the different gaits. In this data set the magnitudes appeared to be gait dependent. The walk showed the lowest magnitudes, followed by the posting trot, then the sitting trot and canter, which displayed the highest tension values. The magnitudes displayed by rider two at the walk reached a maximum in the range developed by rider one at the posting and sitting trot. The peak magnitudes at the trot for rider two were similar to those at the canter in rider one. Subjective evaluation of the equestrian skills of the two riders suggested that rider one displayed a more advanced or efficient riding technique as shown by having an "independent seat". This indicates an advanced level of proficiency in which the rider is able to control the movements of the trunk and limbs independent of each other. Rider two showed bouncing movements of the arms and hands that are indicative of not yet having achieved an independent seat. The better seat and overall balance observed in rider one seems to be related to the lower rein tension observed compared to rider two. This clearly indicates that the ability of the rider can have a large effect on the rein tension data.

The graphs show that the data recorded are very spiky. The peaks and valleys have a somewhat random pattern during the 5 s trials (Appendix A). Left and right reins show inconsistent patterns and magnitudes when compared to each other. The complexity of the tension graphs and the variability between and within riders made it difficult to interpret the results without the aid of the video recordings, which allowed rein tension data to be related to the riding events and to the stride cycles of the horse for precise interpretation. An initial interpretation of the rein patterns without the use of video data will be presented first.

5.3.3.1 Walk

The walk was the most irregular gait in terms of rein tension patterns. Rider one established a very loose contact and used the reins sporadically. On the other hand rider two had much higher magnitudes and rein tension was present during most of the time taking the form of repetitive spikes with only brief periods of no rein tension (contact) and repetitive spikes (Figure 5.3).

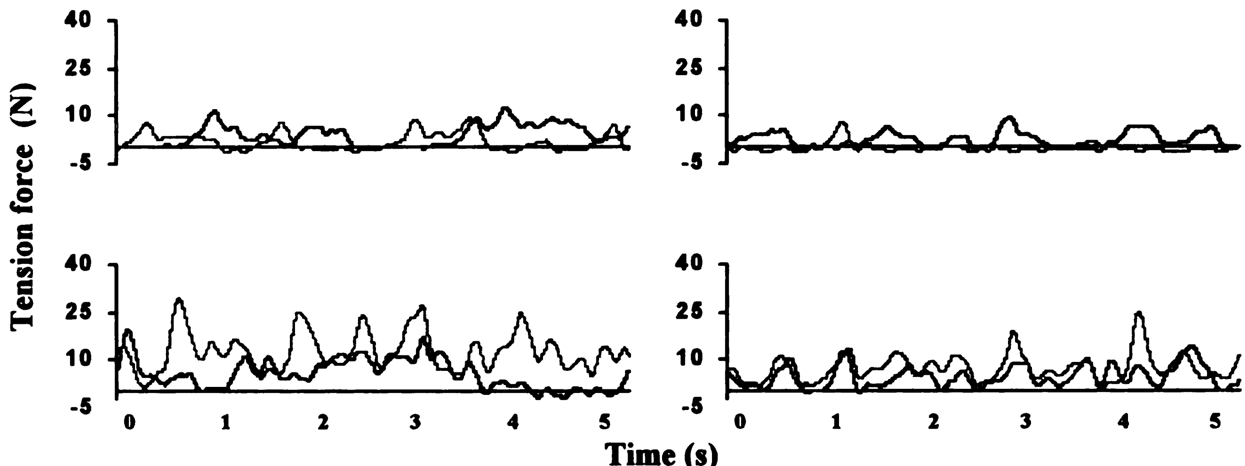


Figure 5.3 Five second walk trials. Top graphs represent rider one, bottom graphs represent rider two. The graphs on the left side were recorded in the left direction and those on the right side were recorded in the right direction. Dark line represents left rein, lighter line represents right rein.

Trial 5 (Figure 5.3 top left) Rider one, left direction, walk:

Irregular patterns are observed in this trial. The right rein showed some scattered peaks and a fair amount of time with no tension indicating a loose rein. The left rein was also loose for much of the time, but the tension peaks were more prolonged than in the right rein. Peaks in the left and right reins rarely coincided.

Trial 30 (Figure 5.3 top right) Rider one, right direction, walk:

When rider one walked in the right direction (Figure 5.3) there was only one distinct right rein peak during the entire 5 second trial. The left rein showed a larger number of broader peaks. There were times when no rein tension was present on either rein and at no point did both reins develop tension at the same time.

Trial 5 (Figure 5.3 bottom left) Rider two, left direction, walk:

Rider two showed much more activity than rider one. Many peaks were present especially on the right rein where tension frequently exceeded 20 N. The peaks on the right rein were more defined than those on the left rein, which had lower peaks but more prolonged tension and also some periods when the rein was loose.

Trial 34 (Figure 5.3 bottom right) Rider two right direction, walk:

Rider two walking on the right rein showed concurrent peaks in both reins. Besides many peaks, a set of valleys can be observed repetitively on both reins.

5.3.3.2 Posting trot

Compared to the walk, both trots presented higher magnitudes and more defined peaks and valleys but with different magnitudes and pattern shapes in the two riders (Figure 5.4). The posting trot showed more inconsistent patterns than did the sitting trot

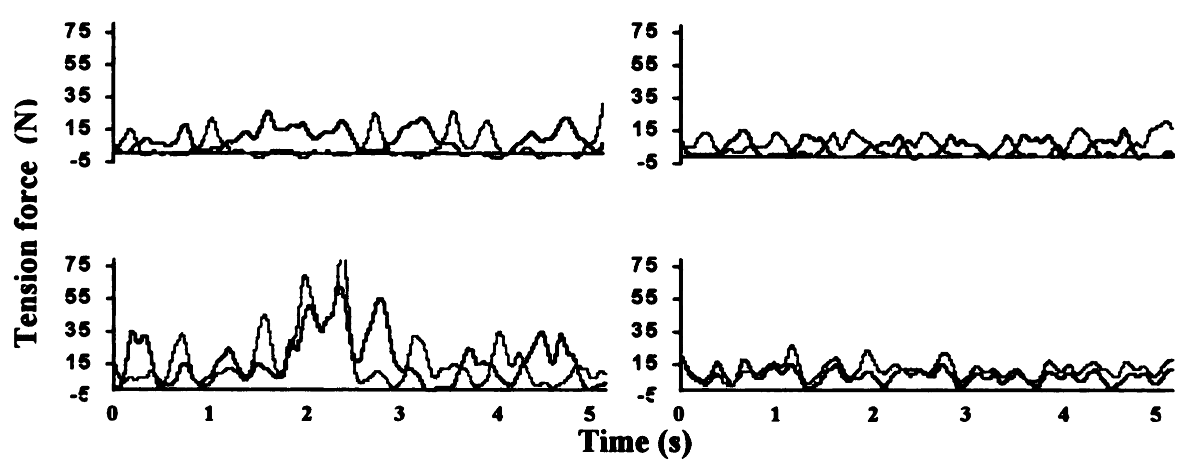


Figure 5.4 Five second trials at the posting trot. Top graphs represent rider one, bottom graphs represent rider two. The graphs on the left side were recorded in the left direction and those on the right side were recorded in the right direction. Dark line represents left rein, lighter line represents right rein.

Trial 12 (Figure 5.4 top left) Rider one, left direction, posting trot:

Rider one in the posting trot trial in the left direction showed a non-concurrent pattern in the peak location between the left and right reins. When the left rein developed tension the right rein was loose and vice-versa. Peaks in the right rein tended to be short and sharp, whereas those on the left rein were more prolonged and irregular. The rider was able to release the right rein while holding the left rein.

Trial 34 (Figure 5.4 top right) Rider one, right direction, posting trot:

Good representation of what happens in all trials performed by rider one on both the posting and sitting trot on the right direction (clockwise). There was an alternating pattern between left and right rein, with all the peaks reaching approximately the same magnitude, which was about half that achieved in the left direction.

Trial 11 (Figure 5.4 bottom left) Rider two, left direction, posting trot:

Rider two in posting trot shows large amounts of tension in both reins. At the beginning of this trial the left and right reins act synchronously. During the middle of the 5 second trial both reins display very high peaks with tension exceeding 50 N in each of two peaks that are separated by a small trough. Thereafter, the pattern of rein tension became more alternating instead of synchronous.

Trial 38 (Figure 5.4 bottom right) Rider two right direction, posting trot:

In this trial rider two showed very similar patterns between left and right reins. The magnitudes were small compared to the rest of the posting trot trials and were similar in magnitude to those of rider one.

5.3.3.3 Sitting trot

At the sitting trot, the rein tension showed more repetitive patterns than the posting trot or the walk (Figure 5.5)

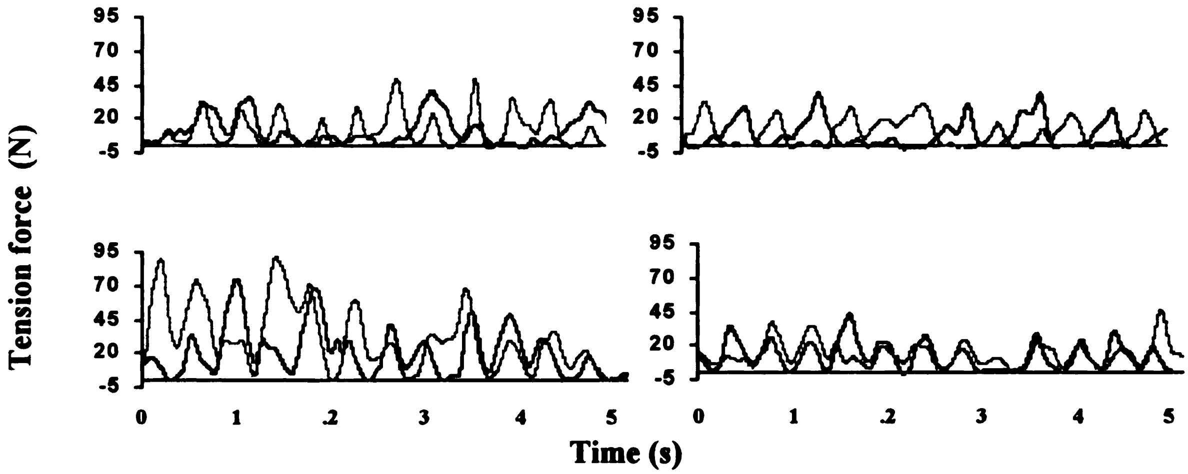


Figure 5.5 Five second trials at the sitting trot. Top graphs represent rider one, bottom graphs represent rider two. The graphs on the left side were recorded in the left direction and those on the right side were recorded in the right direction. Dark line represents left rein, lighter line represents right rein.

Trial 17 (Figure 5.5 top left) Rider one, left direction, sitting trot:

Rider one showed a consistent pattern of spikes in the right rein similar to those observed at the posting trot by the same rider in the same direction. The left rein was almost always lower in magnitude. The troughs of low tension or loose reins generally coincided in the two reins.

Trial 42 (Figure 5.5 top right) Rider one, right direction, sitting trot:

On the right rein the same pattern as in the posting trot in the same direction was observed. An alternating pattern was present but skipped a left peak in the middle part of the trace while the right rein showed an extra peak.

Trial 23 (Figure 5.5 bottom left) Rider two, left direction, sitting trot:

Rider two showed regularly occurring spikes but the distribution between left and right rein was inconsistent. Some regularity was observed at the end of the trial when magnitudes became smaller. At the initiation of the trial, both reins displayed high magnitudes (>70 N) and sharp peaks mixed with some more prolonged peak patterns. In this trial of large magnitudes, the tension changed from 0 to 90+ Newtons (10 kg) in a very short space of time.

Trial 44 (Figure 5.5 bottom right) Rider two, right direction, sitting trot:

In this direction, rider two showed even tension on both reins through most of the trials with clear peaks and low magnitude valleys.

5.3.3.4 Canter

The canter showed the largest magnitudes for both riders. Patterns were different between direction and rider, but showed repetitiveness within trials (Figure 5.6).

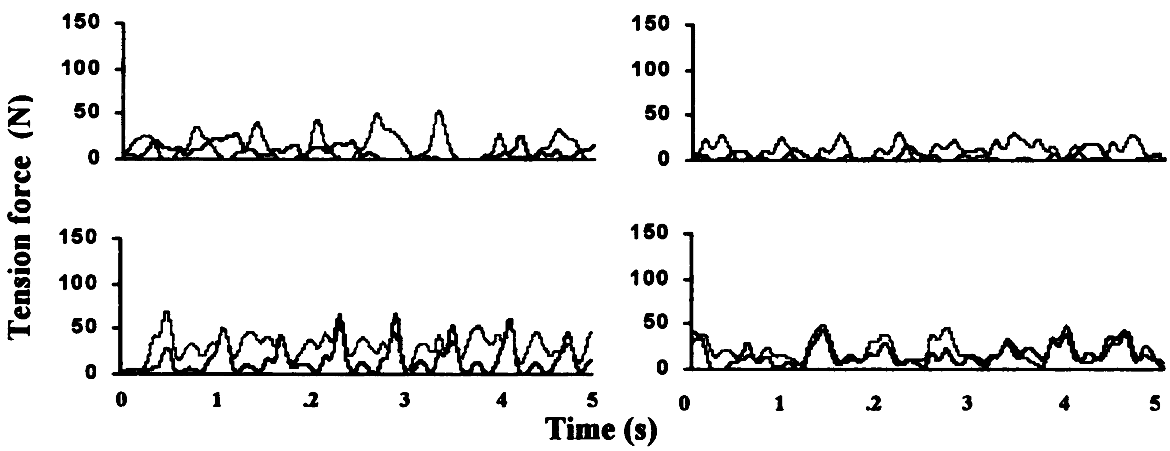


Figure 5.6 Five second trials at canter. Top graphs represent rider one, bottom graphs represent rider two. The graphs on the left side were recorded in the left direction and those on the right side were recorded in the right direction. Dark line represents left rein, lighter line represents right rein.

Trial 22 (Figure 5.6 top left) Rider one, left direction, canter:

In this trial there was a regular pattern of peaks in the right (outside) rein that increased in magnitude through the early and middle part of the recording. The left (inside) rein was less active and had a more irregular pattern. Contact was released during the later part of the 5 second trial by the left (inside) rein.

Trial 48 (Figure 5.6 top right) Rider one, right direction, canter:

Peaks on the left (outside) rein are very small in magnitude alternating with larger, usually double humped peaks in the right rein. The right rein showed regular and consistent peaks, while those on the left rein were smaller and less consistent.

Trial 27 (Figure 5.6 bottom left) Rider two, left direction, canter:

This trial showed high symmetry between the left and the right rein peaks in terms of their magnitudes and locations, though tension in the right rein was generally higher between the peaks, whereas the tension in the left rein was released.

Trial 48 (Figure 5.6 bottom right) Rider two, right direction, canter:

Regular repetition of peaks similar in magnitude on the left and right reins and double humped peaks.

5.3.4 Data description with forelimb contact times

In section 5.3.3 some of the trials were analyzed without considering the effect of the horse's movement on the occurrence of peaks and valleys in the rein tension graphs. Knowing the time of the forelimb contacts with the ground, which were obtained from the video, provided information that was useful in understanding and interpreting changes in rein tension relative to the horse's stride. Again some trials for each gait and rider will be presented and discussed. The graphs presented in this section are the same as those presented in Section 5.3.3, but the scale of the graph has been changed so that they are proportional to the maximum rein magnitude of that trial.

5.3.4.1 Walk

Rider two, trial 34, walk right direction (Figure 5.7)

Rider two at the walk showed a fairly repetitive pattern with a tension peak occurring shortly after each limb contact. In addition, some strides had extra peaks located about two thirds of the time between contacts. Minimum values (valleys) also occurred fairly regularly between strides and between reins.

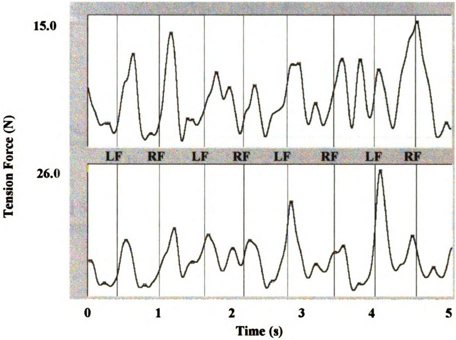


Figure 5.7 Trial 34, walk, rider two, right direction. Left rein (above) right rein (below). LF: left forelimb contact, RF: right forelimb contact. Note that the scales are different for the two graphs

Rider one, trial 5, walk left direction (Figure 5.8)

Rider one at the walk tended to show an alternating tension between the left and the right reins with peaks in the left rein following contact of the left front limb and peaks in the right rein following contact of the right front limb. This pattern disappeared in the second half of the graph when the right rein had no contact for almost a full stride and than became active when tension in the left rein decreased.

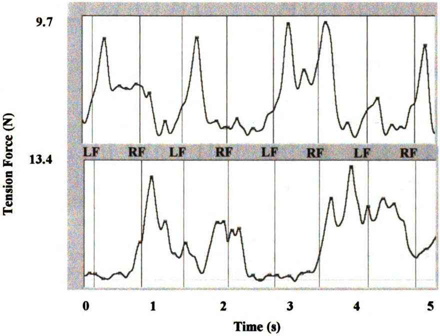


Figure 5.8 Trial 5 walk rider one, left direction. Left rein (above) right rein (below). LF: left forelimb contact, RF: right forelimb contact. Note that the scales are different for the two graphs

5.3.4.2 Sitting trot

Rider one, trial 42, sitting trot right direction (Figure 5.9)

The alternating pattern that was referenced earlier shows that peaks in the left rein almost always occurred shortly after right forelimb contact. The right rein showed a similar but opposite pattern of slightly lower magnitude, with peaks located very close to the left forelimb contacts when the other rein was not tense.

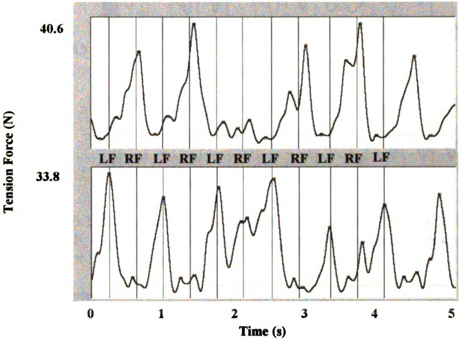


Figure 5.9 trial 42 sitting trot, rider one, rignt airection. Left rein (above) right rein (below). LF: left forelimb contact, RF: right forelimb contact. Note that the scales are different for the two graphs.

Rider two, trial 44, sitting trot, right direction (Figure 5.10)

Trial 44 had a high similarity between left and right rein peaks which corresponded very closely to the forelimb contacts.

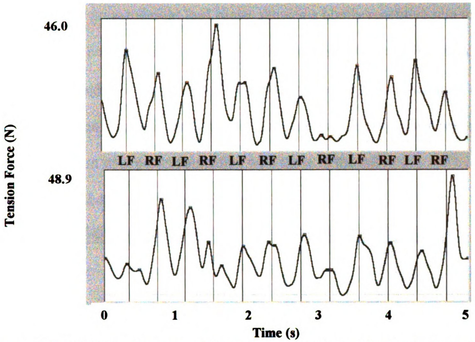


Figure 5.10 Trial 44, rider two, sitting trot, right direction. Left rein (above) right rein (below). LF: left forelimb contact, RF: right forelimb contact. Note that the scales are different for the two graphs.

5.3.4.3 Canter

Rider two, trial 48, canter right direction (Figure 5.11)

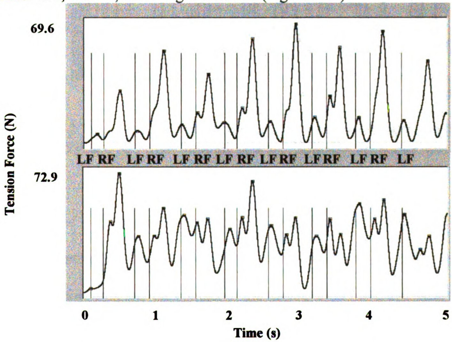


Figure 5.11 Trial 48, rider two, at canter, right direction. Left rein (above) right rein (below). LF: left forelimb contact, RF: right forelimb contact. Note that the scales are different for the two graphs.

Rider two at the right lead canter showed a highly repetitive rein tension pattern in relation to the contact times. The left (outside) rein showed a distinct peak at the time of outside (trailing) hind contact (as observed in the video) and a small peak coinciding with the diagonal limb (leading hind, trailing fore) contact. The right (inside) rein had a more constant tension with peaks coinciding with those in the left rein.

Rider one, trial 48, canter right (Figure 5.12)

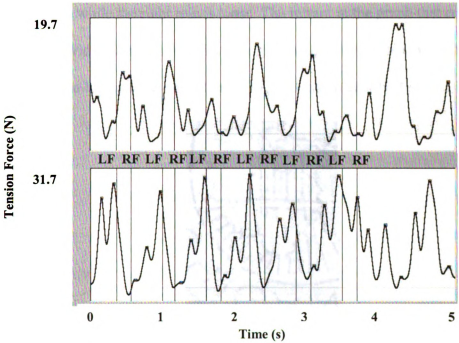


Figure 5.12 Trial 48, rider one, at canter. Left rein (above) right rein (below). LF: left forelimb contact, RF: right forelimb contact. Note that the scales are different for the two graphs.

The left (outside) rein peaks were located between contacts of the trailing and leading forelimbs with additional peaks sometimes coinciding with contact of the right (leading) forelimb and the contact of the trailing hind limb. The tension spikes in the right rein often had double the magnitude of those in the left rein. The larger spike coincided with contact of the left (trailing) forelimb, with a valley at contact of the right (leading) forelimb in most strides.

5.3.5 Video data synchronization results

5.3.5.1 Synchronicity of the video-data program

The video overlay program allowed the rein tension to be related to the movements of horse and rider using the counter numbers to synchronize video and rein data. As an example Figure 5.13 shows an instant in the video when the left rein is tense (stretched) while the right rein is loose. The instant in the graph that corresponds with the displayed video frame shows that the right rein has very little tension 1.8 N (0.4 lb) whereas the left rein has considerably higher tension 28.4 N (6.4 lb)

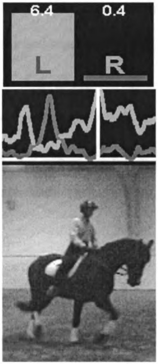


Figure 5.13 Video image with rein tension graph. The vertical white line indicates the time on the graph that coincides with the video (left rein-light line, right rein-dark line). The bar chart shows tension (lb) in the left and right rein at the same instant.

When the rider drops the contact in the rein (loose rein), the weight of the sensor caused a small force to be recorded that was not due to the action between rider and horse. Tension due to the weight of the sensor was very small compared with that produced when the horse and rider establish contact through the reins. The weight of each sensor and connectors was approximately 56.7g (2 oz). When the sensor fell under the influence of the gravitational force, it, accelerated downward at 9.81 m/s^2. A tension of 0.556 N was expected. Other factors like the momentum of the sensor, weight of the reins, and the sudden deceleration seem to increase the amount of tension read. In trials where the rein was observed to be loose, tension reached maximum values in the range of 0.4 lb (1.78 N) (Figure 5.13). The system has a small error only when the rein is loose and the weight of the sensor produces rein tension not related to the horse rider interaction. When contact between rider and horse is established, tension is developed and the weight effect of sensor and reins disappears. Magnitudes are many times larger when tension is established even at slow gaits like the walk and extended periods of loose rein are not often seen, becoming a recognizable event. The system seems to be accurate enough to measure rein tension. Tension caused by the sensor and equipment is very small and needs to be overseen when studying horse rider interaction.

5.3.5.2 Correlation between peaks and cyclic movements of the horse and riders

The data appeared to be well synchronized to the stride cycle because similar peaks occurred at the same instant in different strides. For example, in Figure 5.14 the horse was cantering on the right rein. In the picture on the left, the rider was sitting in a normal riding position. The horse's head was low and the increased tension in the reins was due to the horse leaning against the non-giving hands from the rider during the stance phase of the leading forelimb that preceded the suspension phase. The image on the right shows the same instant during the next stride. The rider was leaning back with the upper body to collect or elevate the forehand of the horse. As a result, the tension in both reins was much higher. The higher tension is probably due to the combined action of the rider leaning on the reins with the upper body and the horse leaning on the bit at this instant in the stride. The amount of tension was similar in both reins since rider two leaned back with both shoulders while the horse was straight in the head and neck and tension was produced equally on both reins.

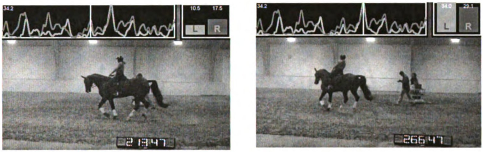


Figure 5.14 Correlation of rein tension with video image in successive strides (left rein-light line, right rein-dark line). The vertical white line indicates the instant on the graph that corresponds with the video image below. In the image on the left, the rider is sitting upright and rein tension is low. In the image on the right the rider is leaning back, putting more tension on both reins.

5.3.5.3 Occurrence of peaks at different times within the stride

Peaks and valleys in the rein tension were observed to occur at different times during the stride cycle. Peaks in rein tension usually occur within the stance phase(s) of one or more limbs. The next two examples (Figure 5.15) and (Figure 5.16), show how peaks in rein tension can occur at different instances in the stance phase.

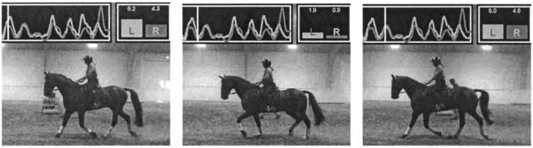


Figure 5.15 Video images at trot with corresponding rein tension indicated by vertical white line in graph (left rein-light line, right rein-dark line). The images on the left and right show the instants of successive diagonal limb contact, which correspond with tension spikes. The center image shows the instant in the stride corresponding with a valley in the rein tension traces. It occurs just after midstance.

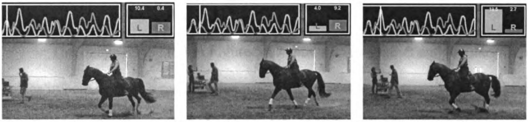


Figure 5.16 Video images at trot with corresponding rein tension indicated by vertical white line in graph (left rein-light line, right rein-dark line). The rein tension peak occurs at midstance on the left rein, left and right images, while a peak is present in the right rein during the suspension phase (middle image).

Figure 5.15 and Figure 5.16 show images from two trot trials performed by rider two. From the images presented and the video captured we can subjectively attribute Figure 5.15 with a better overall movement than Figure 5.16. In Figure 5.15 images 1 and 3 show how the peaks develop in the early part of stance, while in Figure 5.16 images 1 and 3 show how peaks occur when the horse is close to mid-stance. In image 2 on both figures we also see a difference in the movement and action of the rider. While on Figure 5.15 we see a valley in rein tension, in Figure 5.16 the rider actively pulls the right (inside) rein causing a peak very close to the suspension phase. From this and other trials we can observe that the peaks can occur at different instances within the stance phase and that they could be related to the quality in the horse's movement. Peak location seems to be the result of the flow of the horse's movement and intervention and ability of the rider. The horse's head and neck position may also have an effect through the rider's interaction with the horse's natural head movement. Peaks occurring during different parts of the stride are not attributed to a mistake in the synchronization between video and rein tension data since approximately four to five frames elapse between contact and mid stance when video recordings are made at 30 Hz.

5.3.5.4 Regular and irregular rein patterns.

The image on the left in Figure 5.17 shows three distinct and regularly repeated spikes in both reins as a result of consistent movement of the horse and rider. In the middle image the horse was facing toward the exit from the arena and the rider was using the left (inside) rein to indicate the turning direction to the horse. As a result a broader spike was generated in the left rein. The right (outside) rein maintains the same repetitive peak pattern, probably indicating a "consistent" outside rein contact. In the picture on the right the gentle turning rein is being released momentarily. The decrease might be to reward the horse for yielding to tension in that rein or the rider may have decreased the active turning rein aid to avoid upsetting the regularity in the horse's movement. More turning signals with the left rein are given during the next strides.

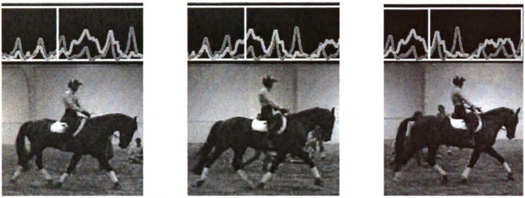


Figure 5.17 Regular and irregular rein pattern due to the turning aids by the left rein (left rein-light line, right rein-dark line).

5.3.5.5 Alternating reins

Rider one displays a distinct pattern during both posting trot and sitting trot while circling to the right. These patterns were distinctly different from those shown when circling to the left and from those produced by rider two circling on the same direction. Figure 5.18 shows four consecutive limb contacts at the trot. The corresponding tension spikes occurred alternately in the left and right reins. The video frames suggest that the horse displays adequate riding form as well as forwardness in its movement. When the left forelimb contacted the ground there was a peak on the right rein and when the right forelimb contacted the ground there was a peak on the left rein.

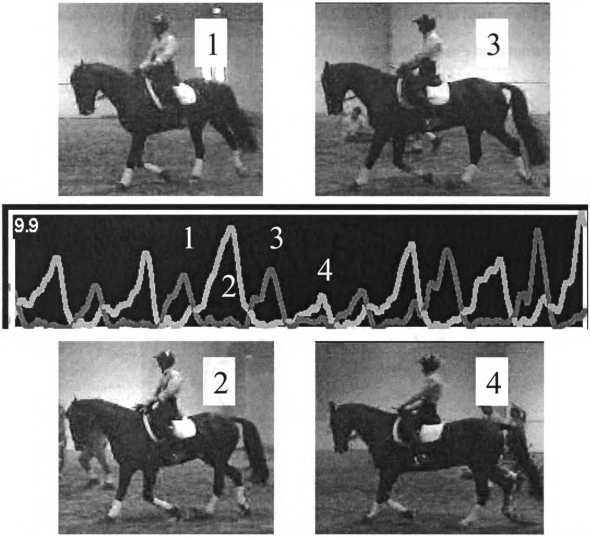


Figure 5.18 Alternating rein pattern. Peak on the right rein correspond to contact with the left forelimb, while left rein peaks occur at the instant of right forelimb contact (left rein-light line, right rein-dark line). Value on the top left in graph shows the maximum tension in pounds (lb)

5.3.5.6 Reaction of the horse to high tension

The reaction of the horse to high tension in the reins is shown in Figure 5.19. In the picture on the top left the first spike occurred between contact and mid stance. The horse's motion and rider's position suggest a lack of forwardness. In the second picture (middle of top row) the rider initiated the use of the right (inside) rein just after the middle of the stance phase. Tension peaks close to the suspension phase, meaning the rider is actively pulling back at this moment when the horse needs to finalize and project the stride forward (third picture). As a result of this tension the horse's head turns to the inside but also goes up to evade the contact in the right rein (picture 4 and 5).

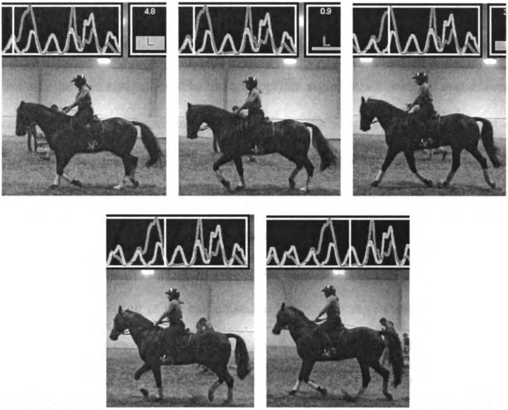


Figure 5.19 Reaction of horse to excess tension changing the neck position (left rein-light line, right rein-dark line).

Many more examples could be shown to convince the reader of the adequate display, use and synchronization of the video-data program.

Chapter 6 Discussion

The primary goal of this study was to develop a technique for measuring accurately the rein tension developed during riding activities. This was accomplished using small, lightweight commercially available force transducers intercalated between the bit and the rein and tethered to the appropriate signal processing equipment and storage device. This commercially available force transducers show linearity between 0 and 100 lb. of tensile force. In this data set rein tension did not reach more than 150 N, which was within the linear range of the sensor. The data were analyzed for frequency content by running a frequency power spectrum. It was shown that the signal had a very low noise contamination, possibly coming from the 60 Hz phase from the arena lights and magnified as a result of the cable used to tether sensors to the other equipment. As a result of the horse's movement this cable also was subjected to some bouncing that may have added some noise to the data. The noise in the data was relatively low in magnitude compared to the magnitudes of rein tension. High frequencies (60 Hz phase light) was only significant for walk trials performed by rider one with very low magnitudes of rein tension ($\approx$ 10 N), where they showed up within the 95% for frequencies contained in data. With regards to the noise added by the bouncing cable, similar magnitudes are found when tension is applied with the cable on the ground as with the cable moving. The calibration performed prior to data collection was performed using this same cable ensuring the same noise effect on the data. As to the difference in the regression lines yielded by the different sensors and signal processing units, we can point out that this difference is solely due to the use of different signal processing units since the same sensors attached to another amplification device yielded identical regression slope between both sensors. The accuracy of the data is maintained since the regression line shows linearity and only the bit increments between sensors vary. This bit increment variation (34 vs. 79 g/bit) is very small when compared to the magnitudes displayed during rein tension and therefore does not significantly change the results.

The secondary goal of this study was to analyze how rein tension is developed and to formulate an explanation for the fluctuating nature of rein tension. This was accomplished by combining synchronized video images to the actual rein tension. This not only provides visual cues on the rider's activity and balance, but also how the horse's movement affects the rein tension pattern. When the technique was applied to measure rein tension during walking, trotting and cantering on a circle, the data were characterized by a series of rhythmical peaks and valleys. The patterns resembled those published by Preuschoft et al. (1999), who also used a tensile force transducer but collected data from one rein only. The fact that we found marked differences between tension in the left and right reins, since they can be manipulated independently by both the horse and rider, indicates that the inability to instrument both reins simultaneously is a serious drawback to fully understanding rein tension.

There were several other differences between the equipment and methodology used in this study and Preuschoft's study. The weight of the transducer and its attachments was much lower in our study (56 g vs. 300 g). The reason for the large difference in weight resides in the fact that Preuschoft's instrumentation of the reins included battery and circuitry, while in our system peripheral devices other than the sensor were located elsewhere. Weight of the instrumentation is important because it affects rein tension when the reins are loose. The methods of data collection and data storage were also different between the present study and that of Preuschoft et al. (1999). In the study described here, the data could be seen directly on the computer screen as they were generated. Data were stored on the hard drive and later retrieved from the computer for evaluation. By contrast, Preuschoft et al. (1999) used a data logger to collect and store the data, which had the advantage that it allowed the riders to ride freely around the arena or on the roads and to perform movements along straight lines. These activities were not possible when the horse was tethered to the computer, which limited the riding activities to a circle around the data collection devices. The ability to synchronize video images with the rein tension data proved to be invaluable for interpreting the factors or events governing changes in rein tension. The lack of video data in Preuschoft's study limited the ability to interpret and understand the findings.

Despite these methodological differences, there were some marked similarities between the two studies in the rein tension patterns and magnitudes. In both studies the shape of the rein tension trace is spiky with the frequency of the spikes showing characteristic patterns within the different gaits. It should be noted that the time scale (x-axis) is different between the graphs presented in this study and the graphs presented in Preuschoft's study. This may give the initial impression that the data are different, but a more careful evaluation shows a similar number of peaks per unit time at each gait in both studies.

The magnitudes of the rein tension spikes have similar ranges for each gait in the two studies, but they can vary with experience of the riders as shown by the results of this study. The graphs published by Preuschoft (1999) showed lower magnitudes of the rein tension peaks at the canter, but it is not reported whether these traces are for the rein on the side of the leading limb or the trailing limb. Also it is not indicated whether the traces at the different gaits are generated for the same rider or the same horse. The horse and riders used in this study showed higher magnitudes of the rein tension peaks at the canter for both reins compared to their trot. The magnitudes in this study are within a similar range to those reported by Preuschoft. The maximum forces shown in the graphs presented by Preuschoft (1999) are 30 N at the walk, 80 N at the trot and 60 N at the canter. In our study rider one was usually below such values while rider two exceeded those values during most of the trials. The maximum value at the walk performed by rider one was 20 N while rider two reached 40 N. At the trot rider one reached maximum values of 45 N while rider two exceeded 90 N. Canter maximums rarely reached 75 N for rider one with most of the trials averaging a maximum tension of 50 N, while rider two occasionally reached 150 N.

The high tensile forces observed in this study and Preuschoft study explain the fact that as a result of having a bit fitted in their mouth horses develop certain wear patterns in their teeth (Anthony and Brown 1991). Also that the tension observed is high considering the little effort required by the rider to generate together with the horse this high tensile forces, which explains in part the restrictive actions of reins and bits and the reason why they have been successful.

The results presented in this study and in Preuschoft (1999) are different than the rider's subjective interpretation of rein tension described in the equestrian literature. Two factors may play a role in these differences. The first factor is that the interpretations of rein tension published in equestrian books are based on the impressions of renowned and experienced riders describing rein tension on highly trained horses. It seems likely that high caliber horses and riders would have different rein tension profiles than those studied here. The second factor is that the output of the transducers is much more accurate than the perception ability of the rider in discriminating dynamic weight changes in rein tension. Most likely it is a combination of both of these factors, skill of the horse-rider combination and perception issues, that explain the discrepancy between the equestrian literature and the rein tension obtained using objective methodology. Most of these horses described historically in the literature were probably ridden with curb bits, which have a more severe effect on the horse's mouth with less effort from the rider, causing the horse to produce a more yielding effect in the rider's hands, which could explain what Baucher (1852) described as butter-like contact. The data in the present study were obtained using a snaffle bit, which does not act by providing leverage.

The assumption made by Steinbrecht (1884) that each horse is going to establish a different rein tension according to its conformation and training level seems to be more reasonable then Baucher's butter-like contact. Based on the results of this study we cannot support or refute this assumption since only one horse was used, but we can support the fact that the level of ability of the rider is key in determining the amount of tension and the pattern in rein tension displayed. Based on this findings, it seems likely that when the horse is being ridden on a contact, as opposed to being ridden on a loose rein, the rein tension recorded is directly related to the skill of the rider in displaying an independent seat (British Horse Society, 1982). Steinbrecht's assumption that the rein aids are closely linked to the efficient use of all other aids supports this contention. Rein length was not measured for the two riders in this study, but that may also contribute to the difference in rein tension displayed by rider one and rider two.

The detailed description of the rein aids provided by D'Endrody (1976) refers to the actions performed by the rider, not the interaction between horse and rider. Separating the rider's contribution (action) to rein tension from that of the horse is not possible using this technology. If the rider keeps a quiet, steady hand, a consistent pattern of spikes in the rein tension may develop as a result, mostly caused by the horse's movement within the quiet and steady rider's restriction. Changes in this pattern may indicate active rider intervention, like that presented in Figure 5.15. Pressure profiles beneath the saddle during riding activities are not constant for more than a few seconds at a time, in other words several stride cycles (Jeffcott et al., 1999). This seems to correlate with the results obtained in this study. Basic repetitiveness of the rein tension pattern was observed during some of the trials but a high correlation between rein patterns was not present.

Since data was collected when circling on both directions, it was expected to find a mirror image between rein patterns, that is the outside and inside reins would behave similarly on both circled directions, as expected in the dressage riding style. We did not find this mirror image at all in any of the three gaits nor between and within riders, which leads to assume that the interaction between horse and rider is more complex then expected and differences may be partly due to sideness of both rider and horse. This assumption is supported by the fact that Weber (1834) showed how weight discrimination changes between left and right hand depending on the favored side of the individual.

This fact leads to our believe that large perception issues seem to mask the assessment of real rein tension by the rider since in this study none of the riders were aware of the spiky nature of rein tension. Riders confidently described the rein tension as a constant contact or a smooth contact like that described by D'Endrody (1976). The sinusoidal movement of the head and neck in the vertical axis seen when the horse is viewed in a sagittal plane (Buchner et al., 1996) may explain the spiky nature of the rein tension. No studies have described if this sinusoidal movement is equally present in ridden horses compared to horses trotted and walked on the treadmill. It seems likely that the restrictive effect of the rider's rein aids gives rise to tension spikes each time the horse's head and neck nod downward. Therefore, the spikes represent a modifying effect of the rider's aids on the natural movement of the horse. It is also important to understand that these spikes are not only produces by the downward movement of the horse's head and neck. It was seen in the synchronized video-data that spikes sometimes correspond with the tension that occurs when by horse moves its head in either direction as a result of discomfort or bad timing from the rider's aids. Because of the high flexibility of the horse's head and neck and all the possible rider interference, it is not possible in this study to describe the details of all these possible resistances and faulty rider's action, but only to mention that they may occur and may show a different rein pattern.

Chapter 7 Conclusion and future studies

The primary purpose of this study was to develop and test an objective system to measure rein tension while performing horseback riding activities. The system that was developed used force transducers that were intercalated between the bit and the rein. Tension data were transmitted via a long cable to a laptop computer as the horse was ridden in circles around it. The output was displayed in real time on the computer screen and the data were stored on the hard drive. The system proved to be accurate under static laboratory conditions and in dynamic riding scenarios. Under the laboratory setting, tension generated through the reins could be easily visualized on the computer screen and this procedure showed the sensitivity and accuracy of the sensors as well as the computer's capability to display rein tension on the screen in real time. Different tension magnitudes and patterns could be generated in the two reins. Applying short pulls on the reins and bit could easily generate an intermittent rein tension. If both rein and bit were held in a steady fashion a flat rein tension could be observed.

Dynamic data were collected while a horse was ridden in circles around the data collection device at three gaits (walk, trot and canter) by two riders. The rein tension data were displayed graphically to yield interesting information, but it proved difficult to interpret these data without the use of synchronized video images. These video images proved indispensable for correlating tension data with the movement patterns and footfalls of the horse. In all three gaits the rein tension showed a spike pattern, even when the rider described the contact as constant or smooth. At each gait repetitive patterns could be observed within the different strides in the 5 second trials that were recorded.

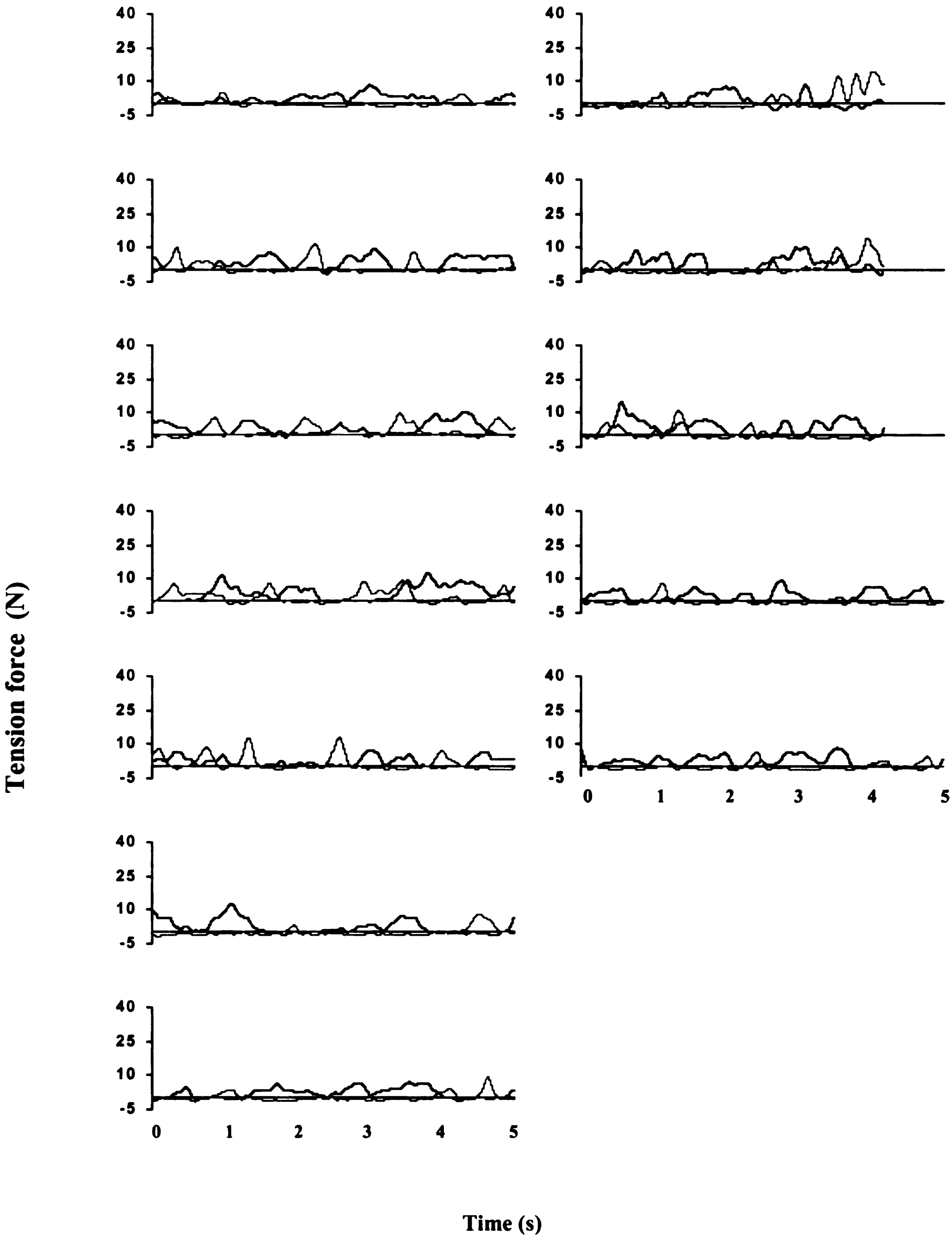
Superimposition of the rein tension data on the video image facilitated interpretation of the rein tension patterns by slowing down or pausing the video images while studying the events governing rein tension between horse and rider. Movements of the horse and rider could be carefully observed in relation to changes in rein tension.

Based on the results of this study, we cannot make assumptions regarding the "ideal" rein tension pattern, if there is such. It seems that the pattern recorded by the sensors is the product of the interaction between rider and horse. Certain aspects related to the magnitude and frequency of the spikes in rein tension appear to be a consequence of the natural movements of the horse. The differences between riders suggested that the aids given by the rider and the rider's level of expertise are modifying factors.

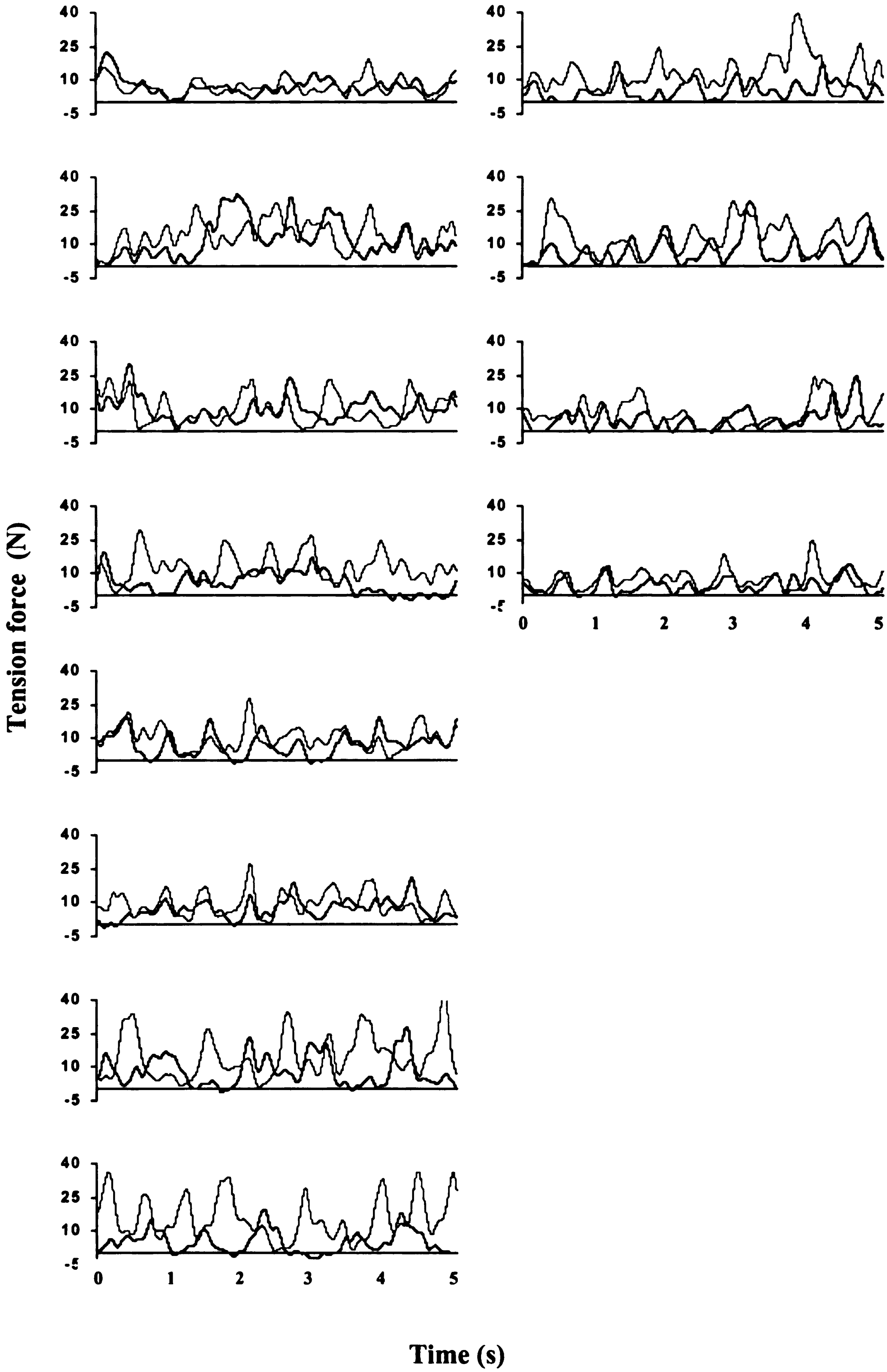
In future studies, more information on the horse's movement would be obtained, including head and neck movements, speed traveled and tempo of the gaits. It may be difficult to pinpoint the most useful parameters for assessing the horse's movement related to rein tension until more research has been performed on the basic mechanics of horse motion. Elite horse and rider combinations should be studied to address this issue since they are likely to show less variability combined with a more sophisticated level of communication.

In the future, use of telemetry to transmit data to the computer without the need of a cable and accurate stride identification devices such as accelerometers would allow for better numerical interpretation of the data. The use of correlation calculations to compare stride patterns, and more accurate location of the rein tension peaks in relation to stride events could be used to further our understanding of the more scientific aspects of rein tension.

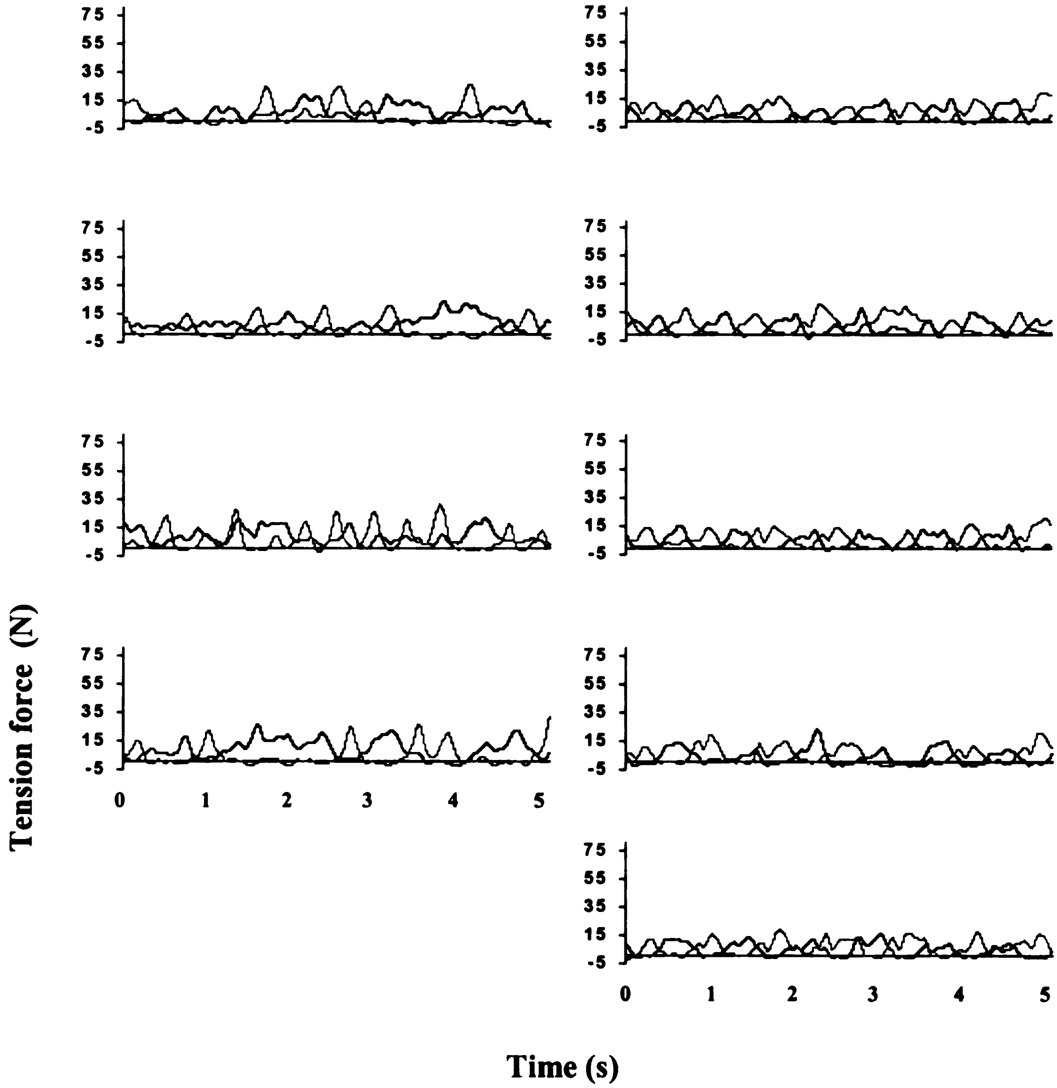
Appendix A (Page 1) Rider one at walk. Tension recordings in left (dark line) and right (light line) reins. Left column (left direction) Right column (right direction).



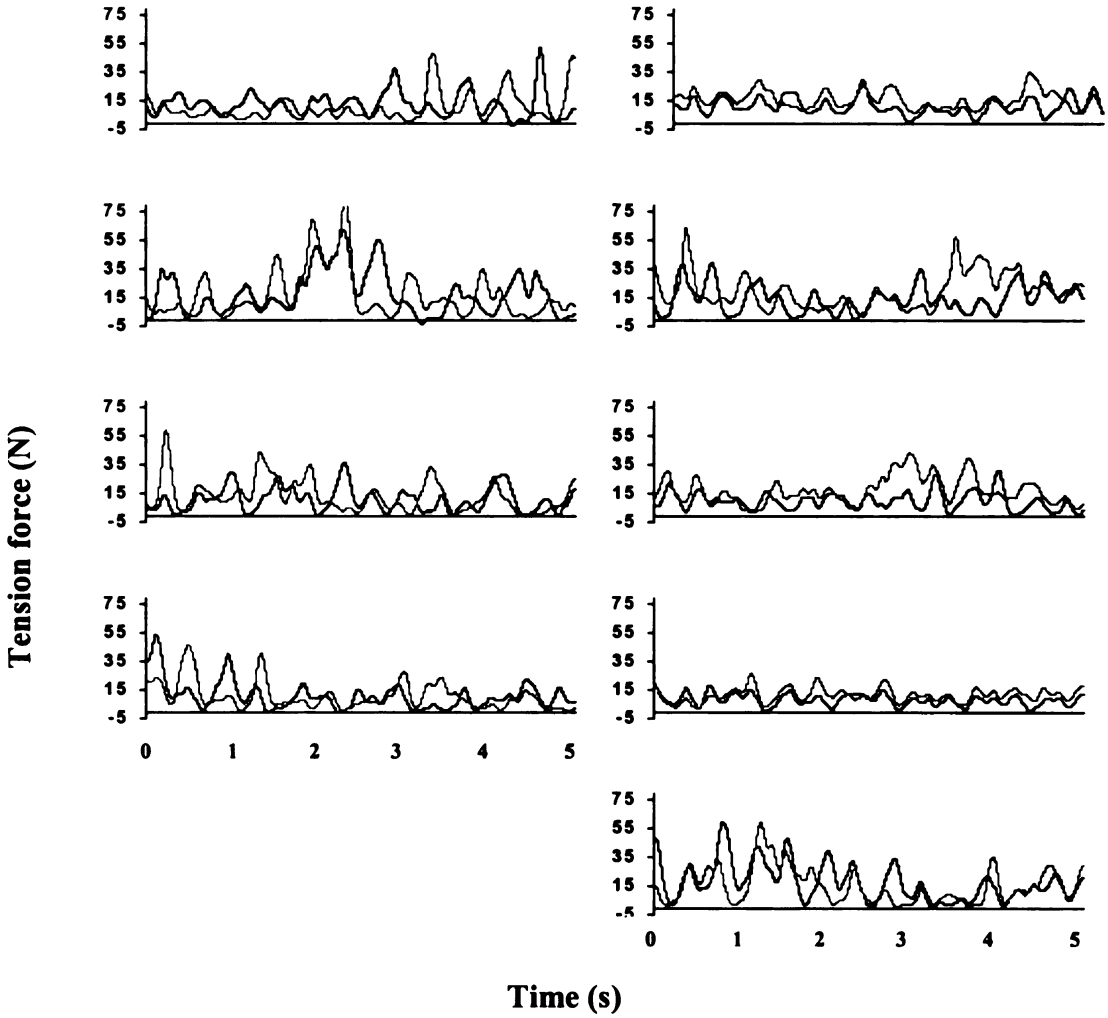
Appendix A (page 2) Rider two at walk. Tension recordings in left (dark line) and right (light line) reins. Left column (left direction) Right column (right direction).



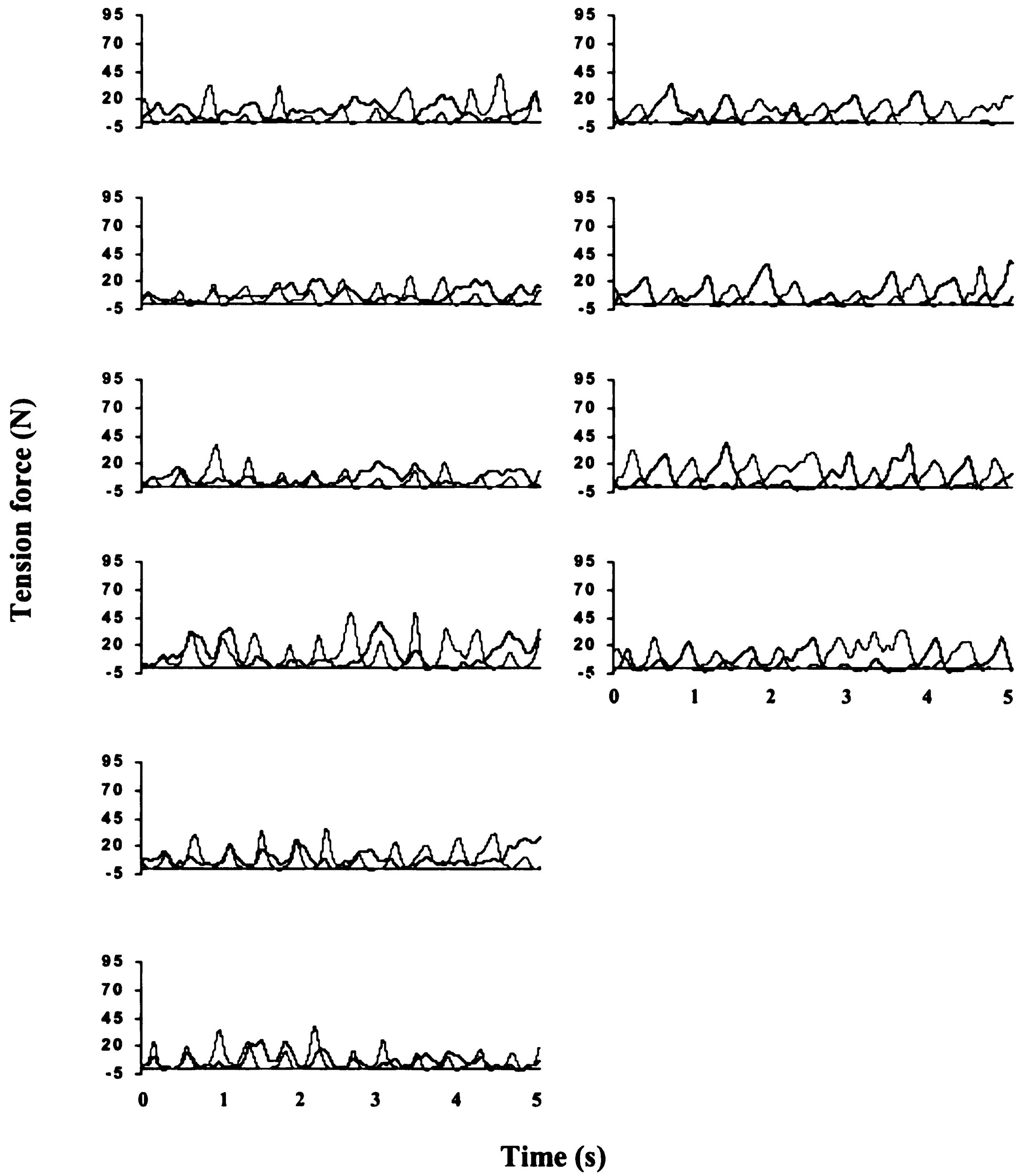
Appendix A (page 3) R ider one posting trot. Tension recordings in left (dark line) and right (light line) reins. Left column (left direction) Right column (right direction).



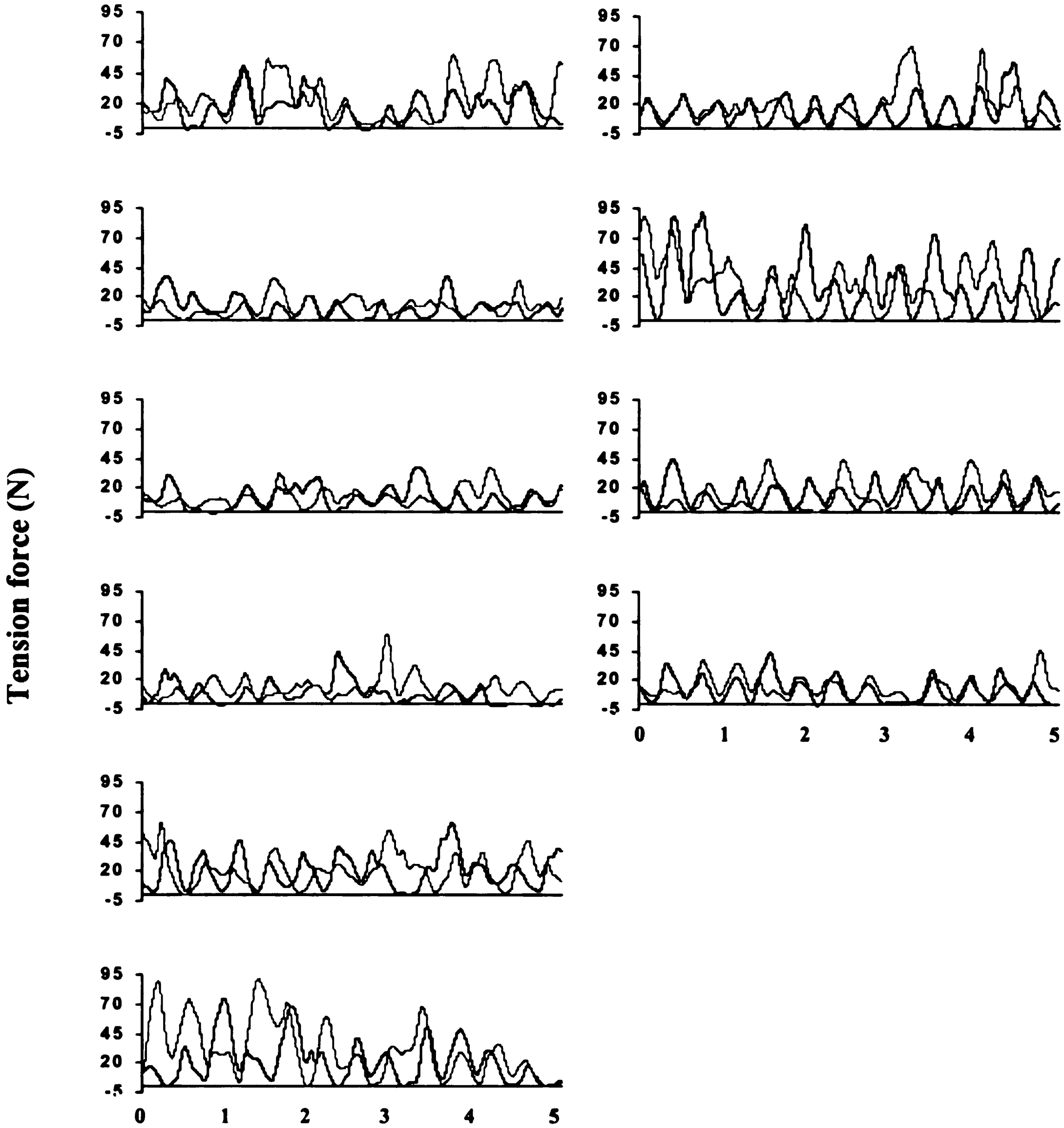
Appendix A (page 4) Rider two at posting trot Tension recordings in left (dark line) and right (light line) reins. Left column (left direction) Right column (right direction).



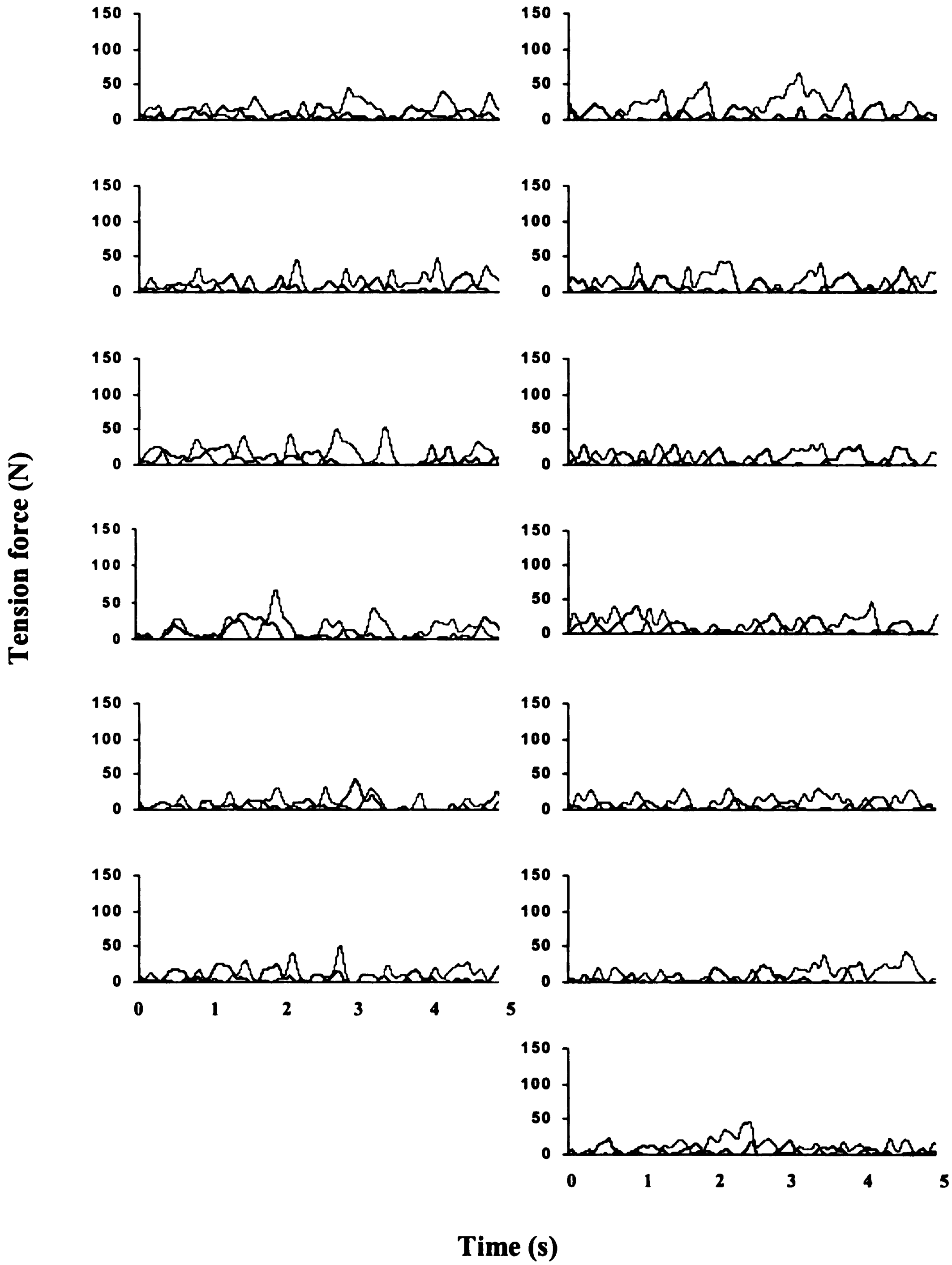
Appendix A (page 5) Rider one at sitting trot. Tension recordings in left (dark line) and right (light line) reins. Left column (left direction) Right column (right direction).



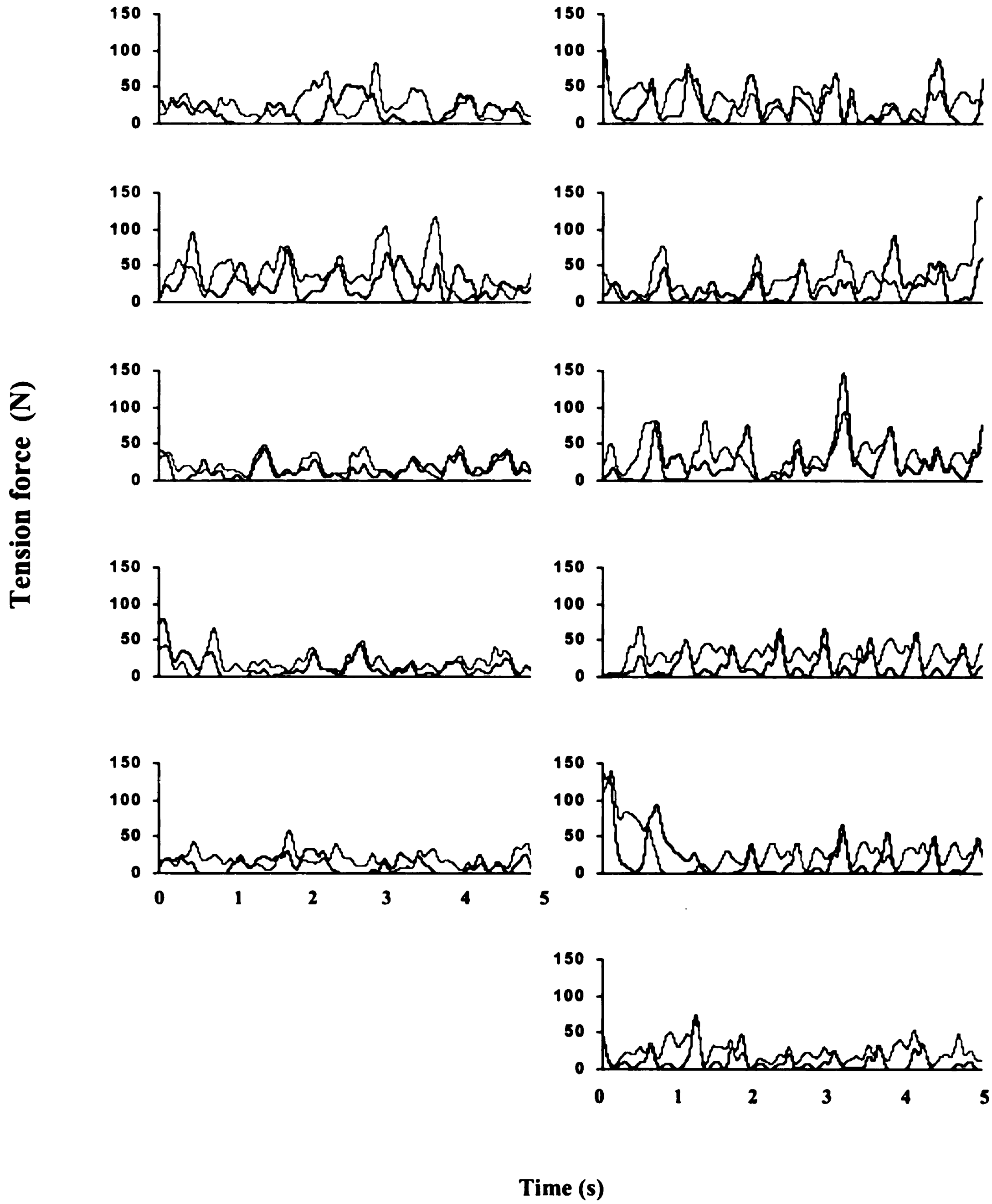
Appendix A (page 6) Rider two at sitting trot. Tension recordings in left (dark line) and right (light line) reins. Left column (left direction) Right column (right direction).



Appendix A (page 7) Rider one at canter. Tension recordings in left (dark line) and right (light line) reins. Left column (left direction) Right column (right direction).



Appendix A (page 8) Rider two at canter. Tension recordings in left (dark line) and right (light line) reins. Left column (left direction) Right column (right direction).



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