HOW DOES AN AVERAGE WARMBLOOD HORSE MOVE?

Movement analysis of warmblood horses

Research report

Bachelor thesis

In Cooperation with Paardenkliniek de Raaphorst & Gaitsmart

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1. Abstract

A perfectly healthy horse is the aim for every rider in the Equine industry. Nevertheless, lameness is the most common health problem in horses which does not only result in a discomfort for the horse but also results in significant economic loss to horse owners and professionals (Anon, 2001). Lameness can be recognized as an asymmetrical movement between two stance phases of a pair of limbs (Pfau 2011) whereby even a slight injury can influence the movement pattern of the horse. For the detection of lameness a veterinarian will perform a visual assessment although it has been investigated that this visual assessment is less sensitive than technology and therefore an insufficient tool (McCracken et al., 2012). Because veterinarians, horse owners and equine experts aim for the early detection and prevention of lameness, objective gait analysis methods have been developed including the Pegasus Gait Analysis system (European Technology for Business Ltd.). This tool can measure the stride parameters of the horse and when knowing the normal movement pattern, subtle changes can be identified early. Therefore, the aim of this study was to investigate the normal distribution pattern for healthy warmblood horses on a hard and soft surface in walk and trot and investigate if there is a difference in movement pattern between hard and soft surface and between horses which are determined sound by a veterinarian and horses which are determined lame by the same veterinarian. In total sixty-four healthy looking, with no clinical signs of disease, warmblood horses were used in this research. All horses were measured in a straight line, using the six inertial sensors, on a hard and soft surface both in walk and in trot. Video recordings of the horses measured were analysed by a veterinarian who declared the horses sound (n= 51) or not sound/lame (n=13). As a result all the horses which were measured with the ETB Pegasus system, the mean values, standard deviations, minimum and maximum values of the range of motion and asymmetry were calculated. The results for comparing the gait variables between hard and

soft surface, showed that there is a significant difference ($p < 0.05$) in movement pattern between hard and soft surface namely for the range of the fore cannons in walk and the range of the Tibia in trot. The hypothesis that type of surface does have an influence on the gait parameters has also been investigated and confirmed in other previous research (Henry Chateaua et al., 2013; N. Crevier-Denoix et al., 2013; C.J. Scheffer & W. Back, 2013).

Finally, the most interesting result from this research is that there is no significant ($p < 0,05$) difference measured between horses which were determined sound by a veterinarian and horses which were determined lame by the same veterinarian. Although in every gait and for almost every parameter the lame horses have a slighter lower range of motion compared to the sound horses, this difference is not significant ($P > 0,05$). This result might be in line with the fact that human visual evaluation is a poor tool which is less sensitive than technology (McCracken et al., 2012).

2. Introduction

Lameness in horses is a big problem in the equine industry, it is the most common health problem and causes horses to retire early or the horses are in need of special care and attention which takes a lot of time, effort and money.

In the horse industry keeping the horse healthy is the most important aspect, every rider or horse owner aims for a perfectly healthy horse because only healthy horses can be ridden on, compete or even win a competition. Lameness is not only a large medical problem in horses which results in discomfort for the horse but also results in significant economic loss to horse owners and professionals (Anon, 2001). Because of this much care is taken of the horses to reduce the chance of illness or an injury. Many research has been done on horses but in the field of equine locomotion there is still not many knowledge gained due to the fact that is hard to investigate and despite this effort lameness is still a very important problem in the equine industry, namely the most common health problem in horses (Kaneene et al, 1997; Pfau, 2011; Weishaupt, 2008). The evaluation for whether a horse is lame or sound is usually done by a veterinarian who will perform a number of steps during this detection to make the evaluation as accurate as possible.

The aim of this study is to better understand the movement of a warmblood horse. Warmblood horses are the most commonly used sports horse in the world which is the reason this research focuses only on warmblood horses. The ultimate aim for the future is to detectlameness and other locomotion health problems more easily, earlier and maybe even prevention of these problems. But before this future goal can be realized, the healthy movement patterns first should be determined in this research to be able to gain knowledge about lameness and other locomotion health problems in the future. Therefore the range of motion and normal distribution pattern of healthy sound warmblood horses are being determined during this research. For reaching the aim of this current study, a veterinary analysis will be needed to help compare the data as accurate as possible. Although veterinary analysis has been demonstrated to not always be reliable, which will be discussed later on in this research (chapter 4: literature review), for now the veterinary assessment which is commonly accepted as a reliable method, will be used.

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2.1 Research Objective

To investigate a normal distribution pattern for healthy warmblood horses on a hard and soft surface in walk and trot and investigate if there is a difference in movement pattern between hard and soft surface and between horses which are determined sound by a veterinarian and horses which are determined lame.

2.2 Research questions

Main question:

What is the normal distribution pattern for sound warmblood horses in walk and trot?

Sub-questions:

1) What is the normal distribution pattern for warm blood horses in walk on a soft surface?

2) What is the normal distribution pattern for warm blood horses in walk on a hard surface?

3) What is the normal distribution pattern for warm blood horses in trot on a soft surface?

4) What is the normal distribution pattern for warm blood horses in trot on a hard surface?

5) Is there a difference between hard and soft surface in the movement pattern?

6) Is there a difference in movement pattern between horses which are declared sound by a veterinarian and horses which are declared not sound by a veterinarian?

3. Literature review

3.1Lamenessin Horses

It is already known that lameness is the most common health problem in horses. As mentioned before it is not only a large medical problem but also a financial problem, but what are the characteristics of lameness?

The description of lameness is an asymmetrical movement between two stance phases of a pair of limbs (Pfau 2011) whereby indicators are horse’s head nodding, fetlock dropped, hip hike and differences in the length of the strides (Ross, Dyson 2011). This is called the compensatory mechanisms which is explained by redistributing the load by unloading the affected limb or altering the event timing during a movement. Even a slight injury can influence the movement pattern of the horse and thereby influence his performance negatively. The injury, when not treated, can develop in a large locomotion problem whereby the horse is in need of constant care and should be monitored properly until he is fully recovered. This often takes a lot of time, energy and has high financial costs as a result which has already been highlighted in many studies (Jeffcott et al., 1982, Kaneene et al., 1997, Vigre et al., 2002, Keegan, 2007, Dyson et al., 2008 and Egenvall et al., 2009). Because of these negative aspects, the equine industry is highly interested and in need for proper lameness prevention methods.

3.2 Veterinarians

Evaluation of lameness is mostly done by veterinarians but what do we know about this evaluation and is this the best way possible for an objective and in depth evaluation?

Most commonly horses which are lame are evaluated by a veterinarian, these veterinarians are highly schooled and detecting lameness is done on a daily basis. During this detection the veterinarian performs a number of steps, including a visual assessment which is mostly combined with regional anaesthesia techniques to locate the pain which causes the problem. Although veterinarians are highly schooled and detecting lameness is a common occurrence , the visual evaluation can be a poor tool because it is less sensitive than technology (McCracken et al., 2012). Especially when the lameness is subtle and mild in which the asymmetrical movement or indicators are very small and are very difficult to see for the human eye. There are two main reasons for this problem which lowers the reliability of subjective lameness assessment, namely the anatomical limitations of the human eye and subjectivity (Keegan et al., 1998). This can be a good explanation for why research has revealed that even when veterinarians are experienced, amongst those experienced veterinarians there is a major difference in opinion about whether or not a horse is lame and on which limb (Fuller et al., 2006; Hewetson et al., 2006; Keegan et al., 1998, 2010; Pleasant et al., 1997; Starke et al., 2013). In these studies the evaluation of lameness in horses is primarily evaluated by reviewing videotapes. In the study of Keegan in 1998, 24 horses with forelimb lameness trotting on a treadmill were evaluated by evaluating soundless videotapes (Keegan et al., 1998). During this study the inter-rater agreement was lower (k = 0,21) when compared to a study with lameness evaluation measurements in current 'live' (k = 0.5 for forelimb lameness and k = 0,3 for hindlimb lameness). In another study which also used videotape recordings and a 10-point rating scale, for the measurement of 20 mild to moderate lame horses, resulted in an inter-rater agreement of severity of lameness of k=0,41 (Fuller et al., 2006). The overall agreement on the severity of lameness of experienced veterinarians was also lower in a study with evaluating videotapes, namely 60% of the time (Hewetson et al., 2006) when compared to 'live' lameness evaluation, namely 70% (Keegan et al., 2010) but exact comparison is excluded due to differences in models used.

Arkell (2006) also demonstrated that observers can be one-sided towards improvement once they knew a horse was nerve-blocked (Arkell, et al., 2006) and it is also known that the visual system of the humans has its limitations in detecting changes (Holcombe, 2009). As conclusion these studies have shown that subjective evaluation of lameness, especially when mild, is not reliable.

3.3 Kinetic vs kinematic

Some research has already been done to get a better understanding of the equine movement with help of two different types of methods; Kinetic and Kinematic. Both have shown to be successful in identifying lameness. But there are also some restrictions when using these methods.

Because veterinarians, horse owners and equine experts aim to get better understanding of locomotion so they can work towards prevention or early detection, the findings of previous research has resulted in the development of objective gait analysis methods. These motion studies can be divided into two different types of methods namely: Kinetic methods which is a forced based method and kinematic which is a motion based method (Clayton, Schamhardt, 2001; Pfau, 2011). Examples for kinetic methods are force plates, pressure mats, accelerometers etc. and examples for kinematic methods are optic systems with inertial motion units such as video graphic recording combined with using infrared or visible light techniques. Lots of research has been done, with regard to both methods, to find the best possible option in detecting lameness in an early stage (Mc Cracken et al., 2012; Clayton, Schamhardt, 2001; Starke, 2013; Ishihara et al., 2005; Weishaupt, 2008). Both types of methods have also been shown successful in identifying lameness and are even more sensitive than the human visual assessment (Mc Cracken et al.,2012). Ground reaction force methods with the use of force or pressure plates are the most optimum method to detect mild lameness in the field of kinetic approaches (Clayton, Schamhardt, 2001; Starke, 2013; Ishihara et al., 2005; Weishaupt, 2008) As Ishihara stated: “Among the kinetic gait parameters, vertical force peak and impulse had the best potential to reflect lameness severity and identify subclinical forelimb gait abnormalities”. Also Weishaupt has done many studies in the field of equine lameness and kinetics (Weishaupt et al,, 2001; Weishaupt et al., 2004; Weishaupt et al., 2006., Weishaupt et al., 2008). As Weishaupt describes in his research, in kinetic measurements there is a differentiation between internal and external forces and torques. Internal forces are forces inside a system such as tendon forces or bone strains which could be defined directly, though are limited to research applications because they are invasive. The mostly used forces are the external forces which address to forces which are generated from outside a system, for example the force the ground exerts on the body which is called “ground reaction force” (GRF) (Weishaupt et al., 2008). Weishaupt also explains that ins that at inetic measurements there is a differentiation between internal and external forces and torques. Internal forces arFx), the longitudinal-horizontal (Fy), and the vertical (Fz) force components (Weishaupt et al., 2008) and states in his research: n his research, 2008) force components s rements there is a differeWeishaupt et al., 2008).

In the field of kinematic approaches, the most popular techniques are video graphic recording, high-speed camera systems, combined with using skin markers and infrared or visible light techniques. Although these systems are used successively, there are also some restrictions when using them. Such systems are mostly very expensive, complicated to use so they can only be used by professionals and may be restricted to indoor use in specialized gait laboratories in combination with a treadmill (Clayton and Schamhardt, 2001; Pfau, 2011; Starke, 2013). For example with the skin markers: the position of the skin markers have to be calculated and they have to be attached by a professional. Problems can occur when they are not placed correctly on the horse's body and the markers are placed close together or cross each other during locomotion which influences the measurement. Another problem is the self-adhesive backing which may not be sufficient enough to hold the markers in the same place, especially during sweating of the horse, and super glue can be used to secure the markers but this might give problems with a client-owned horse because super glue is difficult to remove completely afterwards (Clayton and Schamhardt, 2001).

Even when the system is able to be used outdoors it has the restriction that it is limited to only a few number of strides and that the horse is marked by a number of sensors which might influence the movement pattern of the horse (Pfau et al., 2005). This in result might give an indication about the movement pattern of the horse but is not able to give detailed information due to the small number of strides measured.
These systems are also poorly available and due these restrictions mentioned they are mostly not accessible for most trainers, riders or even veterinarians.

Not only for the humans but also for the horses there is a certain restriction namely the treadmill. The treadmill is considered a good tool for equine gait analysis because the speed of the movement of the horse is controlled (Clayton, Schamhardt, 2001) but this also has disadvantages because movement on the treadmill differs from the natural movement of the horse. Previous research has shown that the locomotion of the horses is influenced by the treadmill namely the stance duration of the forelimbs in trot on the treadmill is significantly longer when compared to overground (Bruchner et al., 1994). Also the general stride length is shorter and the fore and hind limbs are moved more caudally during retraction phase (Bruchner et al., 1994; Fredericson et al., 1983). Another important aspect is that a horse is required to habituate for a period of time before it will move consistently on a treadmill (Clayton, Schamhardt, 2001), the kinematics of the trot adapt rapidly and after the third session of 5 minutes the kinematics of the trot have been stabilized but the walk kinematics do not fully adapt, not even at the tenth session (Bruchner et al., 1994a). These are all important aspects that should be taken into account when working out a gait analysis.

3.4 Lameness Locator

There are many different tools to detect lameness in horses, as described above many systems have some restrictions when using them, such as: expensive, complicated to use, restricted to indoor use etc. The equine world is in need of systems which do not have these limitations. One of these systems is the Lameness Locator, which is used often these days. The Lameness Locator, is an accurate system which is easy to use and not extremely expensive.

In the field of development of objective gait analysis methods, a new tool has recently been developed to detect lameness in horses. Recent studies with the lameness locator have indicated that the Lameness Locator is an accurate and sensitive system which is appropriate for clinical use (Keegan et al., 2012; Keegan et al., 2011). As J. Schumacher describes: "The lameness locator, a commercially available, inertial sensing device that measures asymmetry of torso motion used to objectively quantify the degree of lameness induced and resolved in horses during the trail". (Schumacher et al., 2013). During the movement of the horse in trot, the head moves up and down twice in one stride, however, when the horse has a unilateral lameness this head nodding is asymmetric. This visual adaptation is also used often by veterinarians as a lameness indicator when evaluating a horse. Nowadays, this knowledge has been used into a system namely the lameness locator. The lameness locator uses 3 small, wireless, body-mounted inertial sensors which are attached on the horse's head between the ears, on the dorsal aspect of the right pastern and on top of the pelvis between the tubera sacralia(Schumacher et al., 2013). These sensors record the torso motion and calculate the differences between the left and right halves of the stride by the differences in height of the pelvis (evaluation of the hind limbs), and the differences in height of the head (evaluation of the forelimb). The data of the sensors is transmitted wirelessly to a tablet PB with the use of a Bluetooth connection. The data is collected, stored an analysed by using a specialized software program (Veteldiagnostics, 2015).

As an end result the system displays the numbers and a x and y graphs where right and left front or hind limb lameness can be measured. The system also provides a report with information such as the average position of the head and pelvis of the horse in millimeters, and the symmetry of movement for each limb. The lameness locator gives an objective analysis which indicates whether the horse is lame, it gives an amplitude of the severity of the lameness, mentions the limb or limbs which are involved, and the part of the motion cycle at which the peak pain is occurring (at impact, mid-stance, or push off (Veteldiagnostics, 2015).

The lameness locator does give objective information about asymmetric movement and can measure even mild lameness but it is designed for usage at trot only (Veteldiagnostics, 2015). This is the most common gait for lameness examination but problems might be overlooked when excluding the other gaits, which are also important. Especially for an in depth en specialized analysis, all gaits should be measured and taken into account. Also the Bluetooth connection might give problems during measurement, the user should be aware that the data can only be send over a short distance which means that the measured horse and the tablet PC which receives all the data should always be kept close together.

3.5 Pegasus

The ETB Pegasus system is a newly developed systems which can objectively analyze the movement of the horse. This system makes use of wireless IMU's which have proven their benefit in several studies for humans as well as horses. The ETB Pegasus system is another system which is easy to use, not expensive, is not restricted to indoor use etc.

Another tool which also can be used for an objective study of the equine kinematics is the ETB Pegasus system. This newly developed gait analysis method can be applied in a less lab-constraint setting due to the used miniaturized inertial sensors, which are called IMU's (inertial measurement units). The IMU's can measure the locomotion of 'real-life' activities in horses (Parsons et al, 2008a,b; Pfau et al, 2006; Pfau et al, 2009; Starke et al, 2009). The IMU's have been investigated in several studies to prove their benefit in the assessment of equine locomotion (Barrey et al., 1994; Starke, 2013).

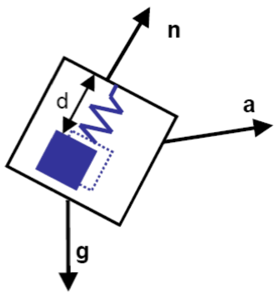

Figure 1: A single axis accelerometer. The distance of the mass (d), difference of acceleration (a) and gravity (g) along the sensitivity axis (n) (Luinge, 2002).

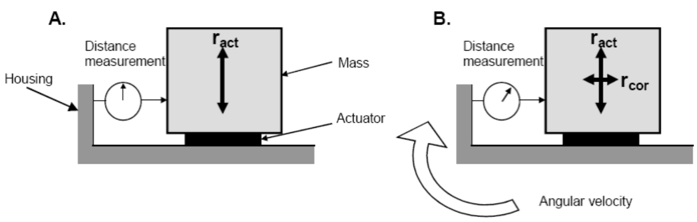

Figure 2: A: a gyroscope consists of a mass, which is brought into vibration by an actuator in the direction given by r_{act}. B: Due to the rotation of the gyroscope, the mass will vibrate in the actual direction and will undergo a (small) displacement, Coriolis effect (Luinge, 2002).

The data from each sensor is gathered at 102.4 Hz and is being stored on a memory storage device card (SD card) which is also processed in each sensor. Although the sensors are combined with these systems, the sensors are still small in size, lightweight and robust. This is a big advantage because the sensors do not interfere or have a significant impact on the movement pattern of the horse (Pfau et al, 2005) and as Fong and Chan (2010) describe are "highly transportable, low cost and consumes low power during operation".

In Human motion analysis research (Cooper et al., 2009; Cuesta-Vargat et al., 2010; Fong and Chan, 2010; O'Donovan et al., 2007) these kind of sensors have been compared with many other tools for measuring human movement and they have concluded that " the inertial sensors can offer an accurate and reliable method to study human motion " (Cuesta-Vargas et al., 2010). Another study which compared the IMU's with optical measurement system showed that the IMU's measurements are very accurate and precise (Monda et al., 2013; O'Donovan et al., 2007). The ETB Pegasus Gait Analysis system contains of one laptop with accompanying Pegasus software installed, four cannon brushing boots, two tibia straps and six sensors. These sensors measure three systems namely the limb phasing system, the cannon angle system and the hock angle system. The limb phasing system measures the stride pattern of the horse such as the stride length, speed, gait and the temporal limb phasing to the reference limb. The cannon angle system monitors the cannons of the horse in the sagittal plane, which is the protraction or retraction, and the coronal plane, which is the abduction and the abduction, of one stride. Lastly, the hock angle system measures the flexion and extension of the hock. These measurements are assured to be reliable and accurate when used in the correct way, which is described in the user manual, due to the fact that each system has been validated against an optical system (ETB Pegasus, 2013).

Figure 3:
The ETB Pegasus system consisting of a laptop with accompanying Pegasus software, several sensors and equipment for attaching the sensors to the horse.

Dieckmann (2014) carried out a study with the ETB Pegasus system to develop a database which includes gait profiles of a variety of horse breeds, in the case of this specific study the breed Islandic Horses in comparison to Warmblood horses (Dieckmann, 2014). In total 61, healthy, Icelandic horses (both four- and five-gaited horses) were measured in walk and trot on a hard surface. The trot of the 61 Icelandic horses was compared to the trot of 77 Warmblood horses.

As a result of this study Dieckmann concluded: “that Icelandic horses showed a higher range of motion, both in the sagittal and in the coronal plane” and she stated : ”this paper confirms that the movement patterns in Icelandic horses vary from those of other horse breed” (Dieckmann, 2014). Thus movement patterns which are breed specific do exist and with regard to the Pegasus system this study also proves that the Pegasus system is a very accurate device which can measure even the smallest irregularities and is easy to use in the field (Dieckmann, 2014).

To recapitulate, the ETB Pegasus gives objective measurement and detailed information about the characteristics of all gaits of the horse, when mounted on the legs of the horse. It can measure the natural over ground movement and can monitor any subtle changes. When compared to a motion capture system, which is used many in equine biomechanics laboratories, the results show that the Pegasus system produces information which are very close to those produced by a motion capture system and as Nankervis stated: “the differences are unlikely to be considered of physiological or practical significance”. With more detailed information and measurement, a better understanding of the moving horse and early detection of lameness can be developed. The ETB Pegasus system therefore can be used in the field at top level jumping stables or race yards because no laboratory setting is needed and is nowadays already used in several research institutions (University of Utrecht (NL), Hadlow College (GB)) (Voskamp et al., 2011; Voskamp et al., 2012; Naylor and Holmes, 2008; Nankervis et al., 2008; Walker et al., 2013; Sonneveld et al., 2011; Walters et al., 2009) and veterinary clinics (for example: P&M Vet Services Vancouver, Canada). Furthermore, at the Olympic Games in 2012 the English team was supported by ETB Pegasus (ETB Pegasus, 2013). As a result, many data was collected from gait analyses with many different types of horses (dressage horses, show jumping horses, race horses etc.) and with this data Diana Hodgins, the managing director and developer of ETB Pegasus, could compare gait parameters and get a better understanding of the equine locomotion. Both healthy horses as lame horses were measured and compared. Nowadays the number of data is growing but still a lot more research is needed to gain more knowledge and eventually gain a software which can automatically compare the results against normal healthy population.

4. Materials and methods

4.1 The horses

In total sixty-nine (n=69) healthy looking warmblood horses, with no clinical signs of disease which are owned by different riders, participated in this study. Different types of breeds within the warmblood horses were measured, mostly Dutch warmblood horses KWPN (n=66) but also Rhinelander (n=1), Oldenburg (n=1) and BWP (n=1). All the horses were filmed with a Sony Cyber-shot DSC-WX7during the measurements. These videos were viewed by one veterinarian, Morgan Lashley, from Paardenkliniek De Raaphorst who, with use of the videos, did declare the horses sound or not sound. The data of the horses which are declared sound (n= 51) were separated from the horses which are declared not sound (n=13) and the horses with a faulted measurement were removed (n=5). For investigating the normal distribution pattern, only the horses which are declared sound were used in this research.

Moreover, the horses which were declared sound had a mean (± SD) year of birth of 2004 ± 4,48 years (range 1994 – 2011) and a mean height of 1.70 ± 0,04m (range 1.62 – 1,84 m).With regard to gender there were 30 geldings (58,8%) , 21 mares (41,2%) and no stallions. The number of horses which participated in dressage were 31 horses (60,8%), for jumping 4 horses (7,8%), for recreational use 1 horse (2%) and there were also a 15 horses (29,4%) which were used for Police purposes. The level of training was also variable with 31 horses (60,8%) which were trained at basic level (B/L), 7 horses (13,7%) which were trained at medium level (M), 12 horses (23,5%) which were trained at advanced level (Z/ZZ) and 1 horse (2%) which was trained at international level. With regards to shoeing of the equine feet, most horses had shoeing on all 4 feet namely 27 horses (52,9%), 15 horses (29,4%) had shoeing on the front feet and 9 horses (17,6%) were barefoot (Annex lll: Horses used in this study and determined sound).

The horses were declared not sound (n=13) also had a mean (± SD) year of birth of 2004 ± 3,81 years (range 1999 – 2011) and a mean height of 1.71 ± 0,06m (range 1.63 – 1,84 m).In this group the gender was divided into 4 mares (30,8%), and 9 geldings (69,2%). With regards to discipline: 8 horses (61,5%) participated in dressage, 3 horses were used for police purposes (23,1%) and 2 horses for recreational purposes (15,4%). The level of training under these horses differed from 9 horses (69,2%) trained on basic level (B/L), 2 horses (15,4%) trained on medium level (M) and 2 horses trained on heavy level (15,4%). None of the horses which were declared not sound were barefoot, 6 horses (46,2%) had shoeing on the front feet and 7 horses (53,8%) had shoeing on all 4 feet (Annex lV: Horses used in this study and determined lame).

4.2 The measurement system

The movement patterns of the horses were measured by using the ETB Pegasus gait analysis system which uses six inertial sensors, a GPS sensor and a laptop with associated analysis software. These inertial sensors have a size of 78 x 25 x 10 mm and weigh of 52 gram, which transmits 100 measurements per second. Every sensor contains three accelerometers, three orthogonal gyroscopes, a precision clock and a memory storage device (SD card). The sensors are attached to the horse's legs by four appropriate brushing boots and two specialised soft straps for the tibia (Figure

4), the GPS can be attached to the horse with an accompanying elastic band if desired.

For recording and processing the data the specialized computer software (Poseidon version 9.0.0, ETB Ltd.) was used. Before every trial of data collection, the sensors were first synchronized by the software. During the measurements the data was stored on the sensors of the Pegasus system itself and after the collection was complete the data was connected to a laptop by USB connections. Subsequently, the data was downloaded from to sensors to the computer by using the Poseidon software which transformed the data from the sensors into a readable output with numbers and graphs (Annex I : Example of graph with explanation and Annex V: Example of Gait Analysis Report). The data for each gait (yellow = walk, green = trot, red = canter) is displayed as: total number of strides, time taken, distance covered and the average, stride duration, low and high values of limb phasing, speed and stride length. With this overview, the user can choose from several options for a further and in-depth analysis: for each gate make a selection of strides, zoom into any section of the time graph to be enlarged, look at different movement patterns one by one and look at joint angles between right and left limbs, and to visualize the output one can make a plot. For further in depth analysis, the raw data can also be converted into an excel file.

Figure 4:
A horse with the ETB Pegasus equipment attached (four brushing boots, two attached to the front and two at the hind cannons, and the two tibia straps all including sensors), ready for a measurement trail.

4.3 The protocol

Before starting the measurements, every horse owner which participated was asked to fill in the examination sheet (Annex II: Protocol used in this research) to collect information and characteristics of the horse. Afterwards, the two soft straps were attached on the tibia and four brushing boots were attached on each of the 4 legs of the horse (Figure 4) at the distal metacarpal and metatarsal region. When the straps and brushing boots were securely fastened, the Pegasus system was prepared. The sensors, attached to the laptop, were time stamped and synchronised with the use of the Poseidon software. When synchronization was completed, the sensors were disconnected from the laptop, put in specialized plastic bags against dirt and water, were switched on and located in the appropriate pockets in the brushing boots and tibia straps. When all the sensors were switched on and in place, the horse had to stand still for at least 10 seconds in order to let the sensors calibrate. Now the horse is ready for the gait analysis and was led around in walk for approximately 2 minutes to habituate to the equipment.

After habituation the measurements starts. All horses wore a halter and were led by the same handler on a loose rope. The handler always walked on the left side of the horses and made sure that the horses were not disturbed by external factors which could influence the results of the measurement, if the horse was significantly excited or distracted, this measurement trial was not further used in the investigation but was repeated until a usable and correct measurement was received. Furthermore the handler also tried to maintain the horse moving at the same, natural, speed. At first the horse was led on a hard surface for approximately 40 meter up and 40 meter down in walk (6.4 km/h) and afterwards at trot (13 km/h).Between the transition from walk to trot, the horse was asked to stand still for approximately 5 seconds in order to read the data more easily afterwards. After the measurement on the hard surface, the horse was led to the soft surface at which the horse was again asked to stand still for approximately 10 seconds in order to see the transition from hard surface to soft surface more easily in the data. All horses were first measured on hard surface and afterwards measured on soft surface. On the soft surface the same trial was repeated, first leading the horse 40 meters up and 40 meters down in walk (6.4 km/h) and afterwards in trot (13 km/h).

During the trials on the hard and soft surface all the horses were filmed by an assistant with a Sony Cyber-shot DSC-WX7 camera.

At the end the horse was led to the laptop, the sensors were removed from pockets from the tibia straps and brushing boots, switched off and connected to the computer to transfer the data from the sensors to the computer so they could be analysed.

Figure 5:

Placing the sensor in the appropriate pocket

Figure 6a & b:

Left: leading a horse on hard surface during measurement

Right: leading a horse on soft surface during measurement

4.4 Data analysis

During this research all the horses were filmed and measured anonymously. For the expansion of the Pegasus databank, detailed information about: age, sex, height of withers, discipline, educational level, type of shoeing, medical history and breed were collected. Once all the information was collected and the measurements were completed successfully, all the data was processed by the use of the Poseidon software which was installed on the accompanying laptop. For every horse the data was observed and personally cut into data streams. These streams had to have at least 10 coherent strides and the speed had to be practically in line to be reliable for calculating the most common gait pattern in walk and in trot for hard surface as well as for soft surface. As a result, the following parameters produced a set of values in a table for each set of chosen data:

1. The ROM of the hock, tibia, cannon fore and cannon hind (sagittal angles in degrees, protraction = positive numbers and retraction = negative numbers)

2. The medial lateral movement of the tibia, cannon fore, cannon hind (coronal range in degrees, lateral = positive numbers and medial = negative numbers)
3. The timing at the following four moments:

at A = Maximum protraction of the hind cannon,
at B = Maximum protraction of the fore cannon,
at C = Maximum retraction of hind cannon
at D = Maximum retraction of fore cannon.

All the values above are stated for left and right limbs.
The symmetry in percentage of the stride which is the difference in the sagittal range between the right and left limbs.

Once all the data were collected and all the values were presented, the Poseidon software made it possible to summarize the analysed data for each horse into a short PDF report (Annex V: Example of Gait Analysis Report). Thereafter, all the data and information of the horses which were declared sound by the veterinarian by viewing the videos of the horse, were transformed into one large excel file for further analysis. Also, for horses which were declared not sound by the veterinarian, the same processing steps were followed but the data was collected into another excel file.

Secondly, the processing of the collected data was done by performing statistical analysis using SPSS Version 22. For every gait and surface the average values and normal distribution of the limbs parameters were calculated by applying descriptive statistics on SPSS. The stride parameters on soft surface was compared to the stride parameters on hard surface using related samples t-test. Furthermore, the difference between stride parameters of horses which were determined 'sound' by the veterinarian and the horses which were determined 'not sound' was calculated by using the independent samples t-test. For every test, P values ≤ 0.05 were considered significantly different.

5. Results

5.1 Average values and normal distributions

For all the horses which were measured with the ETB Pegasus system, the mean values, standard deviations, minimum and maximum values of the range of motion and asymmetry were calculated and the results for are displayed with in table 1 & 2: Range of motion and 3: Asymmetry, the percentage difference in symmetry.

Table 1

Mean values, minimum range, maximum range and standard deviation of the range of motion of all horses, which were determined sound by the veterinarian, in walk on hard and soft surface are given.

Gait	Surface	Gait parameter	Plane	Minimum Range (°)	Maximum Range (°)	Mean Range (°)	Std. Deviation
Walk	Hard	Range Hock Left	Sagittal	19.24	46.54	32.89	6.04
Walk	Hard	Range Hock Right	Sagittal	21.64	43.59	33.13	4.81
Walk	Hard	Range Tibia Left	Sagittal	41.48	55.14	48.99	3.31
Walk	Hard	Range Tibia Right	Sagittal	39.34	61.93	49.14	3.85
Walk	Hard	Range Cannon Fore Left	Sagitta	56.50	81.27	70.38	5.33

Walk	Hard	Range Cannon Fore Right	Sagittal	53.51	79.81	69.54	6.07
Walk	Hard	Range Cannon Hind Left	Sagittal	45.13	64.11	54.94	4.60
Walk	Hard	Range Cannon Hind Right	Sagittal	42.65	64.63	55.49	4.15
Walk	Hard	Tibia Left	Coronal	16.69	31.83	23.85	3.95
Walk	Hard	Tibia Right	Coronal	15.66	33.97	24.02	4.13
Walk	Hard	Cannon Fore Left	Coronal	7.90	36.76	23.48	7.24
Walk	Hard	Cannon Fore Right	Coronal	4.65	39.85	21.49	9.58
Walk	Hard	Cannon Hind Left	Coronal	5.21	37.96	17.05	7.59
Walk	Hard	Cannon Hind Right	Coronal	4.64	29.82	14.21	6.60
Walk	Soft	Range Hock Left	Sagittal	20.86	40.92	33.21	4.43
Walk	Soft	Range Hock Right	Sagittal	21.18	41.14	33.00	4.00
Walk	Soft	Range Tibia Left	Sagitta	39.83	57.04	49.22	3.81

Walk	Soft	Range Tibia Right	Sagittal	39.52	55.16	49.07	3.61
Walk	Soft	Range Cannon Fore Left	Sagittal	57.86	74.93	68.18	4.63
Walk	Soft	Range Cannon Fore Right	Sagittal	52.74	75.86	68.10	5.36
Walk	Soft	Range Cannon Hind Left	Sagittal	40.59	63.98	55.87	4.59
Walk	Soft	Range Cannon Hind Right	Sagittal	49.67	62.49	56.30	3.27
Walk	Soft	Tibia Left	Coronal	15.21	32.21	23.80	3.96
Walk	Soft	Tibia Right	Coronal	15.19	32.24	23.29	3.54
Walk	Soft	Cannon Fore Right	Coronal	8.88	41.27	21.73	8.52
Walk	Soft	Cannon Fore Left	Coronal	8.00	37.20	23.17	7.24
Walk	Soft	Cannon Hind Left	Coronal	7.91	37.35	17.77	6.56
Walk	Soft	Cannon Hind Right	Coronal	4.29	29.75	14.63	6.52

Table 2

Mean values, minimum range, maximum range and standard deviation of the range of motion of all horses, which were determined sound by the veterinarian, in trot on hard and soft surface are given.

Gait	Surface	Gait parameter	Plane	Minimum Range (°)	Maximum Range (°)	Mean Range (°)	Std. Deviation
Trot	Hard	Range Hock Left	Sagittal	28.06	55.50	39.42	5.81
Trot	Hard	Range Hock Right	Sagittal	31.30	53.40	39.44	4.28
Trot	Hard	Range Tibia Left	Sagittal	32.15	49.60	41.11	3.69
Trot	Hard	Range Tibia Right	Sagittal	33.67	51.03	41.31	3.64
Trot	Hard	Range Cannon Fore Left	Sagittal	60.57	87.40	75.66	6.29
Trot	Hard	Range Cannon Fore Right	Sagittal	57.29	89.71	75.63	6.33
Trot	Hard	Range Cannon Hind Left	Sagittal	40.78	67.15	52.41	5.57
Trot	Hard	Range Cannon Hind Right	Sagittal	41.60	67.95	53.04	5.47
Trot	Hard	Tibia Left	Coronal	16.11	33.20	26.30	3.77
Trot	Hard	Tibia Right	Coronal	19.05	34.61	26.44	3.69
Trot	Hard	Cannon Fore Left	Coronal	6.13	41.14	23.18	7.30
Trot	Hard	Cannon Fore Right	Coronal	7.97	35.67	20.42	8.11

Trot	Hard	Cannon Hind Left	Coronal	9.21	35.07	20.77	6.94
Trot	Hard	Cannon Hind Right	Coronal	9.00	34.39	18.88	7.41
Trot	Soft	Range Hock Left	Sagittal	30.63	54.45	39.60	4.90
Trot	Soft	Range Hock Right	Sagittal	28.72	52.08	39.10	4.02
Trot	Soft	Range Tibia Left	Sagittal	32.66	52.44	42.48	4.57
Trot	Soft	Range Tibia Right	Sagittal	31.95	56.12	42.60	5.21
Trot	Soft	Range Cannon Fore Left	Sagittal	55.76	86.22	75.10	6.49
Trot	Soft	Range Cannon Fore Right	Sagittal	55.72	88.60	74.88	6.81
Trot	Soft	Range Cannon Hind Left	Sagittal	37.59	62.21	51.85	4.76
Trot	Soft	Range Cannon Hind Right	Sagittal	41.62	63.39	52.65	4.76
Trot	Soft	Tibia Left	Coronal	17.37	33.31	25.42	3.84
Trot	Soft	Tibia Right	Coronal	17.24	31.73	25.54	3.44
Trot	Soft	Cannon Fore Left	Coronal	7.11	40.64	23.31	7.16
Trot	Soft	Cannon Fore Right	Coronal	6.82	36.58	20.99	7.49

Trot	Soft	Cannon Hind Left	Coronal	8.56	34.15	21.44	7.21
Trot	Soft	Cannon Hind Right	Coronal	7.74	34.58	19.55	7.42

Table 3

The symmetry, given in percentage, for all horses which are determined sound by the veterinarian in walk and trot on hard surface and soft surface. The minimum asymmetry, maximum asymmetry, mean asymmetry and standard deviation are given.

Gait	**Surface**	**Gait parameter**	**Minimum Asymmetry (%)**	**Maximum Asymmetry (%)**	**Mean Asymmetry (%)**	**Std. Deviation**
Walk	Hard	Symmetry Hock	-38.60	25.55	-1.38	14.68
Walk	Hard	Symmetry Tibia	-28.98	13.60	-0.18	6.82
Walk	Hard	Symmetry Cannon Fore	-9.70	11.77	1.28	5.74
Walk	Hard	Symmetry Cannon Hind	-17.30	13.20	-1.06	5.12
Walk	Soft	Symmetry Hock	-33.80	29.21	0.48	13.29
Walk	Soft	Symmetry Tibia	-16.97	17.28	0.28	6.46
Walk	Soft	Symmetry Cannon Fore	-11.04	12.35	0.21	5.28
Walk	Soft	Symmetry Cannon Hind	-27.09	8.45	-0.95	5.94
Trot	Hard	Symmetry Hock	-27.33	20.29	-0.51	10.40
Trot	Hard	Symmetry Tibia	-26.85	22.38	-0.51	9.72
Trot	Hard	Symmetry Cannon Fore	-16.21	13.13	0.06	4.81

Trot	Hard	Symmetry Cannon Hind	-15.25	14.14	-1.24	6.64
Trot	Soft	Symmetry Hock	-25.15	22.71	1.03	10.32
Trot	Soft	Symmetry Tibia	-32.01	30.55	-0.18	10.92
Trot	Soft	Symmetry Cannon Fore	-12.66	15.48	0.32	4.82
Trot	Soft	Symmetry Cannon Hind	-20.17	13.22	-1.54	6.17

It has been shown that all gait variables are normal distributed (Annex VI: Distribution charts). For a graph of the comparison of symmetry in walk and hard see Annex VII: Comparison between symmetry on hard and soft (for sound horses) graphs.

5.2 Comparison of movement parameters on soft surface and hard surface in walk and trot

For the comparison of gait variables between soft surface and hard surface was calculated by using the “related samples t-test”. This test showed that in walk there is a significant difference ($p < 0,05$) between hard and soft surface for the range of both left and right fore cannons. The results in trot showed that there is a significant difference ($p < 0.05$) between hard and soft surface on the range of the Tibia, left and right, both sagittal as coronal. All other gait parameters showed no significant difference ($p > 0,05$). For more detailed information about the comparison between soft and hard surface, see Annex VII: Comparison of Soft and Hard surface for sound horses (Paired sample t-test) .

5.3 Difference for horses determined sound and horses determined not sound.

The outcome of the comparison with the use of the “independent samples t-test”, between horses determined sound and horses determined not sound, are that there is no significant difference ($p > 0,05$) in gait parameters in walk and trot on hard and soft surface, as can be seen in the figure nr 7-10with in figure 7: the comparison in walk on hard surface, figure 8:the comparison in walk on soft surface, in figure 9: the comparison in trot on hard surface and in figure 10:the comparison in trot on soft surface.

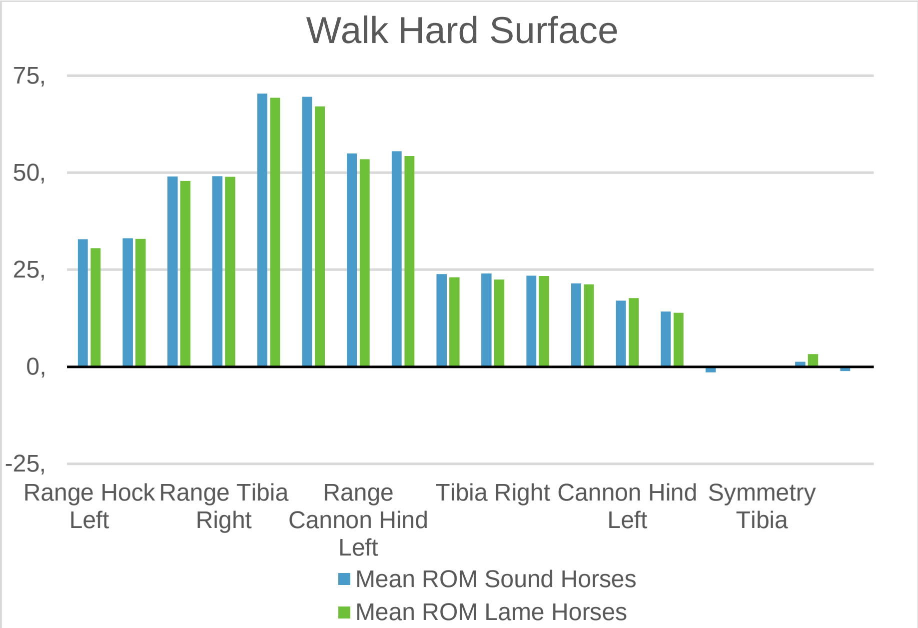

Figure 7:

Bar diagram displaying the comparison of the mean values of the range of motion between horses which are determined sound by a veterinarian and horses which were determined not sound, in walk on a hard surface.

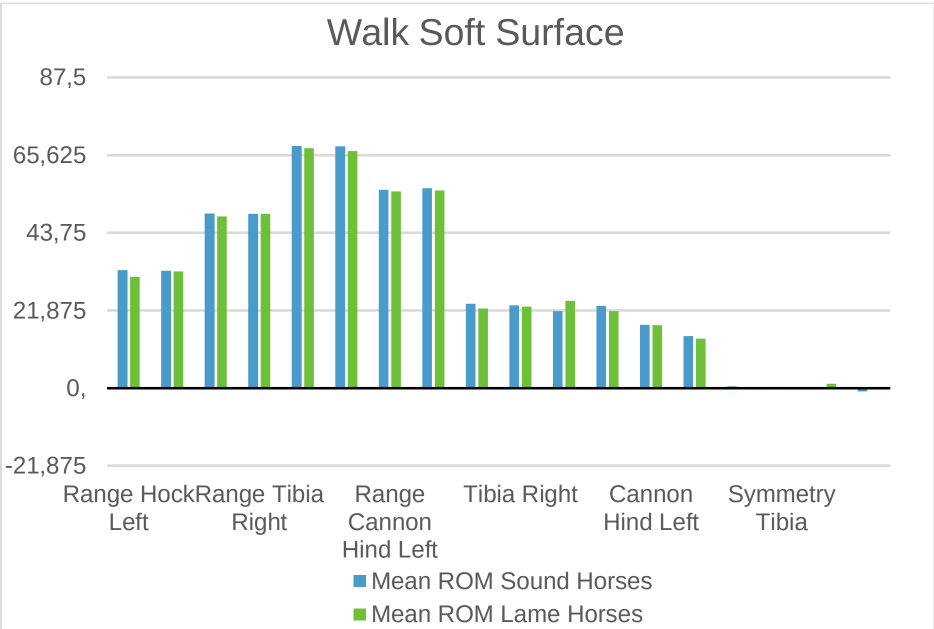

Figure 8:

Bar diagram displaying the comparison of the mean values of the range of motion between horses which are determined sound by a veterinarian and horses which were determined not sound, in walk on a soft surface.

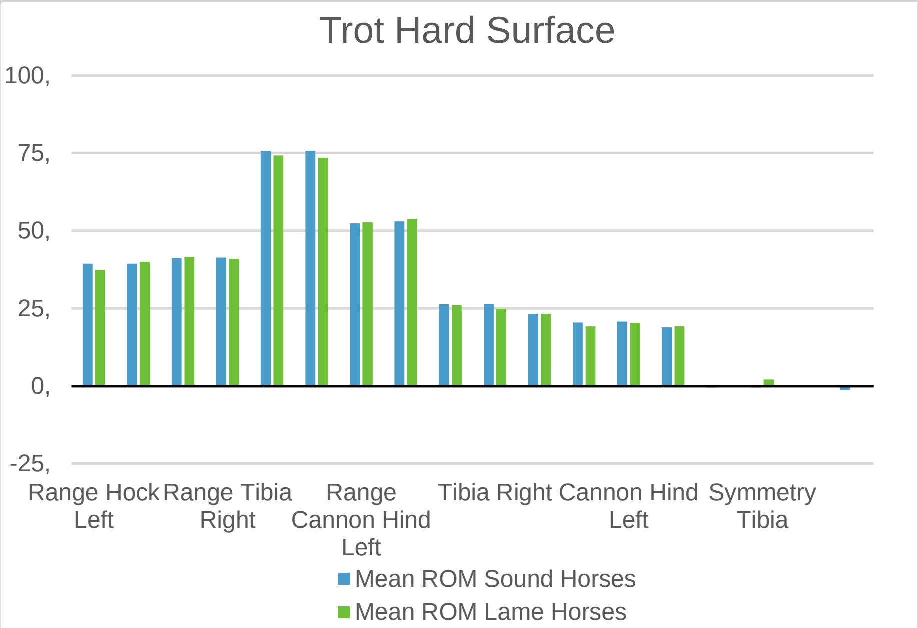

Figure 9:

Bar diagram displaying the comparison of the mean values of the range of motion between horses which are determined sound by a veterinarian and horses which were determined not sound, in trot on a hard surface.

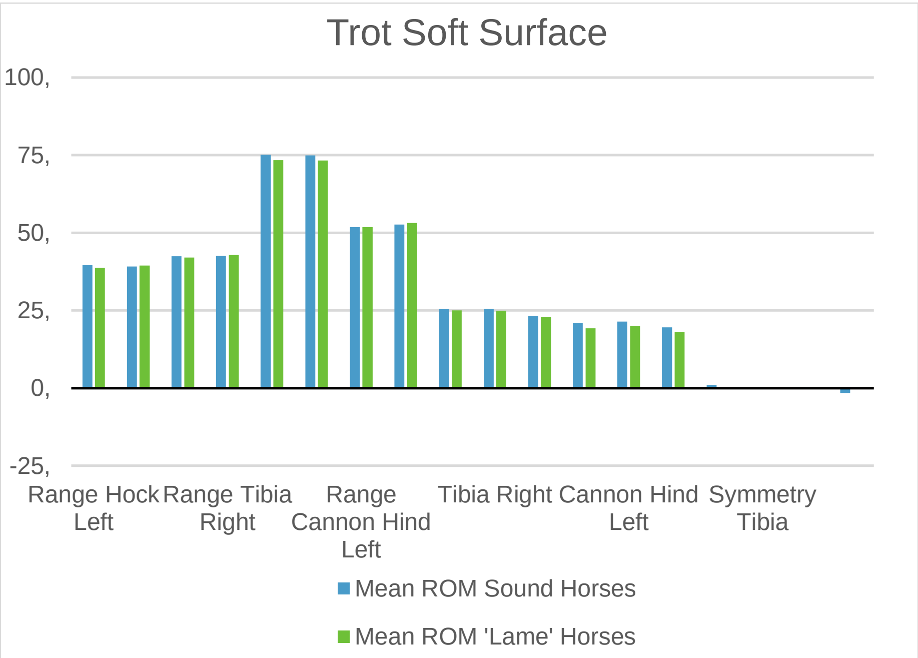

Figure 10:

Bar diagram displaying the comparison of the mean values of the range of motion between horses which are determined sound by a veterinarian and horses which were determined not sound, in trot on a soft surface.

6. Discussion

For this study the aim was to investigate a normal distribution pattern for healthy warmblood horses on a hard and soft surface in walk and trot. Another important aspect of this study was to investigate if there is a difference in movement pattern between hard and soft surface and between horses which are determined sound by a veterinarian and horses which are determined lame.

These measurements for investigating the normal distribution pattern for every gait parameter showed that all gait parameters are distributed normally.

For the investigation of the comparison between movement pattern on hard surface and soft surface, the results showed that in walk there is a significant difference in the range of fore cannons between hard and soft surface with in both left and right fore cannons more range of motion on a hard surface and less range of motion on a soft surface. It thus can be stated that according to this research, a soft surface has a negative impact on the range of motion on the fore cannons in walk. This means that when horses walk on a hard surface the fore cannons stretch a larger range of the joint and thus make a larger movement when compared to walking on a soft surface.During riding and training, the horses (for almost every discipline) move on a soft surface but this finding interferes with the aim for dressage which is noted in the "Skala der Ausbildung" where an aim is that the horse lifts his limbs energetically and swings his limbs far forwards at the moment of suspension. Another aim in dressage is the extended trot which is explained as: "The horse moves freely forward and extends his steps to its maximum" (KNHS, 2015). To reach this aims, this research reveals that horses will do better on a hard surface. The finding of this current research also corresponds to the finding of C.J. Scheffer and W. Back who stated that: "At walk the fetlock extended significantly more on the asphalt track than on other tracks" but they explain that the mechanism of the soft surface, which dampens the energy to a certain extent which would otherwise be stored or dissipated in the internal structures of the limb, may account for this decrease (C.J. Scheffer and W.Back, 2013). Although larger extension of the limbs is desirable, soft surfaces are less injurious for the joint structures of the equine limbs when compared to hard surfaces (C.J. Scheffer and W. Back 2013).

Also, the comparison between hard en soft surface in trot resulted in a significant difference in the range of motion of the Tibia (both sagittal as coronal) with a greater sagittal Tibia range on a soft surface and a greater coronal Tibia range on a hard surface. These results can be conceived as that trotting on a hard surface results in less balance due to the fact that the tibia has a greater coronal range on a hard surface which is not desirable and a greater balance on a soft surface where the sagittal range of the tibia is larger. It could be due to the fact that the horse has less grip on a hard surface and is in need of stability whereas on a soft surface the horse has more grip and more stability and does not need to move the tibia media lateral as much to seek for balance. For trot it thus can be concluded that a soft surface has a positive impact on the range of motion. This current study supports the hypothesis that type of surface does have an influence on the gait parameters which has also been investigated and confirmed in other previous research (Henry Chateaua et al., 2013; N. Crevier-Denoix et al., 2013; C.J. Scheffer & W. Back, 2013). What is not measured in this current study but which can give an explanation for the differences in gait parameters between hard and soft surface is the speed at which the horse was moving in an it's stride duration. As Crevier-Denoix has found in his findings is that horses move slower in sand and the stride duration is longer. This might be explained by soft surface in which the hoof can penetrate the ground which slows down the horse and fall forwards in walk which explains the smaller range of motion in the fore cannons, when compared to hard surface. Although the hind cannons do not differ significantly, there is a trend visible (Hind cannons Left: P = 0,091 and Right = 0,051) at which the hind cannons have less range of motion on hard surface in walk and thus more range of motion on soft surface. This also meets the explanation for the horse moving more horizontal on a hard surface in walk and more downwards on a soft surface. In trot the horse has to push himself more upwards in order to go forwards which in this case leads to a larger range of motion in the Tibia. These suggestions only would interfere with the findings of Crevier-Denoix who stated: “Although there was a lower speed on sand, the maximal tendon force was higher on this surface than on asphalt at the trot (+6%; P = 0.037); at the walk, there was no significant difference between sand and asphalt at the first or second peaks” (Crevier-Denoix et al., 2013). Further research should be done to find an exact explanation.

Both in walk and in trot the coronal movement of the Tibia was greater on the hard surface when compared to the soft surface only in trot this difference was significant ($p < 0,05$) for both left and right but in walk only the right tibia had a significant ($p < 0,05$) greater coronal movement on the hard surface when compared to the soft surface. Although not fully significant, the left tibia also showed a trend (p=0,9). This difference could not be explained.

Besides investigating the normal distribution pattern for every gait parameter and on different surfaces, the most interesting finding in the current study is there is no significant difference in gait parameters found between horses which were determined sound by a veterinarian and horses which were not determined sound and thus lame. Nor in walk, trot on hard and on soft surface. It was hypothesized that there would be a difference measurable. As can be seen in figures 7 -10, the mean values are very similar, although in every gait and for almost every parameter the lame horses have a slighter lower range of motion compared to the sound horses, this difference is not significant (P > 0,05). It can be questioned if another veterinarian would judge the horses, if the outcome would be the same due to the fact that recent research has revealed that amongst experienced veterinarians there is a major difference in opinion about whether a horse is lame or sound and on which limb (Fuller et al., 2006; Hewetson et al., 2006; Keegan et al.,1998, 2010; Pleasant et al., 1997; Starke et al., 2013). Although the used veterinarian was also an experienced veterinarian, the human visual evaluation is a poor tool which is less sensitive than technology (McCracken et al., 2012) and the horses which were determined lame in this research only had a subtle to mild lameness in which the asymmetrical movement or indicators are very small and are very difficult to see for the human eye. Another large factor which could have influenced the decision making process is the fact that the horses were not seen moving live by the veterinarian but videotaped. Previous research has shown that inter-rater agreement within veterinarians with evaluating lameness in horses from videotapes is lower when compared with current ‘live’ evaluation (Keegan et al., 1998). Also the overall agreement on the severity of the lameness was lower in a research with evaluating videotapes (Hewetson et al., 2006) when compared to evaluating the lameness in horses ‘live’ (Keegan et al., 2010). It thus can be stated that it is more difficult for veterinarians to judge a horse by a video when compared to seeing horses move in real life. This may be due the fact that vision is a more sharp image when compared to a video and also the sound on a video is different when compared to real life sound. During this research the veterinarian was not able to be present for the measurements and the collection of the data, for this reason the decision for videotaping the horses was made. Nevertheless, the decision making process could be negatively influenced by the fact that was based on a video’s. As mentioned before, although the results are not significant, the ROM for horses which were determined lame was in deed smaller when compared to horses which were determined sound. The sample size for the lame horses (n= 13) was very small when compared to the sample size for sound horses (n= 51) and the lameness detected was subtle to mild. Hereby it could be the case that due to the fact that the

sample size is to small the difference also does not result in a significant value. More research with larger sample sizes should be done to investigate this problem.

The limitation of the sample size (n= 64) accounts for the entire research. For a more reliable and in specific investigation of the movement patterns and the effect of specific character traits (such as age, gender, height, discipline, level of education, shoeing etc.) further research with a larger sample size would be needed. Taking into account that Krejcie and Morgan (1970) have developed a specific table (with the formula: s = X NP − P ÷ d N − + X P – P) for an easy determination of the sample size with a population size maximum of n= 1.000.000. In the case of Warmblood Horses for this current study, with a confidence level of 95% a minimum sample size of S = 384 should be reached to be representative of the movement parameters for at least one million registered warmblood horses. With regard to this current research the sample size of S=64 would only be representative for a population size of N=75 to meet the confidence level of 95%, this number is much too small.

But for this research the aim was to expand the warmblood horses database with healthy and sound warmblood horses (minimally S = 384 but approximately more) for further improvement of the ETB Pegasus software. This improvement is necessary to gain the ultimate aim for ETB Pegasus which is a system which could automatically compare the results against normal healthy population (GaitSmart, 2014), in case of the Pegasus compare the expected ROM for a typical healthy warmblood horse. For the human system of the ETB, which is called GaitSmart, this feature is already provided and whereby the system is able to give in detailed presumptions about the physical health of a specific person by using data from one single measurement. Although it is much harder to investigate equine locomotion when compared to humans, keeping in mind that it is an animal and it cannot talk, the more research is being done the more knowledge will be gained and eventually lameness could be prevented due to early detection.

7. Conclusion

To investigate equine locomotion the ETB Pegasus Gait Analysis system has showed to be an easy to use and accurate measuring device which could profile the gait parameters in a way which is fast, clear and easy to understand. The results, which were derived from this system, allowed to gain an in depth analyses of the normal distribution pattern for healthy, sound warmblood horses on hard surface and on a soft surface both in walk and in trot. These findings showed that the gait parameters for healthy, sound warmblood horses were normally distributed.

Furthermore, the comparison between hard and soft surface revealed that there is a difference in movement patterns between walking and/or trotting on a hard surface when compared to walking and/or trotting on a soft surface. Although walking on hard surface seems desirable due to the fact that the fore cannons have a smaller range of motion on a soft surface which also slows the horse down, this soft surface is less injurious and gives more stability when compared to a hard surface. For conclusion: moving on a soft surface is favorable.

Lastly, the most interesting conclusion from this research is that there is no significant difference measured between horses which were determined sound by a veterinarian and horses which were determined lame by the same veterinarian. Although horses which were determined lame had a slighter lower range of motion, this difference was not significant. There could be different explanations for this finding such as the limitation of the human eye or video recording (as discussed before) but the main conclusion from this research, is that a visual evaluation of a (experienced) veterinarian does not correspond to the analysis of a locomotion system which is more sensitive when compared to the human eye.

Recommendations

For the ETBPegasus Gait Analysis system (European Technology for Business Ltd.) my recommendations are to further develop the system and expand with more data from sound and lame horses but also from different breeds to gain a system which can give a quick but an in depth analysis and can ultimately detect lameness or other locomotion health problems early and maybe even prevent these problems in the future. This can be reached by developing a feature in the ETB Pegasus software such as the human device, gaitSMART, already has developed. Namely a software which can automatically compare the results against normal healthy population (gaiSMART, 2014). The human, gaitSMART, clearly shown the results in the assessment report by a traffic light system. Values which are marked in orange show that the test person is just falling out the normal distribution for a typical healthy person, values which are highlighted in red show that the test person is significantly different from the normal distribution for a typical healthy person which is seen as unhealthy. When values are marked in orange or red, it is advised to look for professional help (gaitSMART,2014).

By developing this feature in the system, the results will be easy to understand for even a layman. Nowadays the system does give an accurate and in-depth analysis but it is hard to understand what this means and what to conclude from this analysis.

For Paardenkliniek 'De Raaphorst' my recommendations are to invest in a system which can give an accurate and in-depth analysis for detecting lameness or other locomotion problems and to use this system next to their visual evaluation. As have been discussed in this current research, the human eye has it's anatomical limitations and a different opinion is possible amongst different veterinarians. My recommendation will be to not stick with the old fashioned way of detecting lameness or other locomotion problems, by a visual assessment, but to use appropriate technology which is nowadays available and to gain a more accurate and depth analysis which is quick and easy to use. By using this technology in comparison with the knowledge of the veterinarians,‘De Raaphorst’ would be a step ahead of other veterinarian clinics for early detection of locomotion problems. Ultimately a more healthy horse with a healthy locomotion system is the most important aim for the future.

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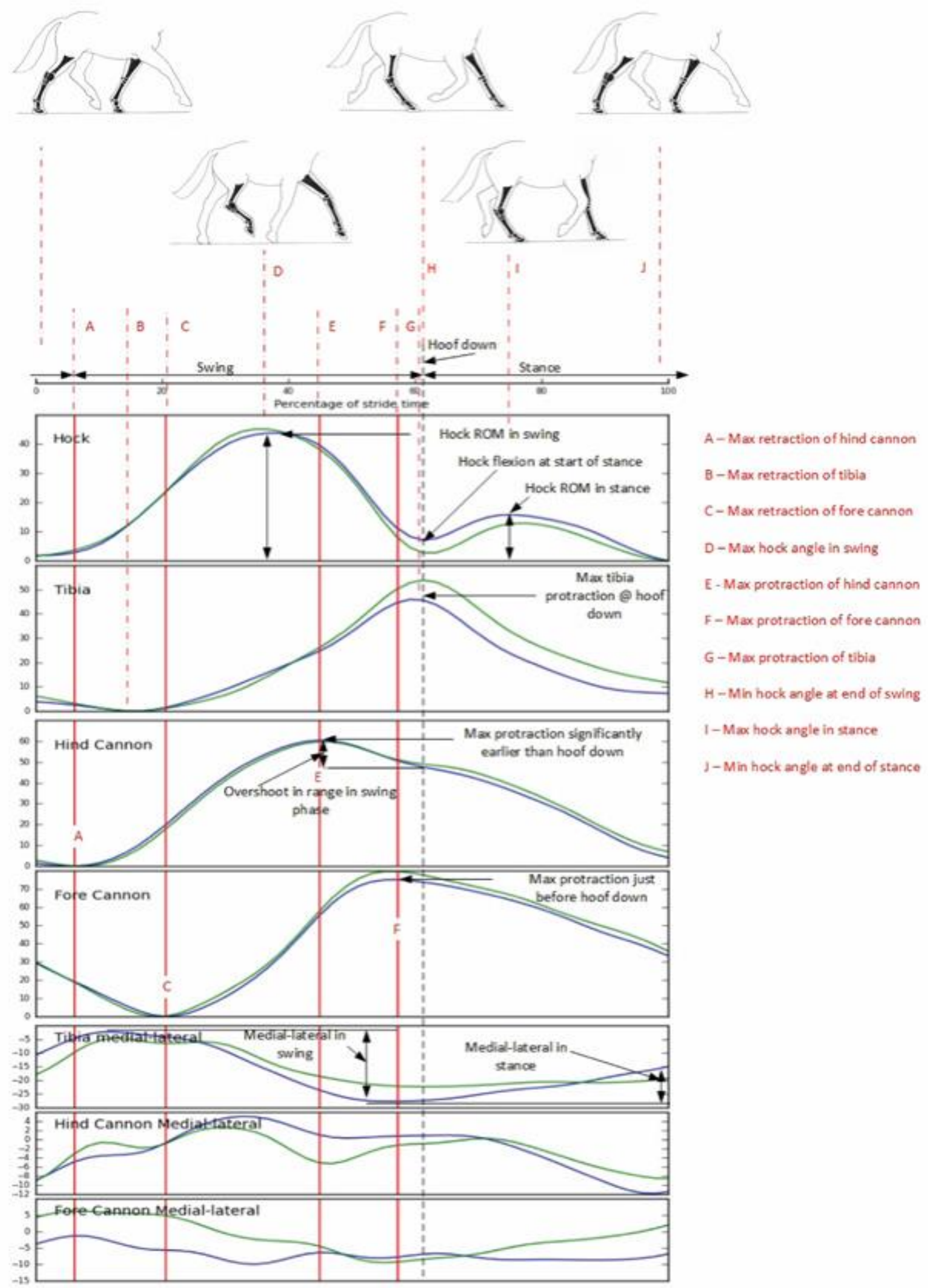
Annex I: Example of graph with explanation



Typical hock angle plot for healthy horse

Annex II: Protocol used in this research

Examination sheet for Pegasus Gait Analysis

Measurement procedure for database

Datum: ____________________

Tijd van de meting: ____________________

Naam Paard: ____________________

Ras: ____________________

Leeftijd: ____________________

Geslacht: ☐ merrie ☐ hengst ☐ ruin

Schofthoogte: ____________________

Discipline: ____________________

Niveau: ☐ B/L ☐ M ☐ Z / ZZ ☐ Internationaal

Medische Historie: ____________________

Opmerkingen: ____________________

Measurement procedure:

1. De 6 sensoren + GPS worden gereed gemaakt met de hulp van de Pegasus software (Poseidon version 9.0.0, ETB Ltd.).
2. Het harnachement wordt aan het paard bevestigd. Zorg er voor dat het paard gewend raakt aan het harnachement door het paard rond te leiden.
3. Het paard moet voor minstens 10 seconden stil staan voordat de officiële meting begint zodat de sensoren kunnen kalibreren.
4. De metingen worden gedaan op een harde ondergrond in een rechte lijn voor minstens 10 meter, heen en weer. Het paard wordt aan de hand voorgeleid met een halster om en een los hangend halstertouw. Eerst in stap (1.3 m/s) en vervolgens in draf (3.6 m/s). Zorg er voor dat het paard niet afgeleid is door externe omstandigheden, wat de meting kan beïnvloeden.
5. Tussen de overgang van stap naar draf moet het paard nog eens voor minstens 10 seconden stil staan zodat de data beter na te lezen is.
6. Na de metingen worden de sensoren van het paard verwijderd en wordt de data gedownload van de sensoren naar de computer, hierbij wordt gebruik gemaakt van de Poseidon software, welke de data van de sensoren omzet in leesbaar material (met gebruik van nummers en grafieken).

Annex lll : Horses used in this study and determined sound.

Horses	Stable	Year Birth	Gender	Height of withers (M)	Discipline	Level	Shoeing	Breed
1	2	2005	Mare	1.7	Jumping	Z/ZZ	all 4	KWPN
2	2	2006	Mare	1.7	Dressage	B/L	none	KWPN
3	2	2006	Gelding	1.65	Dressage	Z/ZZ	all 4	KWPN
4	1	1995	Gelding	1.67	Dressage	M	all 4	KWPN
5	1	2007	Mare	1.65	Dressage	M	only front	KWPN
6	2	2007	Gelding	1.68	Dressage	Z/ZZ	only front	KWPN
7	2	2007	Mare	1.7	Dressage	B/L	none	KWPN
8	1	2007	Mare	1.68	Dressage/	none	none	KWPN
9	1	2008	Gelding	1.73	Dressage/	Z/ZZ / B	all 4	KWPN
10	1	2004	Gelding	1.74	Dressage	Z/ZZ	only front	Westfaler
11	1	2008	Mare	1.62	Dressage	Z/ZZ	only front	KWPN
12	1	2008	Gelding	1.68	Dressage	B/L	none	KWPN
13	1	2008	Gelding	1.68	Dressage/	B/L	only front	KWPN
14	2	2008	Mare	1.67	Jumping	B/L	only front	KWPN
15	2	2008	Mare	1.67	Dressage	B/L	none	KWPN
16	1	2003	Gelding	1.67	Dressage	B/L	only front	Rhineland
17	4	2009	Mare	1.7	Dressage/	B/L	only front	KWPN
18	1	2009	Mare	1.7	Dressage	B/L	none	KWPN
19	1	2009	Gelding	1.72	Dressage	M	none	KWPN
20	1	2009	Gelding	1.7	Dressage	M	all 4	KWPN
21	1	2010	Mare	1.67	Dressage	B/L	only front	KWPN
22	2	2010	Gelding	1.62	Jumping	B/L	all 4	KWPN
23	2	2011	Mare	1.72	Jumping	B/L	none	KWPN
24	1	1995	Gelding	1.68	Dressage	Z/ZZ	all 4	KWPN
25	1	1996	Gelding	1.72	Dressage	Z/ZZ	all 4	KWPN
26	2	1997	Mare	1.63	Dressage	Z/ZZ	all 4	KWPN
27	1	2006	Mare	1.69	Dressage	Z/ZZ	all 4	Oldenburg
28	2	1999	Gelding	1.68	Dressage	M	all 4	KWPN
29	1	1999	Gelding	1.65	Dressage/	B/L	none	KWPN
30	1	2007	Mare	1.67	Dressage	M	only front	KWPN
31	1	2000	Mare	1.74	Dressage	Internatio	only front	KWPN
32	1	2000	Mare	1.63	Dressage	B/L	only front	KWPN
33	4	2001	Mare	1.69	Dressage	M	all 4	KWPN
34	1	2003	Mare	1.7	Dressage	Z/ZZ	only front	KWPN
35	1	2003	Gelding	1.72	Dressage	B/L	all 4	KWPN
36	1	2004	Gelding	1.72	Dressage	Z/ZZ	only front	KWPN
37	3	2001	Gelding	1.73	Police	B/L	all 4	KWPN
38	3	2001	Gelding	1.7	Police	B/L	all 4	KWPN
39	3	2003	Mare	1.62	Police	B/L	only front	KWPN
40	3	1998	Gelding	1.66	Police	B/L	all4	KWPN
41	3	2006	Gelding	1.84	Police	B/L	all 4	KWPN
42	3	2006	Gelding	1.8	Police	B/L	all 4	KWPN
43	3	2009	Mare	1.76	Police	B/L	all 4	KWPN
44	3	2000	Gelding	1.76	Police	B/L	all 4	KWPN
45	3	2008	Mare	1.66	Police	B/L	all 4	KWPN
46	3	2002	Gedling	1.7	Police	B/L	all 4	KWPN
47	3	1994	Gelding	1.74	Police	B/L	all 4	KWPN
48	3	2000	Gelding	1.76	Police	B/L	all 4	Gelderlan
49	3	2000	Gelding	1.73	Police	B/L	all 4	KWPN
50	3	2002	Gedling	1.7	Police	B/L	all 4	KWPN
51	3	2003	Gelding	1.73	Police	B/L	all 4	KWPN

Annex IV: Horses used in this study and determined lame.

Horses	Stable	Year Birth	Gender	height (M	Discipline	Level	Shoeing	Breed	Vet Comment
1	3	2001	Gelding	1.79	Police	B/L	all 4	KWPN	Left Hind 1/5
2	3	2001	Gelding	1.73	Police	B/L	all 4	KWPN	Right Front 2/5
3	1	2005	Gelding	1.84	Dressage	B/L	all 4	KWPN	Right Hind 1/5
4	4	2004	Gelding	1.75	Recreatio	B/L	only front	BWP	Right front 1/5
5	4	2007	Mare	1.66	Dressage	M	all 4	KWPN	Right Hind 1/5
6	1	2007	Gelding	1.74	Dressage	B/L	only front	KWPN	Right Front 2/5 & 1/5
7	1	2008	Mare	1.68	Dressage	Z/ZZ	only front	KWPN	Right Hind 1/5
8	1	2009	Mare	1.66	Dressage	B/L	only front	KWPN	Right Front 2/5
9	1	2011	Mare	1.67	Dressage	B/L	only front	KWPN	Left Front 1/5
10	1	1999	Gelding	1.63	Dressage	Z/ZZ	only front	KWPN	Right Front 1/5
11	1	2000	Gelding	1.69	Dessage	L	all 4	KWPN	Left Hind 1/5
12	1	2002	Gelding	1.68	Dressage	M	all 4	KWPN	Right Front 2/5
13	3	2007	Gelding	1.69	Police	B/L	all 4	KWPN	Hypermetric

Annex V: Example of Gait Analysis Report

Pegasus Gait Analysis Report

© 08:33:01 16/01/2015
European Technology for Business Ltd
Codicote Innovation Centre
St Albans Road
Codicote
Hertfordshire
SG4 8WH
United Kingdom

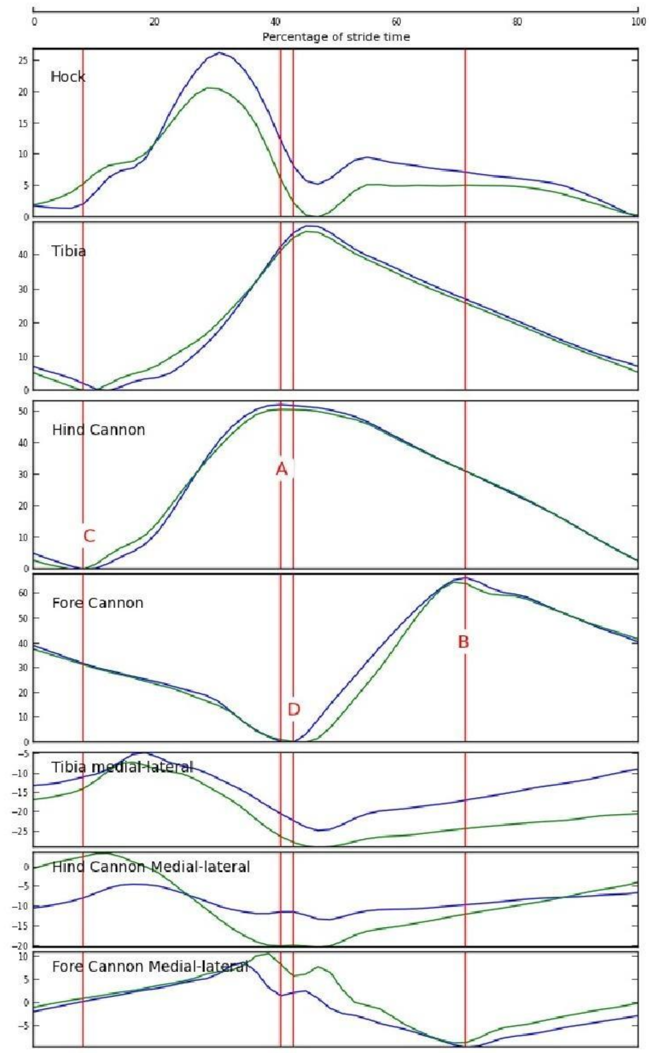
GaitSmart™ Pegasus

Subject - Flanturo

KWPN Gelding born in 2010 (4/5 yrs old), height: 1.62m, B level jumping, shoeing on all 4 feet, recent saturday had an accident in the trailer (horse got stuck)

Region: waha1

Stride from 172.14 to 173.41 seconds



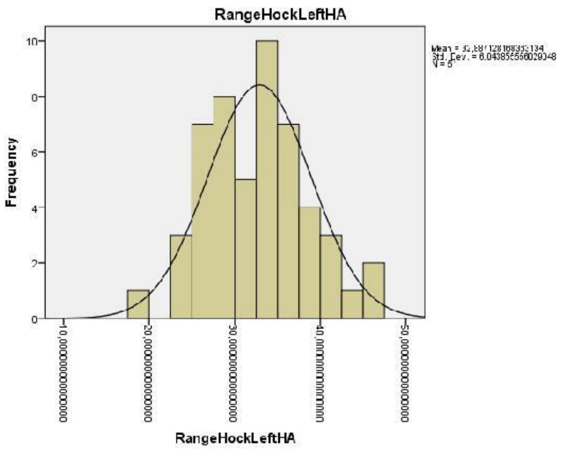
Range of Motion		
	Left	Right
Range hock	26.70	20.67
Range tibia	47.85	47.48
Range cannon fore	66.41	63.07
Range cannon hind	54.11	51.00
Medial Lateral		
Tibia	22.71	22.07
Cannon fore	18.22	20.39
Cannon hind	11.08	24.02
Timing		
A	40.00	40.00
B	70.00	68.00
C	8.00	8.00
D	42.00	44.00
Symmetry		
Hock (%)	25.47	
Tibia (%)	0.78	
Cannon fore (%)	5.15	
Cannon hind (%)	5.92	

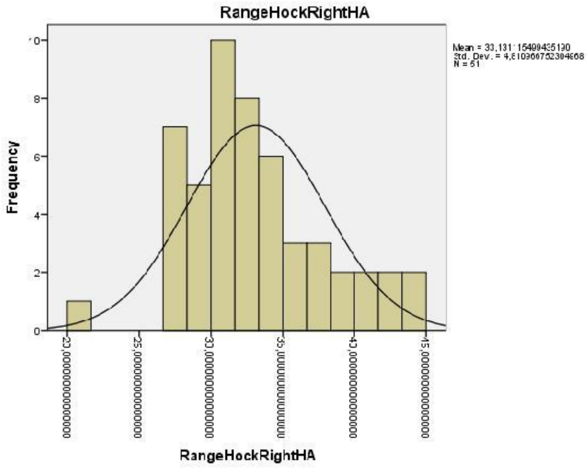
	Walk		
	Strides	Time	Dist.
Total	16	0:20	
	Average	Min.	Max.
Left fore	31.2	28.4	34.4
Right fore	81.5	78.4	83.9
Left hind	0.0	0.0	0.0
Right hind	48.4	46.6	49.3
Diagonal asymmetry			
Hind leg asymmetry			
Stride duration (s)	1.26	1.21	1.31
Speed (m/s)			
Stride length (m)			

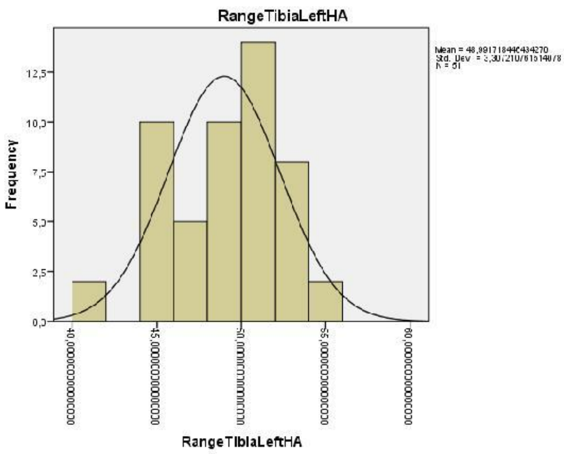
Focus: left; **Angles:** relative; **Y-axis:** autoscale; **Phase:** best fit
Colour coding: **Left** **Right**

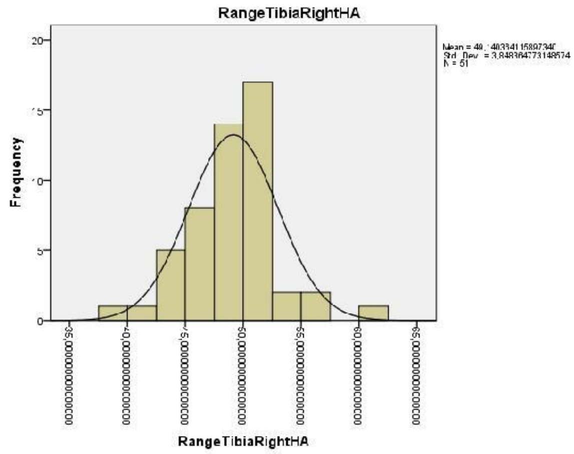
Annex VI: Distribution charts

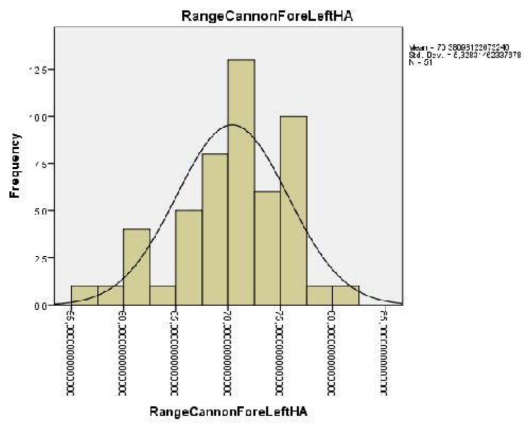
a; walk hard surface, sound horses

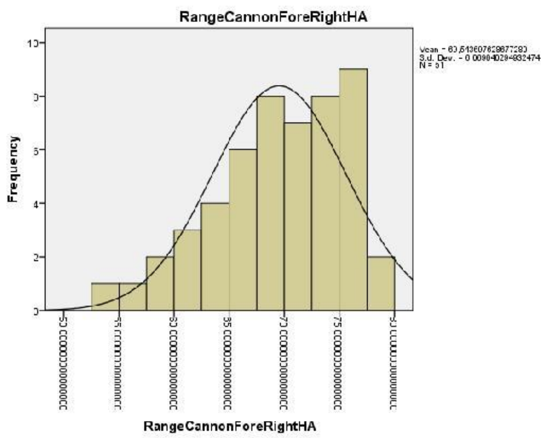


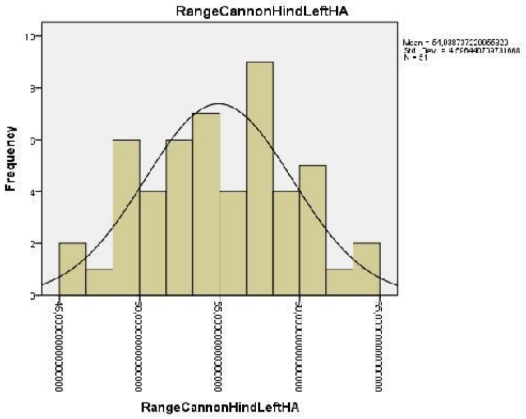


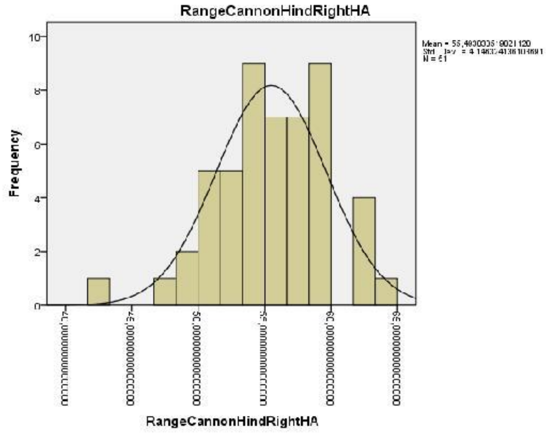


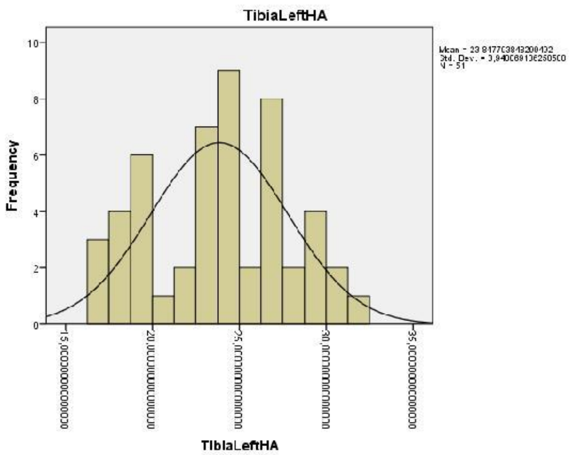


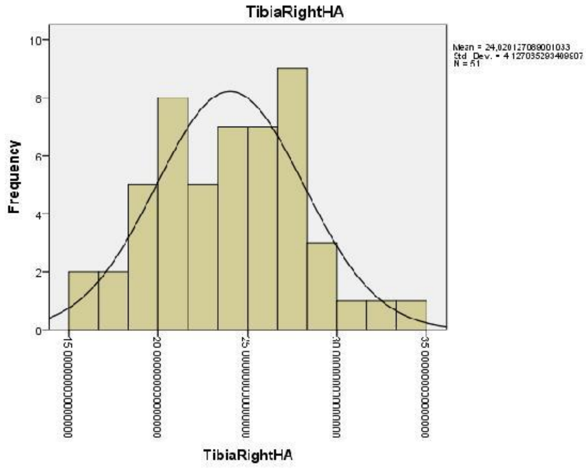


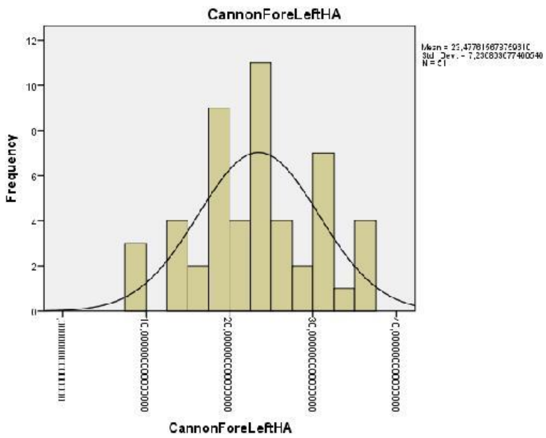


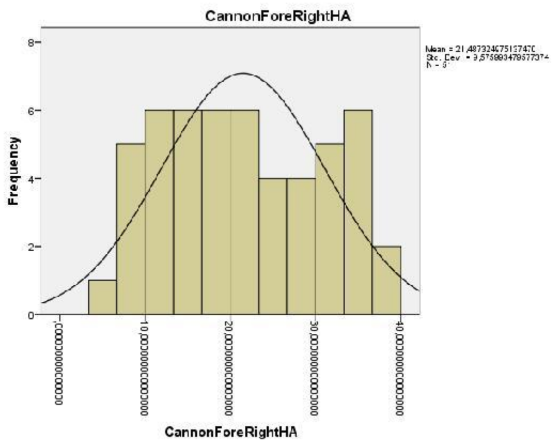

RangeCannonHindLeftHA
Frequency
RangeCannonHindLeftHA

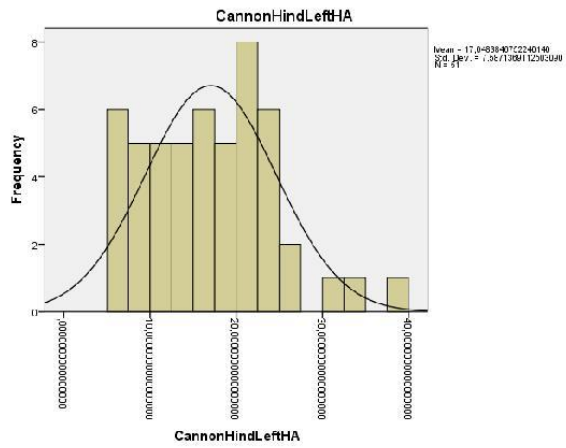

RangeCannonHindRightHA
Frequency
RangeCannonHindRightHA

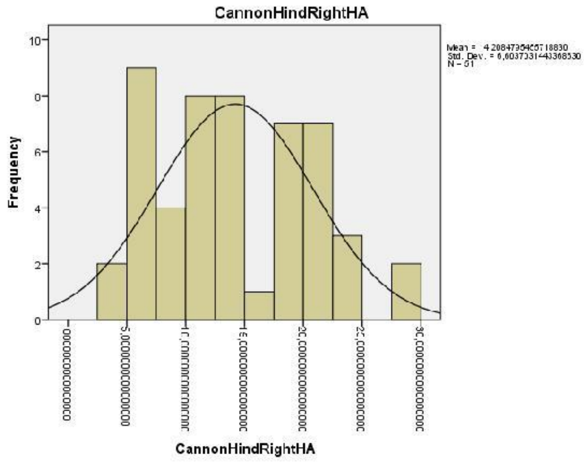

TibiaLeftHA
Frequency
TibiaLeftHA

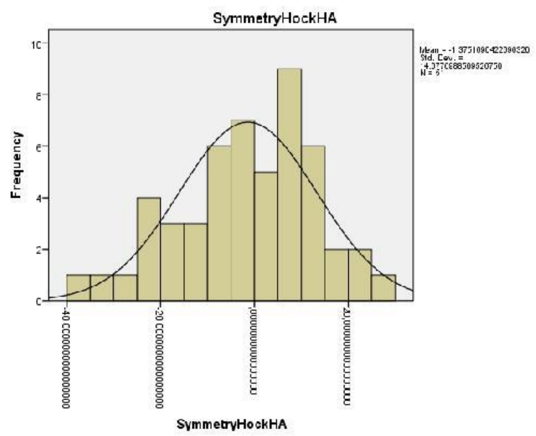

TibiaRightHA
Frequency
TibiaRightHA

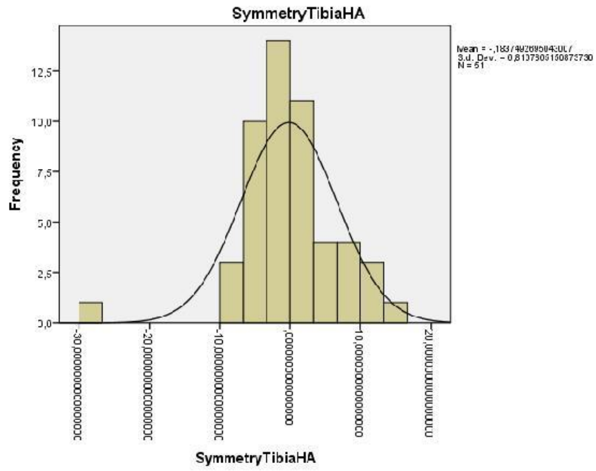

CannonForeLeftHA
Frequency
CannonForeLeftHA

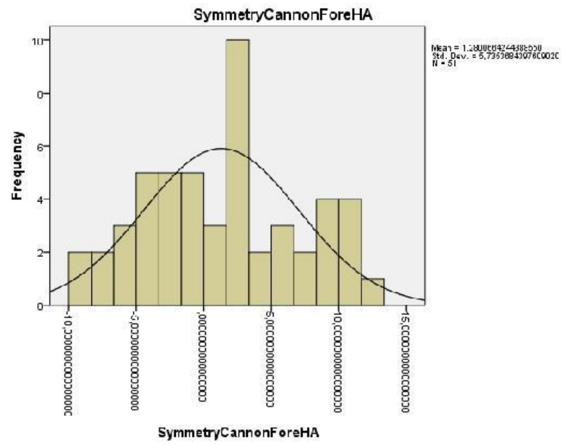

CannonForeRightHA
Frequency
CannonForeRightHA

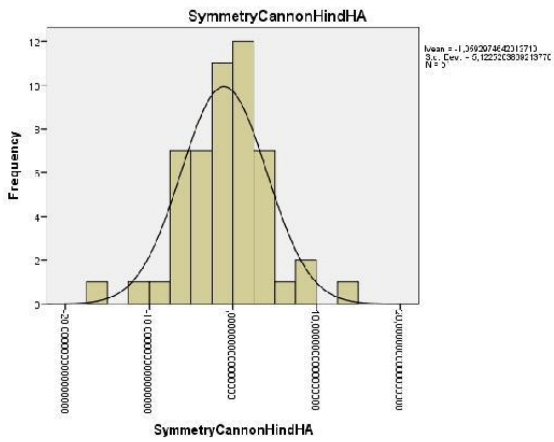

CannonHindLeftHA
Frequency
CannonHindLeftHA


CannonHindRightHA
Frequency
CannonHindRightHA

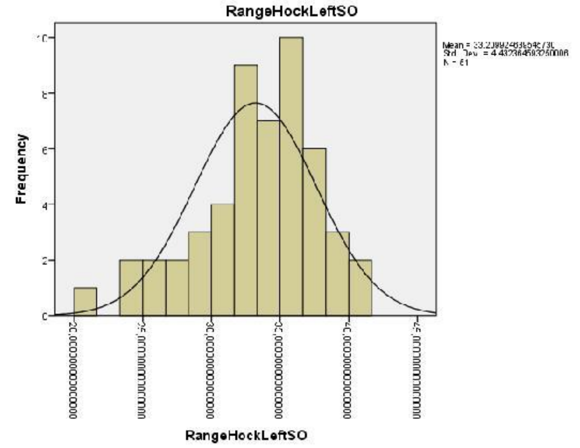

SymmetryHockHA
Frequency
SymmetryHockHA

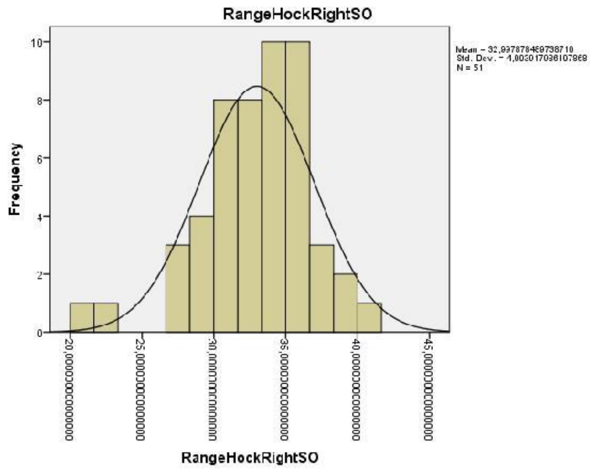

SymmetryTibiaHA
Frequency
SymmetryTibiaHA

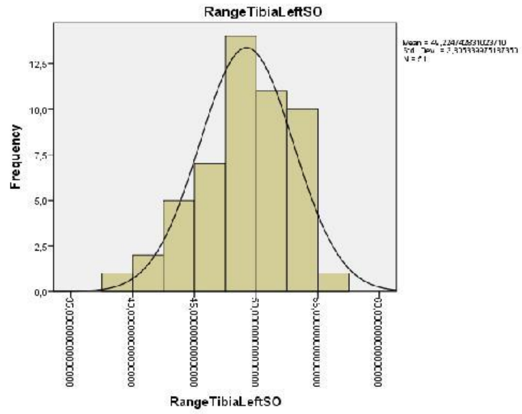

SymmetryCannonForeHA
Frequency
SymmetryCannonForeHA

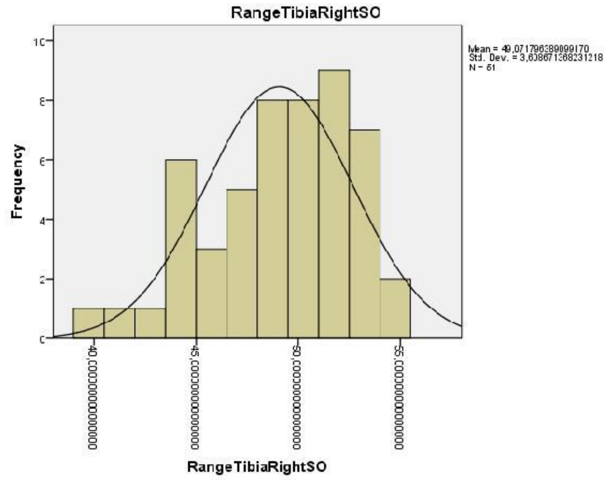

SymmetryCannonHindHA
Frequency
SymmetryCannonHindHA

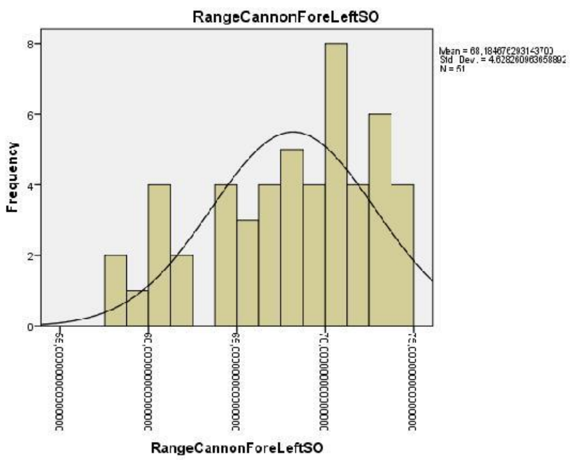
b; walk soft surface, sound horses

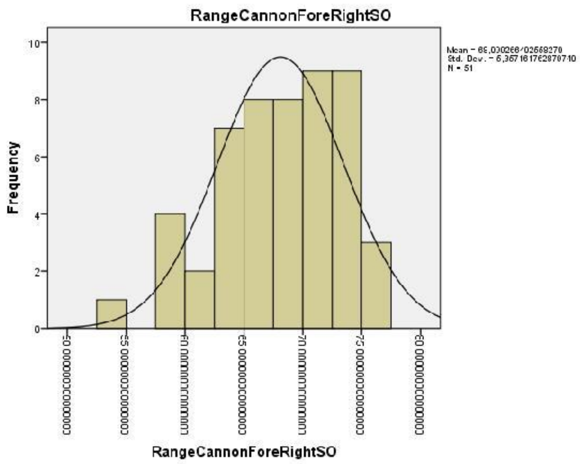


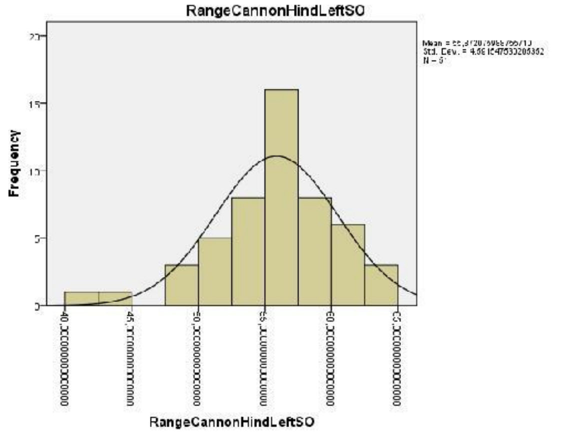


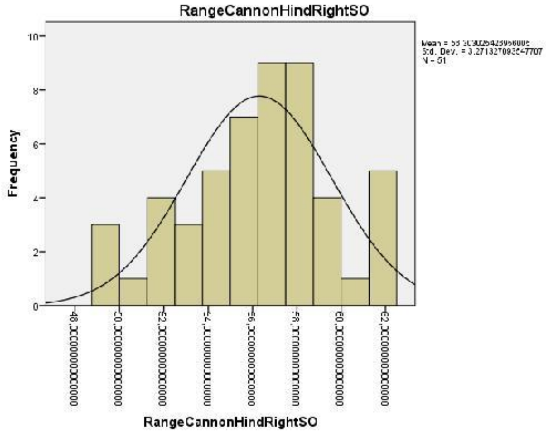


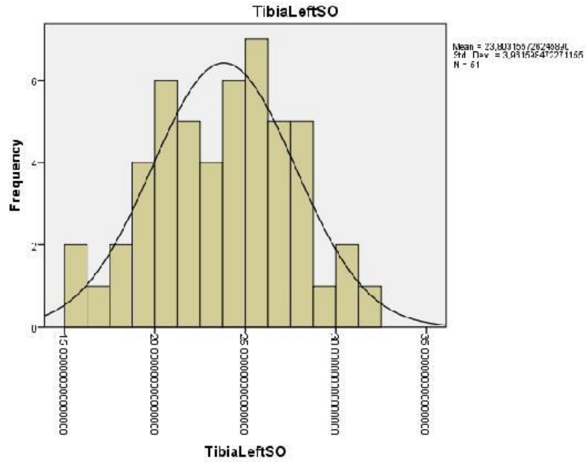


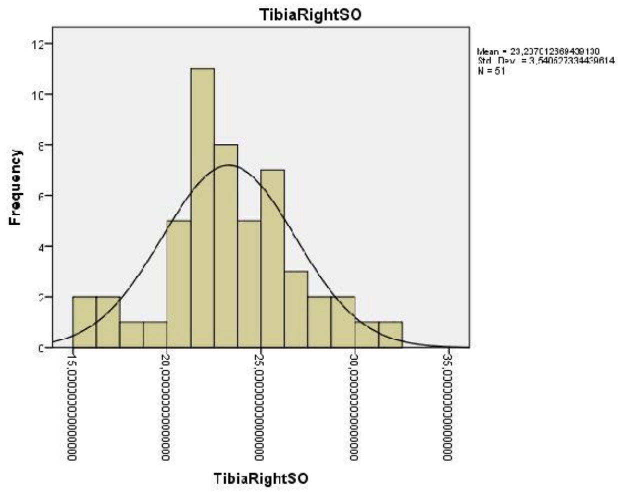


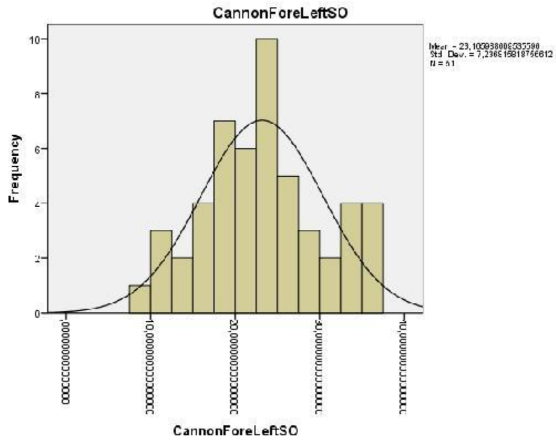


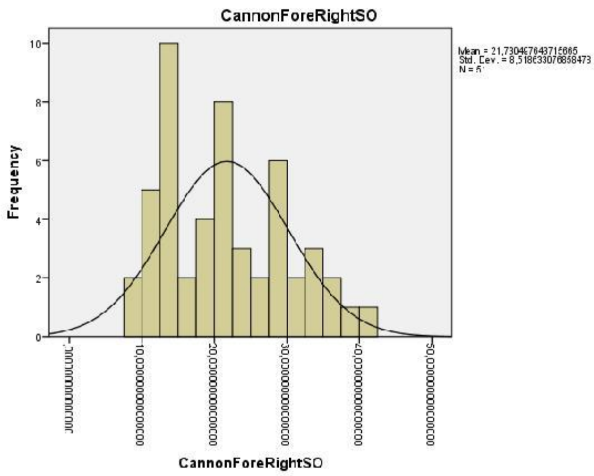

RangeCannonHindLeftSO
Frequency
RangeCannonHindLeftSO

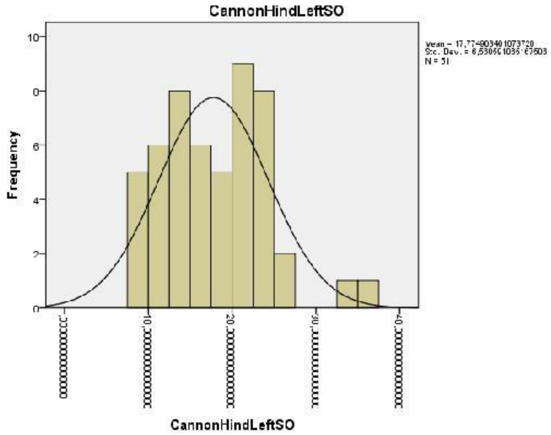

RangeCannonHindRightSO
Frequency
RangeCannonHindRightSO

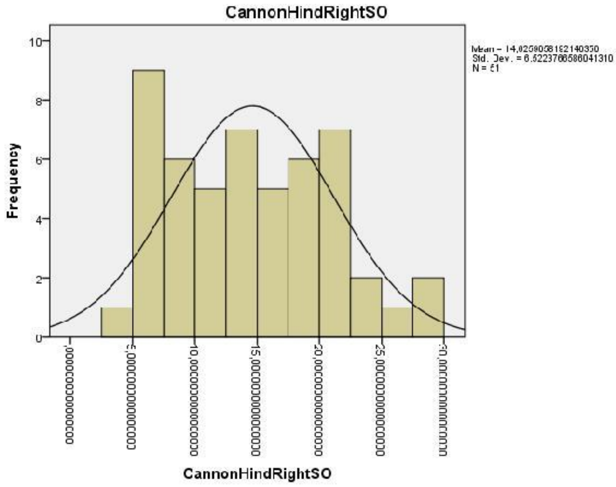

TibiaLeftSO
Frequency
TibiaLeftSO

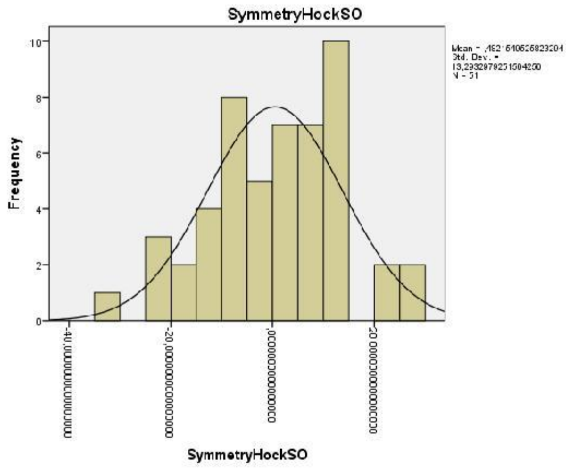

TibiaRightSO
N = 51
Frequency
TibiaRightSO

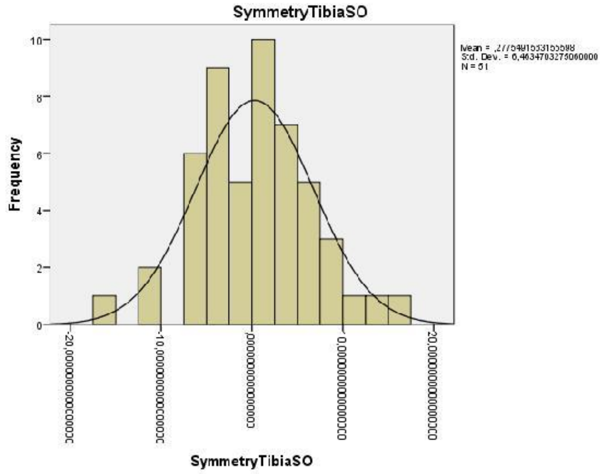

CannonForeLeftSO
Frequency
CannonForeLeftSO

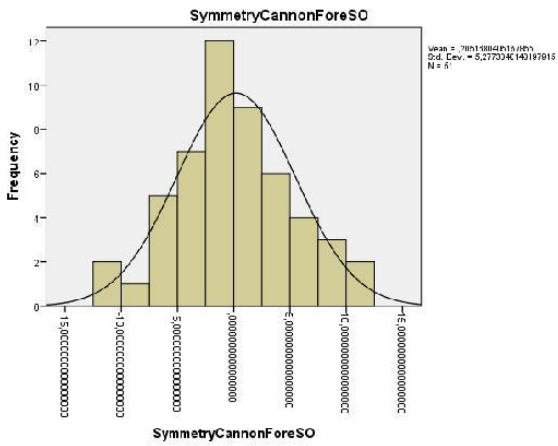

CannonForeRightSO
Frequency
CannonForeRightSO

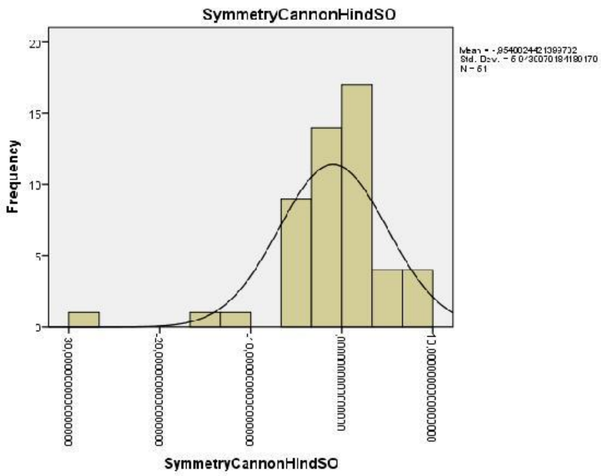

CannonHindLeftSO
Frequency
CannonHindLeftSO


CannonHindRightSO
Frequency
CannonHindRightSO

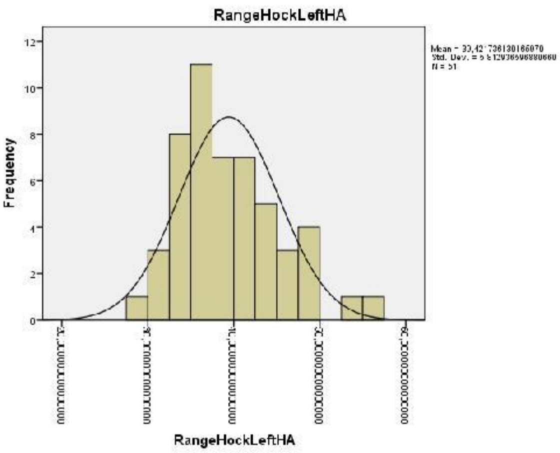

SymmetryHockSO
Frequency
SymmetryHockSO

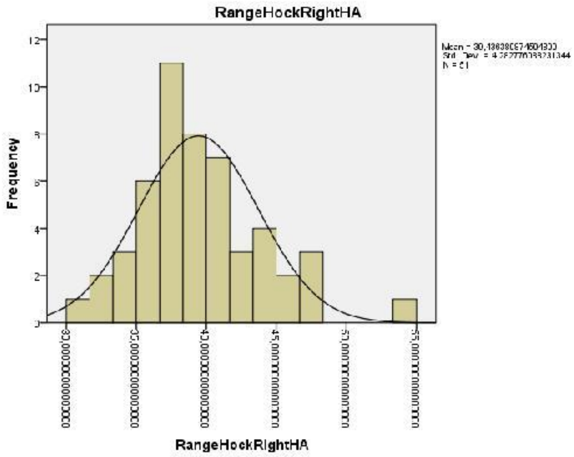

SymmetryTibiaSO
Frequency
SymmetryTibiaSO

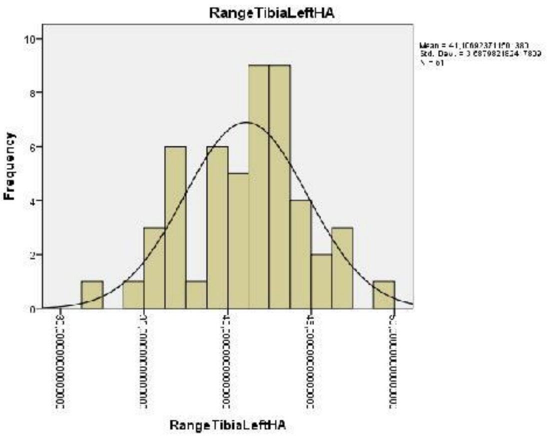

SymmetryCannonForeSO
Frequency
SymmetryCannonForeSO

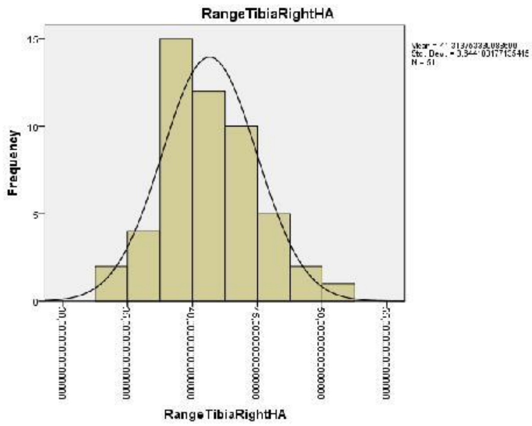

SymmetryCannonHindSO
Frequency
SymmetryCannonHindSO

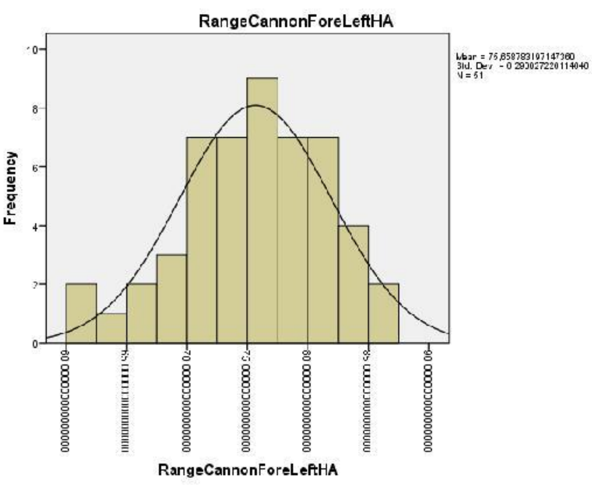
C; trot hard surface, sound horses

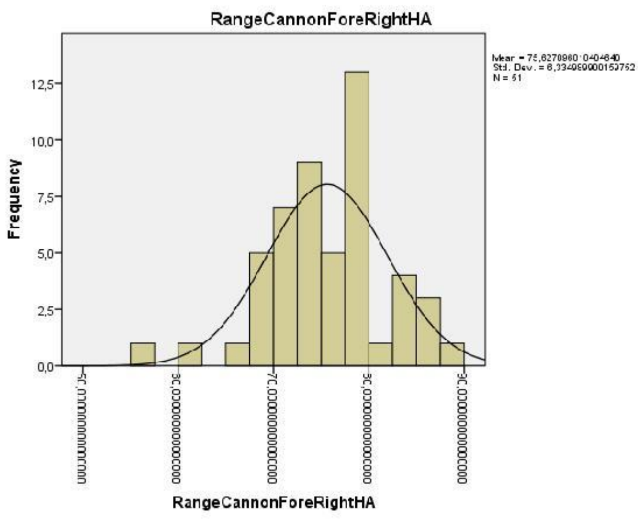


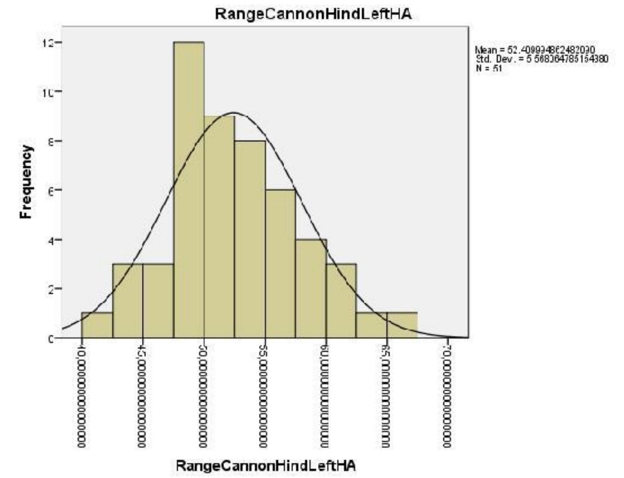


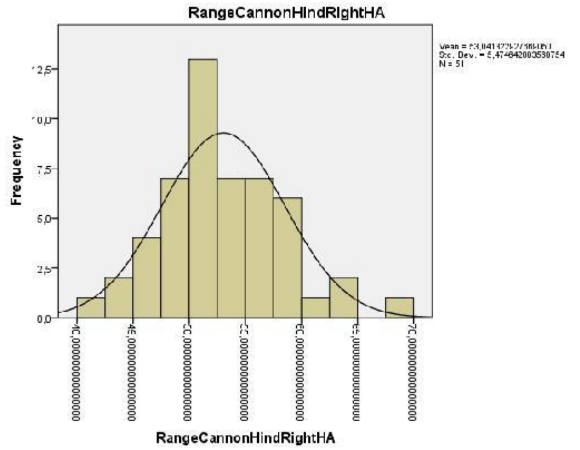


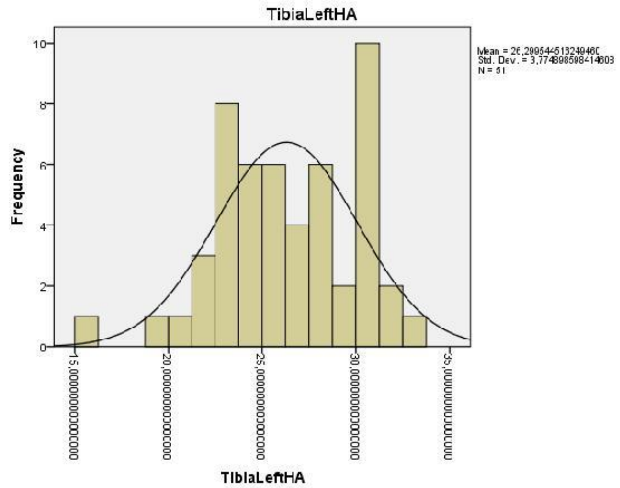


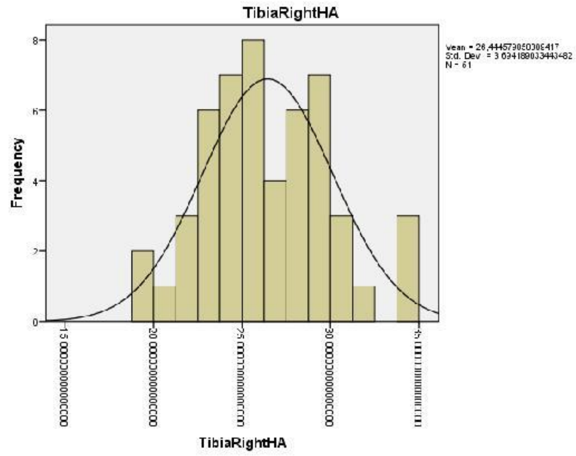


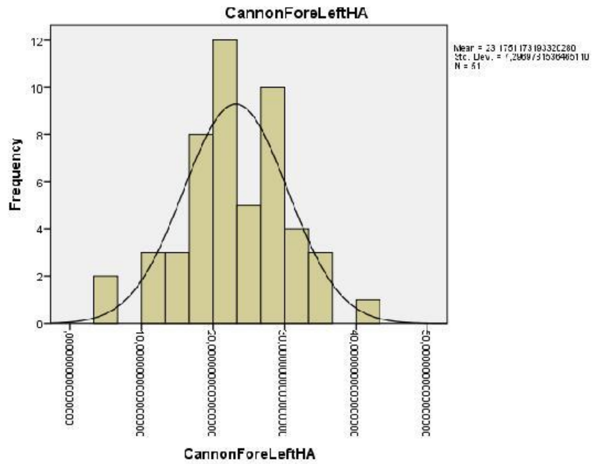


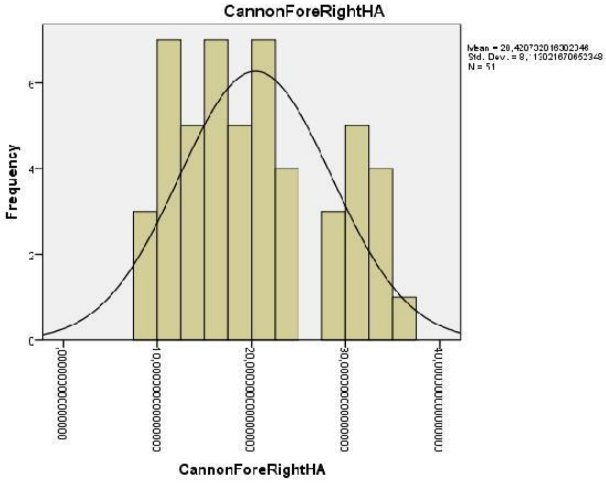

RangeCannonHindLeftHA
Mean = 52,409934862482090
Std. Dev. = 5,568364785154380
N = 51
Frequency
RangeCannonHindLeftHA

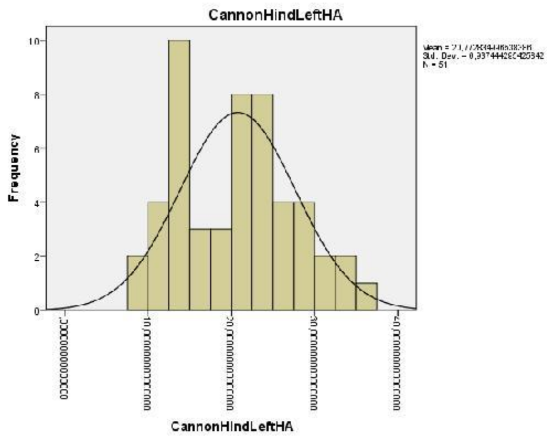

RangeCannonHindRightHA
N = 51
Frequency
RangeCannonHindRightHA

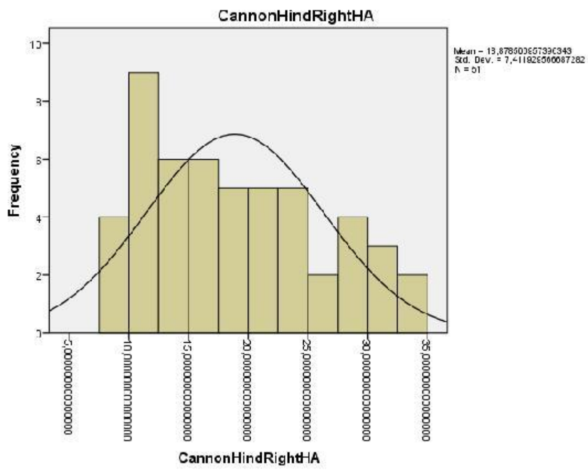

TibiaLeftHA
Mean = 26,29954451324946C
Std. Dev. = 3,774898598414603
N = 51
Frequency
TibiaLeftHA

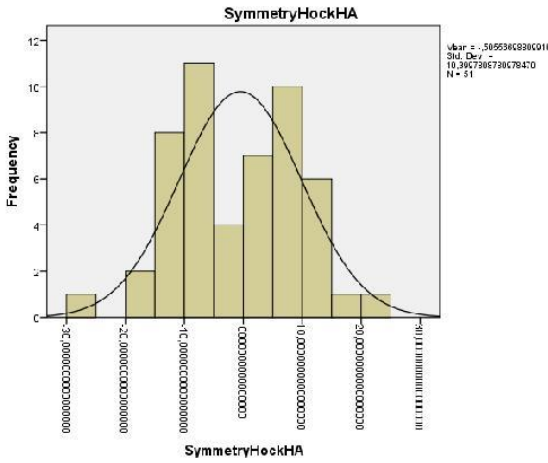

TibiaRightHA
Std. Dev = 3,634189033443482
Frequency
TibiaRightHA

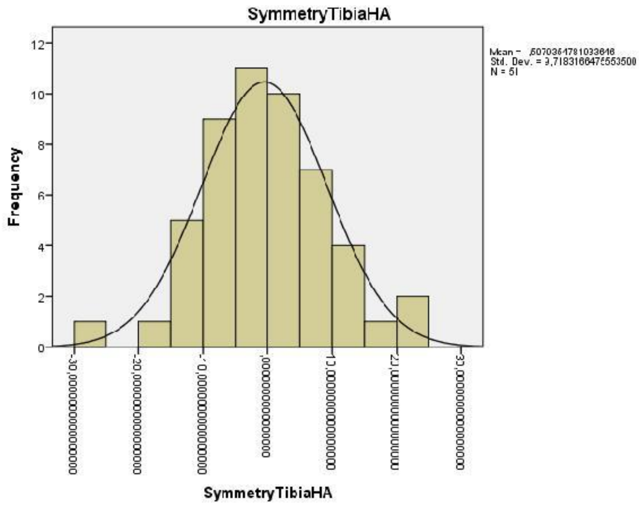

CannonForeLeftHA
Frequency
N = 51
CannonForeLeftHA

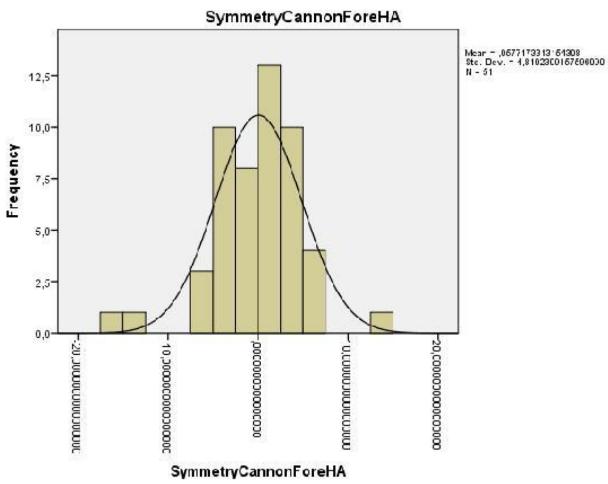

CannonForeRightHA
Frequency
N = 51
CannonForeRightHA

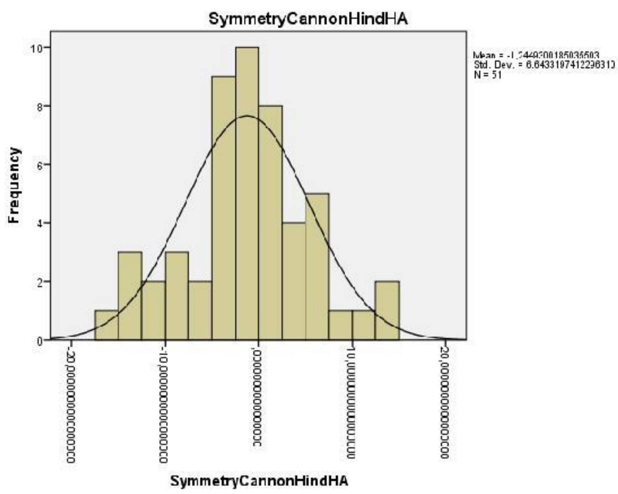

CannonHindLeftHA
Frequency
N = 51
CannonHindLeftHA


CannonHindRightHA
Frequency
Std. Dev. = 7,41182956608 7282
CannonHindRightHA

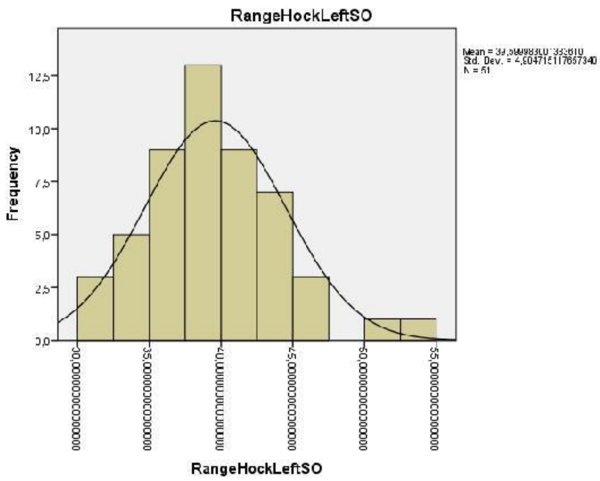


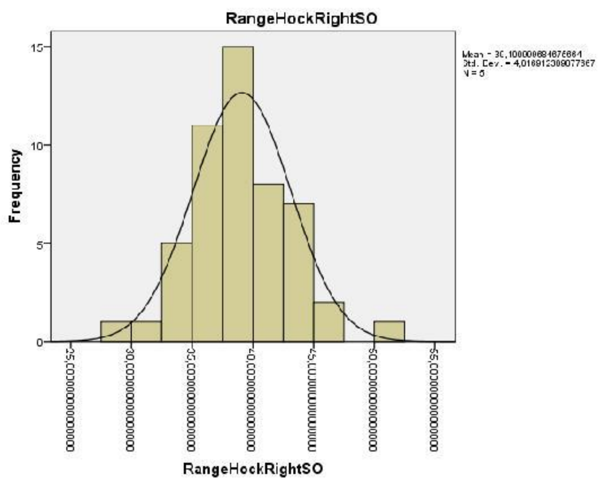


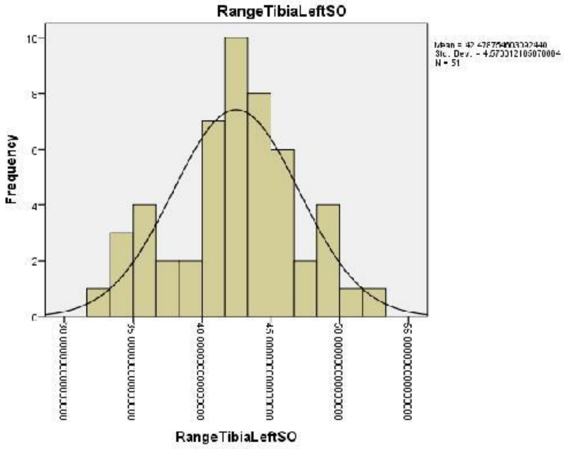


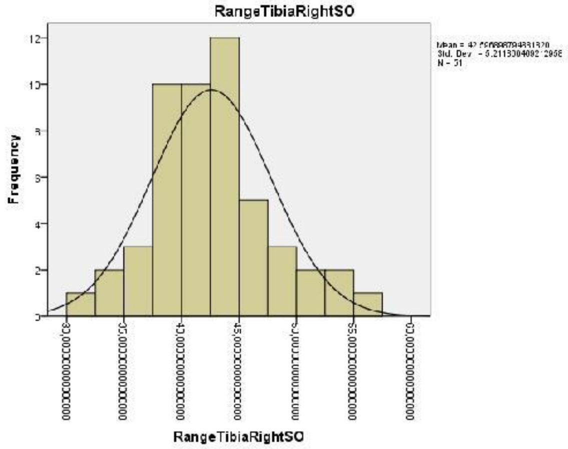


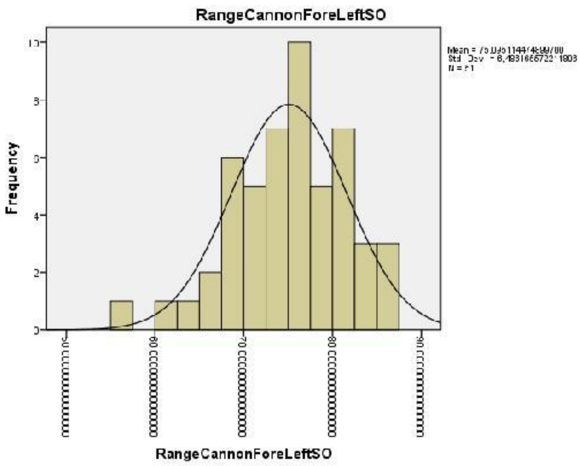
d; trot soft sorface, sound horses

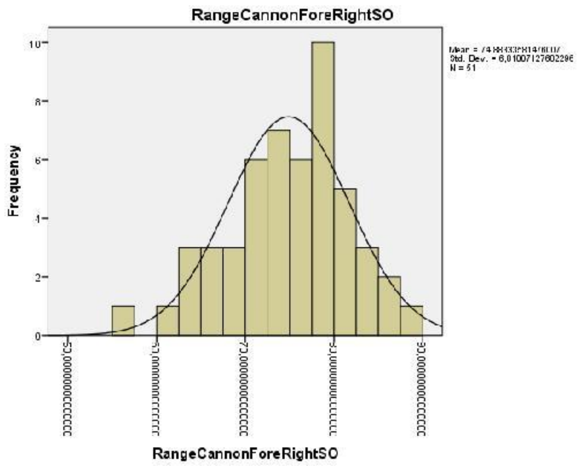


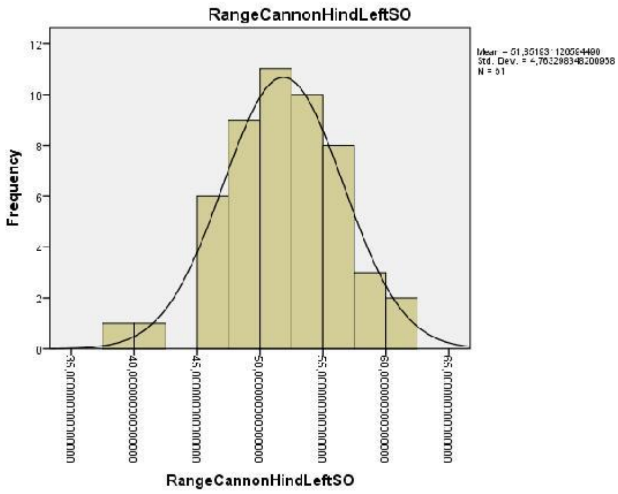


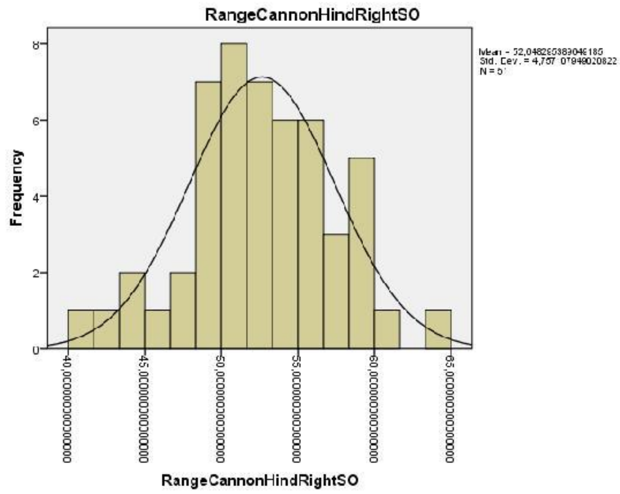

RangeTibiaLeftSO
Frequency
RangeTibiaLeftSO

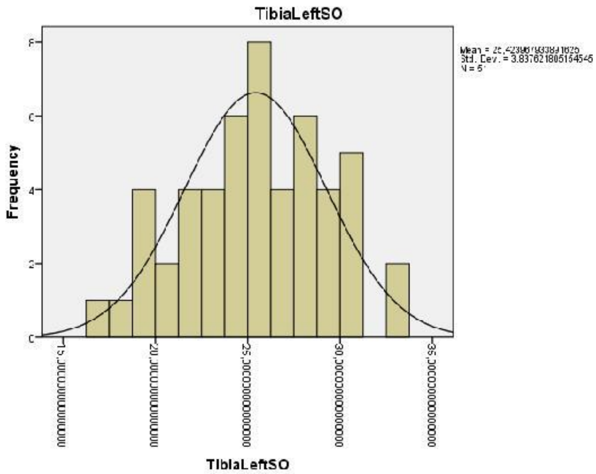

RangeTibiaRightSO
Frequency
RangeTibiaRightSO

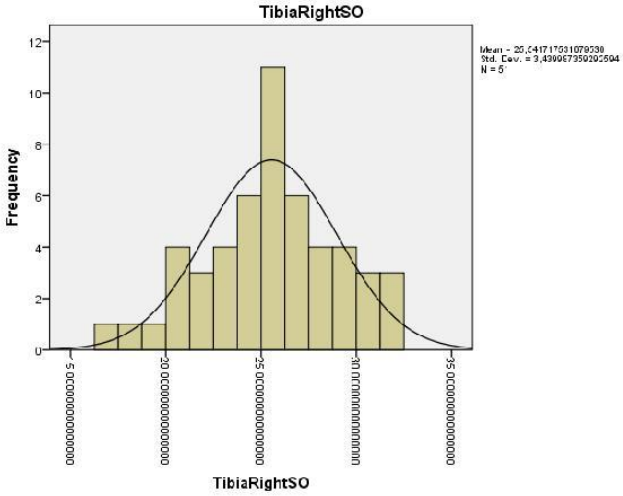

RangeCannonForeLeftSO
Frequency
RangeCannonForeLeftSO

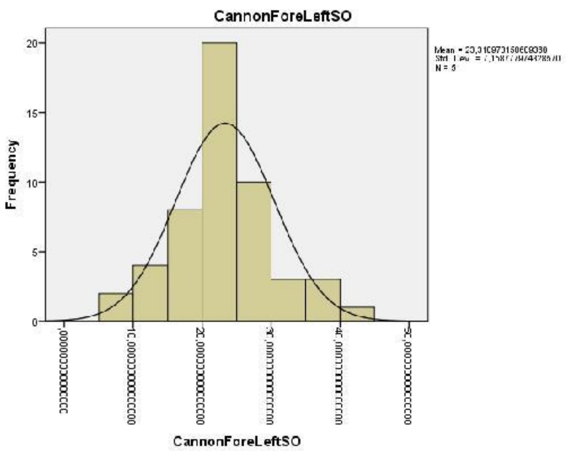

RangeCannonForeRightSO
Frequency
RangeCannonForeRightSO

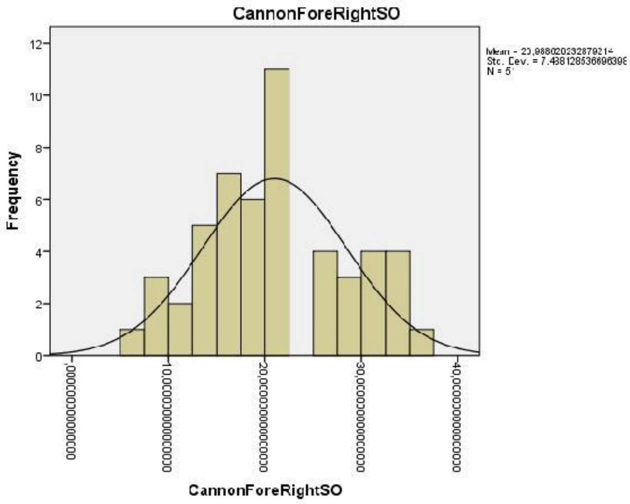

RangeCannonHindLeftSO
Frequency
RangeCannonHindLeftSO

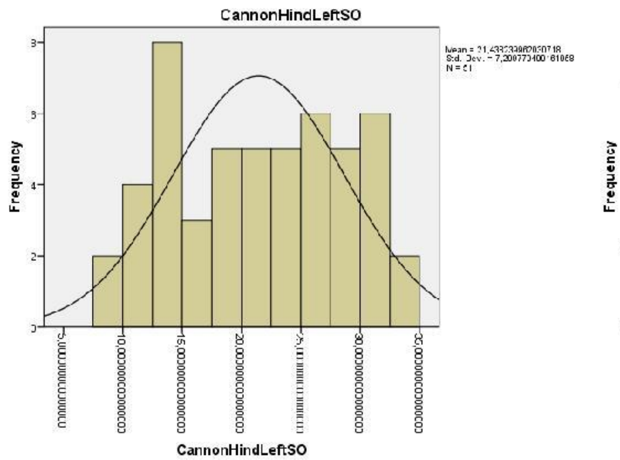

RangeCannonHindRightSO
Frequency
RangeCannonHindRightSO

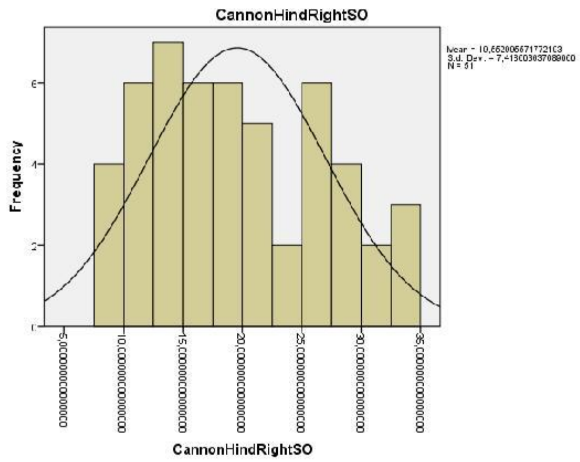

TibiaLeftSO
Frequency
TibiaLeftSO

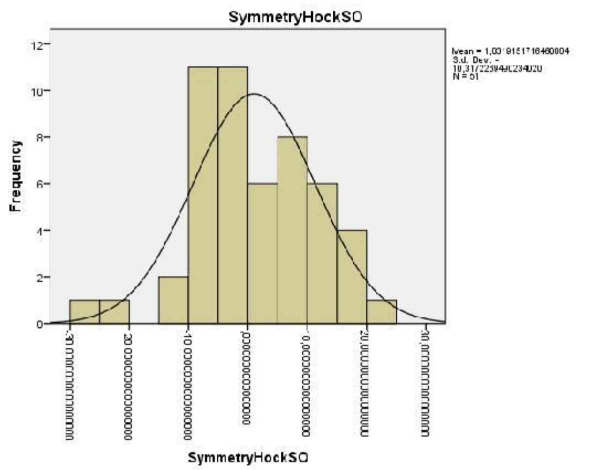

TibiaRightSO
Frequency
TibiaRightSO

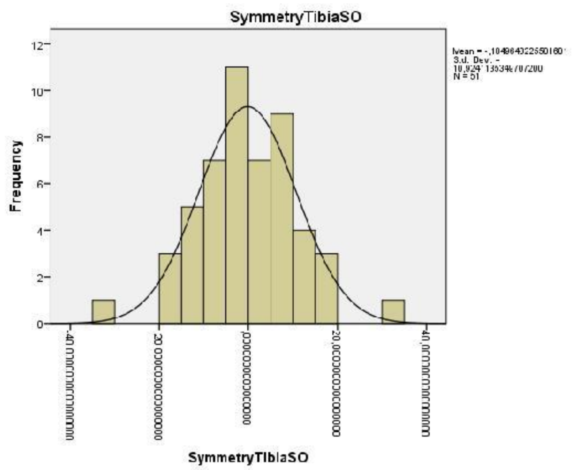

CannonForeLeftSO
Frequency
CannonForeLeftSO

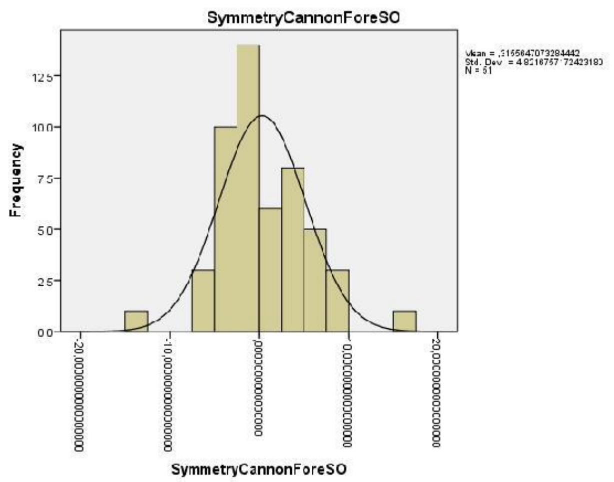

CannonForeRightSO
Frequency
CannonForeRightSO

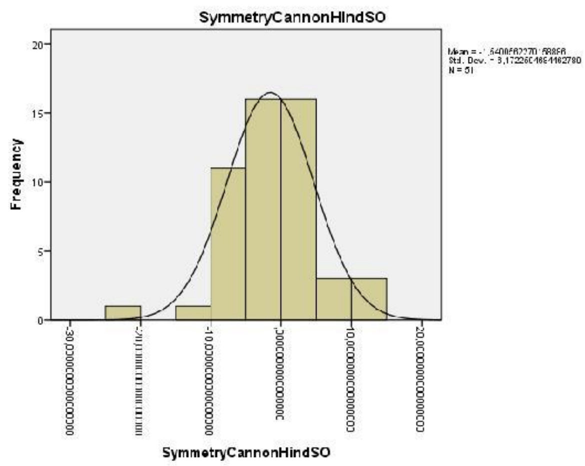

CannonHindLeftSO
Frequency
CannonHindLeftSO


CannonHindRightSO
Frequency
CannonHindRightSO


SymmetryHockSO
Frequency
SymmetryHockSO

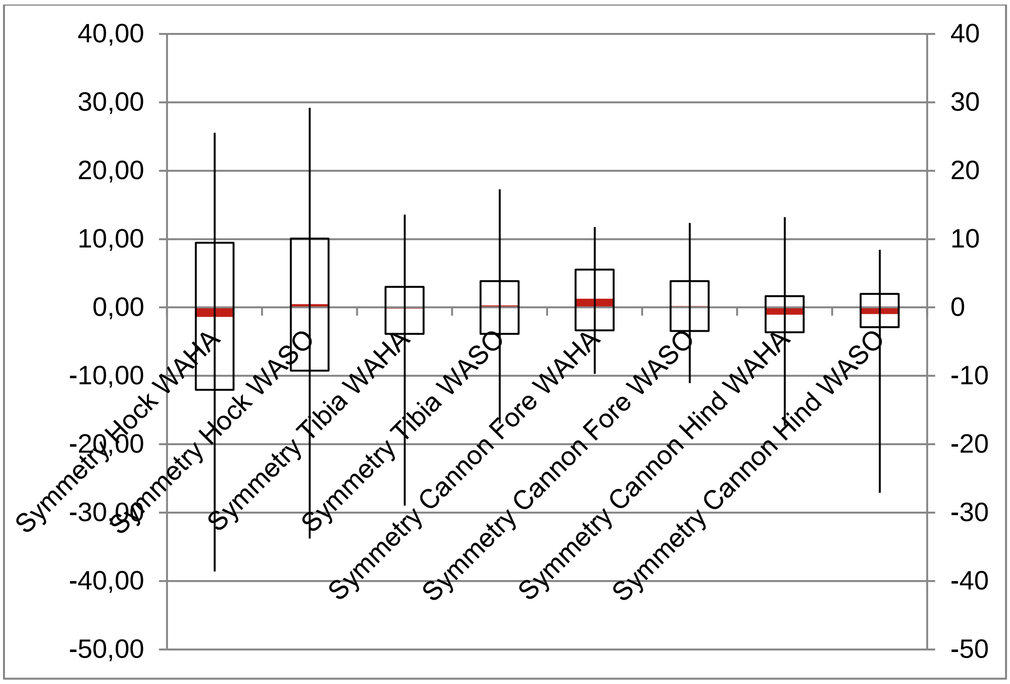

SymmetryTibiaSO
Frequency
SymmetryTibiaSO


SymmetryCannonForeSO
Frequency
SymmetryCannonForeSO


SymmetryCannonHindSO
Frequency
SymmetryCannonHindSO

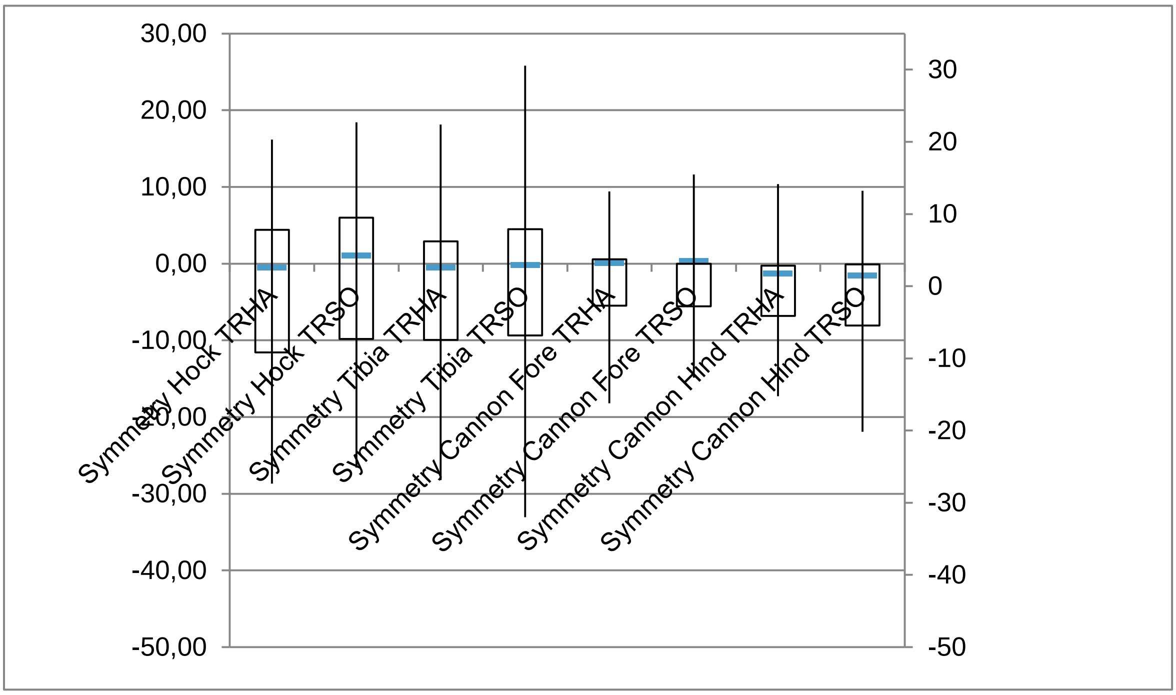
Annex VII : Comparison between symmetry on hard and soft surface (for sound horses) graphs

a. Comparison in walk



* WAHA = walk hard, WASO = walk soft

b. Comparison in trot



* TRHA = trot hard, TRSO = trot soft

Annex VIII: Comparison of movement pattern on soft and hard surface for sound horses (Paired sample t-test)

Hypothesis:

H_0: There is no difference between movement patterns in hard and soft surface

H_1: There is a difference between movement patterns on a hard surface and on a soft surface.

Level of significance $\alpha = 0.05$

WALK	Mean	Std. Deviation	t	Sig. (2-tailed)		TROT	Mean	Std. Deviation	t	Sig. (2-tailed)
Range Hock Left (sag.)	-.323	3.91	-.59	.558		Range Hock Left (sag.)	-.178	3.00	-.424	.673
Range Hock Right (sag.)	.133	3.64	.26	.795		Range Hock Right (sag.)	.335	3.48	.689	.494
Range Tibia Left (sag.)	-.233	2.24	-.74	.461		Range Tibia Left (sag.)	-1.372	3.40	-2.886	.006
Range Tibia Right (sag.)	.069	3.71	.13	.896		Range Tibia Right (sag.)	-1.283	3.90	-2.348	.023

Range Cannon Fore Left (sag.)	2.196	3.26	4.82	.000		Range Cannon Fore Left (sag.)	.564	3.38	1.190	.240
Range Cannon Fore Right (sag.)	1.444	2.73	3.78	.000		Range Cannon Fore Right (sag.)	.745	3.52	1.510	.137
Range Cannon Hind Left (sag.)	-.933	3.87	-1.72	.091		Range Cannon Hind Left (sag.)	.558	4.08	.976	.334
Range Cannon Hind Right (sag.)	-.810	2.89	-2.00	.051		Range Cannon Hind Right (sag.)	.393	4.09	.687	.495
Tibia Left (cor.)	.045	2.62	.12	.904		Tibia Left (cor.)	.876	2.52	2.479	.017
Tibia Right (cor.)	.732	2.41	2.17	.035		Tibia Right (cor.)	.903	2.97	2.173	.035
Cannon Fore Left (cor.)	.312	3.14	.71	.481		Cannon Fore Left (cor.)	-.136	2.69	-.361	.719
Cannon Fore Right (cor.)	-.243	3.61	-.48	.633		Cannon Fore Right (cor.)	-.568	3.26	-1.245	.219

Cannon Hind Left (cor.)	-.727	3.98	-1.30	.198		Cannon Hind Left (cor.)	-.665	3.17	-1.501	.140
Cannon Hind Right (cor.)	-.417	2.31	-1.29	.204		Cannon Hind Right (cor.)	-.674	2.46	-1.957	.056
Symmetry Hock	-1.857	8.71	-1.52	.134		Symmetry Hock	-1.537	7.50	-1.464	.149
Symmetry Tibia	-.461	6.98	-.47	.639		Symmetry Tibia	-.323	7.46	-.309	.759
Symmetry Cannon Fore	1.075	4.26	1.80	.077		Symmetry Cannon Fore	-.258	3.50	-.526	.601
Symmetry Cannon Hind	-.105	6.18	-.12	.904		Symmetry Cannon Hind	.295	5.38	.392	.697

* Correlation is significant at the 0.05 level (2-tailed).