Master Thesis

Defining rider skills by analysing data regarding to regularity, symmetry and damping

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Abstract

Equestrian sports is a popular sport worldwide and covers a wide range of skill levels from professional riders participating at competitions to non-competitive leisure riders. But is success an indication for good riding skill or is it more likely depending on the experience and ability of the horse? There are many factors that influence the performance of the rider. The horse, the environment, the circumstances as well as the rider itself play a big role. Until now, subjective scoring is the only quantification that differentiate between good and bad riding skills. The issue with subjective assessments is it requires a professional to carry out and rate the performance. Having supportive technical devices leads to more accurate outcomes and a higher reliability. First clinics started using motion capture systems as an objective measurement system for lameness evaluation. All these objective quantifications, whether it is for clinical use or for performance diagnostic, have the aim to keep the horse in a sound condition.

The aim of the current research is to define “Rider Skills” based on data, that was taken from horse-rider pairs in summer 2017 with Inertial Measurement Units. Because of its complexity we narrowed down the amount of parameters to four core variables for analysis based on the current literature search.

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1. Introduction

Equestrianism is a highly complex and subjective sport: The interaction between horse and rider, the judgement of performances, and traditional, non-empirical approaches to horse care and riding, are all highly impacted by emotions, opinions and individual perception. No matter if it is for a clinical evaluation, scoring a performance during a competition or to examine the riding equipment like the fit of the saddle - nearly all areas of equestrianism require the judgment of a professional. The various riding styles require specific training programs whereby in between one discipline training instructor have individual methods to train and a subjective anticipation about “good” riding. However, the validity of objective judgements by equine professionals is questioned increasingly since recent research could show limited agreement between individual observers and compared to quantitative data.

One example for this is the clinical lameness assessment. Lameness, which is one of the most widespread medical problem in horses, is diagnosed on the basis of visual inspection by equine veterinarians, whereby both intra- and interobserver disagreement was reported (Arkell, M., Archer, R. M., Guitian, F. J., & May, S. A., 2006; Thomsen, M. H., Jensen, A. T., Sørensen, H., Lindegaard, C., & Andersen, P. H., 2010). During a lameness evaluation, the horse is generally trotted on a straight line while the veterinarian is observing it from the front and from behind. If the head of the horse is “nodding”, this can be an indication for fore limb lameness, while an asymmetric “hip hike” or “hip drop” can be a sign for hind limb lameness. But also the flight arc of the limb, the foot-ground-contact, the push-off and the stride length have to be considered by the observing veterinarian (Keegan et al., 2012). Determining which equine limb is causing the lameness and where exactly the pain is located is therefore very challenging. Local anesthetic nerve blocks are injected to eliminate parts of the horses limb. This exclusion process helps to narrow down the areas where the pain is coming from. But the changes due to anesthesia are sometimes so subtle that it is nearly impossible to recognize changes in movement patterns with the human eye. In general, subjective lameness assessments show a low degree of agreement between different veterinarians (Keegan et al. 2010).

1. Introduction

Given the economic importance of equestrian sports quantifying performance could be of particular interest in some riding disciplines where the performance of the horse-rider-pair is scored by judges. In dressage, scores are given for the quality of the horses gaits, the horses desire to cooperate, the energy of the motion and the riders performance during the test (Diaz, A. E., Johnston, M. S., Lucitti, J., Neckameyer, W. S., & Moran, K. M., 2010). The "Training Scale for Horses" is a guideline based on the classical horsemanship for correct horse riding. It exists of six points that are build up on each other: rhythm, relaxation, connection, impulsion, straightness and collection, but the understanding and interpretation is depending on the the subjective individual, what leads to disagreements of the judges due competition (Hess, C., Kaspareit, T., Miesner, S., Plewa, M., & Putz, M., 2012). At elite level, there are five judges sitting at a fixed point around the 60m x 20m arena. The subjective anticipation as well as the sitting position of the judges were shown to affect the evaluation (Hawson, L. A., McLean, A. N., & McGreevy, P. D., 2010).

The discipline of Western riding, on the other hand, have different demands on the horse-rider -pairs. The horses need to be sturdy, quick and responsive, the abilities which are required for previous farm working in the U.S. Gaited performance has its focus on the two additional gaits tolt and pace which normally appears in icelandic horses. Even though the requirements on the animal and human differ from each riding discipline, scores given during competition are still remaining on an expert whose decision are based on individual previous experiences.

Quantifying performance could thus be of particular interest in disciplines where the winning team is not solely determined by the fastest time or the least faults.

In breeding, the innate quality of the horses gait is essential for later performance. It has been assumed that some of the characteristics in walk, trot and canter could genetically be selected. Besides the gait quality, the conformation characteristics play a major role in breeding (Barrey, E. et al., 2002). From the very beginning, the gait patterns of the young foals are scored by professional judges are sold for a huge amount of money. In Stallion Show young stallions are presented in different disciplines and quantified by their performance quality, their constitution and manner. The stallions with good genetic quality are used for breeding, the destiny of the other stallions is unsure. But individual interest and preference influence the objective quantification. Because of its big economical and ethical impact, supportive measurement devices are needed to guarantee a fair and objective evaluation.

The technical development slowly takes place in the Equestrianism area. Kinetic and kinematic methods enable the quantification of gait asymmetries. Kinetic methods quantify the ground reaction forces upon ground contact of a limb, whereas kinematic methods quantify movements of internal and external body segments during locomotion (Bosch et al., 2018). The first veterinary clinics like “Tierklinik Lüsche” already use 3D motion capture systems to record the movements of the horse by attaching markers on the relevant landmarks. These systems support equine veterinarians in assessing lameness and they provide the opportunity to objectively compare measurements recorded over a prolonged period of time. The development of small, reliable, and comparably inexpensive sensors to quantify movements open up a variety of new options to objectify relevant parameters in equestrian sports, e.g. symmetry of movements or range of movements. Existing studies used IMUs (Inertial Measurement Systems) for horse gait analysis or for evaluating human movement patterns during riding (Brighton, C., Olsen, E., & Pfau, T., 2015; Gunst, S. et al., 2019). Martin and colleagues use the small and inexpensive sensors to measure the humans pelvis kinematics during trot, whereby the light IMUs show adequate results. Supporting subjective assessments with objective, quantitative data, could not only help to enhance training principles, improve the horses performance, or to invent new training devices but it could also positively impact equine welfare.

A sound and healthy horse is crucial for successful performance and should be obvious for every horse owner. But sadly, poor back health is seen in all riding levels from leisure riders to competition riders as a consequence of bad horse riding. Many instructors have their own training principles based on their background as horse person that not can lead to malformed muscles and wrong posture of the horse. Although the rider has such a big impact on the horses well-being, there is no clear definition of good horse riding skills. The animal and the human are strongly connected, therefore it is challenging to quantify the riders ability separately. The locomotion, the age, skill level of the horse and many other factors influence the riders performance (see Figure 1). Technical devices are needed for an objective quantification of the rider skills. Since the technical requirements are given, it is now necessary to extract the most important parameter that are responsible for good rider skills. To this day, it is not known yet which factors have the most impact on the riders ability.

The aim of the thesis is to use IMU data to analyse certain parameters based on literature search that define good rider skills and to see if there are any correlations between the parameters. The topic is more recent than ever as the number of horse back rider is increasing from year to year. From an economical point of view, there is also an interest to investigate further studies as the horse industry is a huge market.

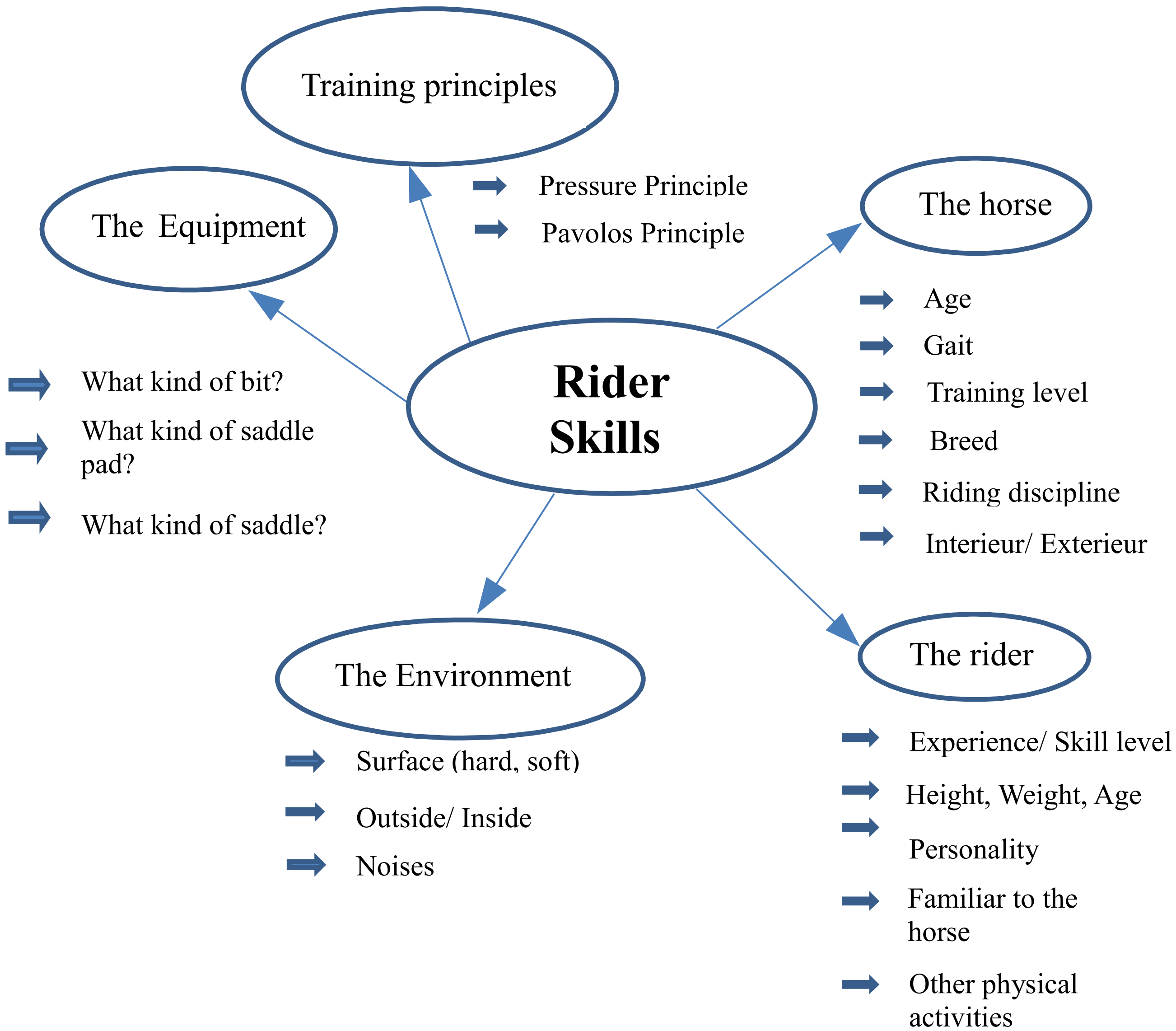


Figure 1: *Factors influencing Rider Skills*

1.1. Economical impact

1.1.1. Switzerland

The “Schweizer Nationalgestüt (SNG)” was established in 1898 and is nowadays not only important for the breeding, but is also investigating a lot in research and science. The institution is also continuously updating the numbers of equines that are registered in Switzerland. Data sources are Agate, the “Tierverkehrsdatenbank (TVD)”and the “Kantonale Erhebung des Bundesamtes für Statistik BFS”. Between 2012 and 2016 the number increased 0,39% per year. In 2016, 105.058 horses were documented including 180 breeds. Because of its dynamic fluctuations, the real number is unknown. A current study reported a number of 125.338 in 2018 (Identitas, 2019).

The “Observatorium der Schweizerischen Pferdebranche” is a report about the economical, social and agriculture state in Switzerland in 2007 (Poncet Pierre-André et al., 2007). There are about 100.000 people participating in equestrian sport aged 15 to 74 years. These are 1,8 % of the total population in Switzerland. The breeding and rearing of young horses is important for the swiss agriculture, too. The yearly impact on the swiss agriculture by horse breeding is estimated to be around 18.0 million Franken. It involves hay, straw and concentrated feed and lease for the grassland (Wägeli, S., Grossniklaus, J., Wülser, T., Herholz C., n. d.)

1.1.2. Europa

The European Horse Network (EHN) is a non–profit network combined of many equine organisations operating in Europe. Although there are no definitive statistics, the economical impact of the horse industry is approximately 100 billions euros a year. The direct impact includes breeding, industrial companies and services linked to horses, education and research. The indirect impact involves competitions or other horse related activities like betting. The various governments are taking advantages of the huge business by at least 5 billion euros of taxes as well. The horse industry represents nearly 400.00 full time jobs, working directly or indirectly (in competition, in breeding) as there are more than 20.000 sporting events every year. The total number of horses in Europe is around 6 million. EHN estimates that at least 6 million hectares are used for horses (The European Horse Network, 2017). And there is still a growing in this sector: The number of horse rider is increasing 5% per year.

2. Theoretical Background

2.1. Gaits

The characteristic of a gait is its cyclic motion. One cycle describes one single stride, including the weight bearing Stand Phase, when the hoof has ground contact, and Swing Phase, the retraction and protection of the limb to prepare for the next stance phase. In general, the gaits are classified as *Stepping* (walking) and *Leaping* (running). Both mechanism show different motion pattern and techniques to minimize energy expenditure. Stepping has no Suspension Phase which means that at least one hoof has ground contact. Compared to Leaping, there is less velocity and only little vertical acceleration. The body of the horse is moving more in the mediolateral (MP) direction than in the anteriorposterior (AP). During Leaping, the horse accelerates upwards as there is a Suspension Phase. The rider has to try to synchronize the motion of the horse and to be “in phase” to avoid a bounce after ground contact. Gaits can also be categorized into symmetrical and asymmetrical gaits, according to the left-right-symmetry of limb movements. In a symmetrical gait (walk, trot, pace, tolt) the kinematics and kinetics (stance duration, swing duration, sweep angle) of each fore and hind limb are used equally and move out-of-phase. The time interval between each ground contact are equally (Robilliard, J. J., Pfau, T., & Wilson, A. M., 2007).

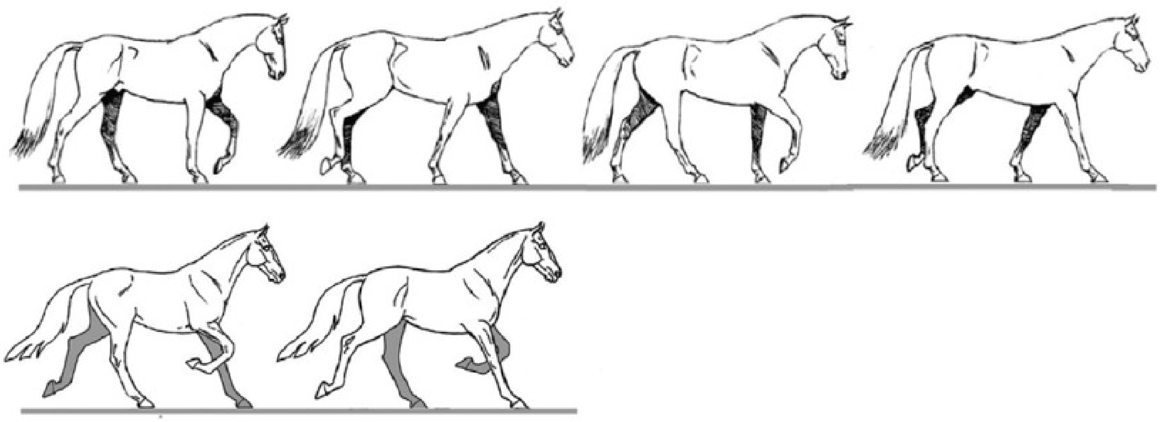


Figure 2: *Symmetric Gaits.(top) walk, the limb order is left hind, left front, right hind and right front. (bottom) trot, the ground contact always with the diagonal limbs, right hind, left front and left hind and right front (Clayton, H. M., 2016).*

In asymmetrical gaits (canter, gallop) foot-contacts of the contralateral (fore and hind limb) pairs appears in different time intervals.

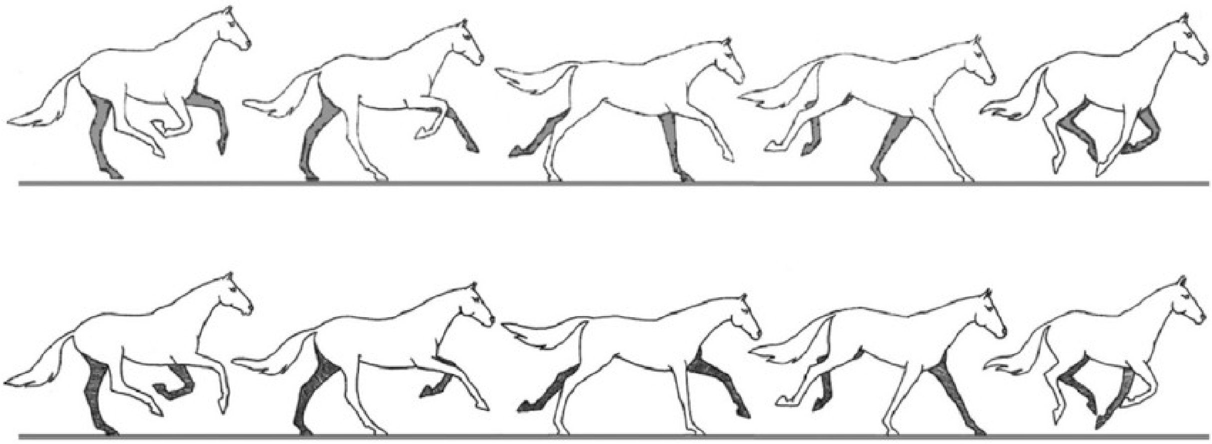


Figure 3: *Asymmetric Gait. Footfall sequence is left hind, right hind, left front and right front (Clayton, H. M., 2016).*

For the analysis it is necessary to know the gait properties for choosing the right data set. Lameness evaluation, for example, are always done in trot because of its symmetrical characteristics. Possible lameness would cause different ranges of asymmetries, although there is no baseline existing at which point a slightly asymmetry is pathological.

2.1.1. Walk

In general, horse locomotion includes walk, trot and canter. Walk is a four-beat gait with no suspension phase and has less velocity. The speed in dressage horses is ranged from 1.37 m/s to 1.82 m/s.

2.1.2. Trot

Trot is a two-beat gait with synchronized movements of the diagonal limb pairs. It has a suspension phase that increases with trotting speed. The different seating positions at the trot are sitting trot and rising. During sitting trot, the rider follows the horses motions without losing saddle contact. Beginners are mostly taught rising trot a sit is more comfortable (Peham et al. , 2010). The rider stands up in the stirrups when one forelimb comes off and sits down when the same leg returns to the ground. The icelandic horse is a five-gaited horse. Besides the typical three gaits they have additional two gaits called tolt and pace. Tolt does not have a Suspension Phase and one leg is always in ground-contact. These gaits are very comfortable for the rider because of the missing vertical acceleration. Pace is a two-beat gait where the limbs on the same side of the body move together and also characteristic for gaited horses. In dressage on the other hand, the goal is a change in stride length to make distinct transitions. An increased speed of the trot with more extension of the front limbs is called extended trot. In comparison the characteristics of the collected trot is less velocity and more load bearing of the hind limbs and a slowly shifting of the Centre of Pressure more backwards. Thru the Suspension Phase, there is a vertical acceleration acting on horse and rider. At this phase, the horse reaches vertically its maximum height.

2.1.3. Canter

Canter is faster than the trot and is a three-bet gait. In canter, one of the horses rear legs propels the horse forwards (Clayton, H. M., & Hobbs, S. J., 2017). The anticipation of the rider on the horses motion seems to be more easy during canter as the suspension interval at the end of a canter stride cycle gives the rider more preparation time for the next stride cycle (Wolframm, I. A., Bosga, J., & Meulenbroek, R. G., 2013).

2.2. Breeds

Horses are one of the animals which have a big impact on humans history. They were not only used for milk or meat but provide rapid transport. During time, their original tasks to carry humans or goods from one way to another, has changed. As the industrial development replaced the horse with new technologies like means of transport or agriculture devices like tractors, we are not dependent on the horse, anymore. But horses are more present than before. Nowadays, a whole society has developed, including the equestrian sports and associated horse industry. The human activities have influenced the evolution of the horse as selective breeding is characterized by a high interbreed and low intrabreed genetic diversity (Librado et al., 2016).

Depending on the riding style, various physical properties are required. The properties are all based on genetic parameters (Koenen, E. P. C., Van Veldhuizen, A. E., & Brascamp, E. W. , 1995). They are crucial for the statue and the character of the breed. Because of the big biodiversity, there is nearly every size, shape and coat colour of a horse present. To distinguish between the breeds, horses are classified depending on their height and weight. As there are various ways of classification, we will focus on warmbloods, draft horses, light horses, ponies and gaited horses.

2.3. General requirements on the rider

A good physical fitness is necessary in equestrianism like in every other sports. Depending on the riding discipline, special requirements on the rider are needed. Jockey rider have to stand up in the stirrups during a whole race over 1800 to 2900 m. This exhausting position takes a lot advantage of the leg muscular. The low body fat and extremely low body weight are remarkable as well (Hitchens, P., Blizzard, L., Jones, G., Day, L., & Fell, J. , 2011). In dressage and jumping is an increased energy expenditure recorded (Devienne, M. F., & Guezennec, C. Y., 2000).

But independently from the riding discipline, the baseline parameters are endurance, mobility and coordination. The “Sportmotorischer Test für Reiter” (Deutsches Olympiade-Komitee für Reiterei,n.d) is a guideline for trainer and rider to be improve the physical requirements, because especially belly and back musculature are essential for a stable seat. The different abilities improve while training and should be recommended. The anticipation of the rider due the horses motion plays a big role. The horse as locomotion generator shows some variability during every stride that demands a fast adjustment and reaction of the rider.

3. Interaction Horse-Rider

The most remarkable and essential factor in equestrianism is the interaction between the horse and the rider. Although the influence of the rider on the horses performance is incontestable, only little is known about factors that have most impact (Peham et al., 2010; Martin et al., 2016). Previous studies highlight certain aspects of rider skills but the interrelationships remains challenging to determine (Greve, L., & Dyson, S., 2013). To this day, there is no Golden Standard or baseline parameters existing describing the dynamics of horse-rider-movements (Wolframm, I. A., Bosga, J., & Meulenbroek, R. G., 2013). In accordance with the literature, the collected data was analysed in respect of Rider Skills regarding to the following parameters:

3.1 Defining Rider Skills Parameter

3.1.1. Synchronicity

In sitting trot the rider keeps contact to the saddle while adapting the horses motion. The vertical acceleration due the push off of the horse is very challenging for the rider. He tries to follow the motion without any delay. Otherwise he would fall “behind the movement” and disturb the flow of the locomotion of the horse. The phase shift can be a measure for rider skills. It describes the synchronicity between the pair. A phase shift of 180 degrees would result in a completely opposite motion cycle like the horse and cause a high impact on the back every time. The counter movement of the rider leads to a greater fluctuation of the combined Centre of mass of the horse and rider (De Cocq, P., Muller, M., Clayton, H. M., & van Leeuwen, J. L., 2013). The unpredictability of the horse motion requires high motor coordination and muscle activation of the rider.

3.1.2. Symmetry

The gait symmetry in trot is crucial for a good performance. Studies use the kinetic and/or kinematic data based symmetry examinations to check for asymmetries in locomotion, which can be an indicator for pain related lameness. Symmetry is an important measure to quantify the horses welfare. To a certain extent, the influence of the rider on the horse symmetry can be proven. In ridden horses, the grade of asymmetry can be influenced by the rider (Greve, L., & Dyson, S., 2013). By shifting the riders Centre of Mass more back or forwards, the horse has to carry increased load on the fore or hind limbs. Especially due collection, where the horse horses Centre of Gravity is shifted more backwards, rider induced asymmetries in the horses locomotion can be seen. Referring to an optimal horse-rider-coordination and a symmetrical adaption of the rider to the horses motion pattern, good rider-skills are needed. Persson-Sjodin and colleagues examined the power of different seating styles on the vertical head and pelvic movement symmetry on the horse. Asymmetries have been documented due to rising trot, when the rider is rising up in the stirrups, he creates a downward momentum counteracting to the horses push off. But depending on the sitting diagonal, horses can also show lower baseline asymmetries (Persson-Sjodin, E., Hernlund, E., Pfau, T., Andersen, P. H., & Rhodin, M., 2018). Supported by these findings the overall symmetry of the horse ad the rider was implemented as one parameter to describe and define rider skills

3.1.3. Frequency

The frequency with which the horse is moving is seen as challenge, too. Imagine a small person with short legs walking next to a tall person with long legs at the same speed. The short person will have an increased frequency to cover the same distance with smaller step width than the tall person (Landers, G. J., Blanksby, B. A., & Ackland, T. R., 2011). Similar observations are done in horses whereby the stride frequency is an important factor for the anticipation of the rider (Heglund, N. C., & Taylor, C. R, 1988).

3.1.4. Regularity

Regularity is described as the inter- stride time variability based on the duration of each stride cycle. The consistency of the variation in the movement pattern can be influenced by the rider. Peham and colleagues investigated the motion pattern of well-ridden and unridden horses (Peham, C., Licka, T., Schobesberger, H., & Meschan, E., 2004). The velocity and acceleration in the forward direction displayed less variability in ridden horses than in unridden. Regularity is a sensitive measure for the quality of the riders ability.

3.1.5. Spring- Damping

The muscle-tendon relationship has been well described in human science as Spring-Damping-Mass-System (SDM) Model. The spring and damper elements represent the mechanical properties of the different segments including bones, muscles, tendons, and ligaments (Nikooyan, A. A., & Zadpoor, A. A., 2011). The models are very useful for describing dynamic locomotion. In the human walk and running both vertical ground reaction forces (GRF) have unlike outcomes. The impact peak in running that occurs when landing on the ground, is the most remarkable distinction and demands adjustments of the musculoskeletal system. In respect of external forces acting on the body, muscles and tendons have to response to reduce impacts that could lead to injuries. The mechanical properties like stiffness and damping are decisively due the changes of the movement pattern and the GRF.

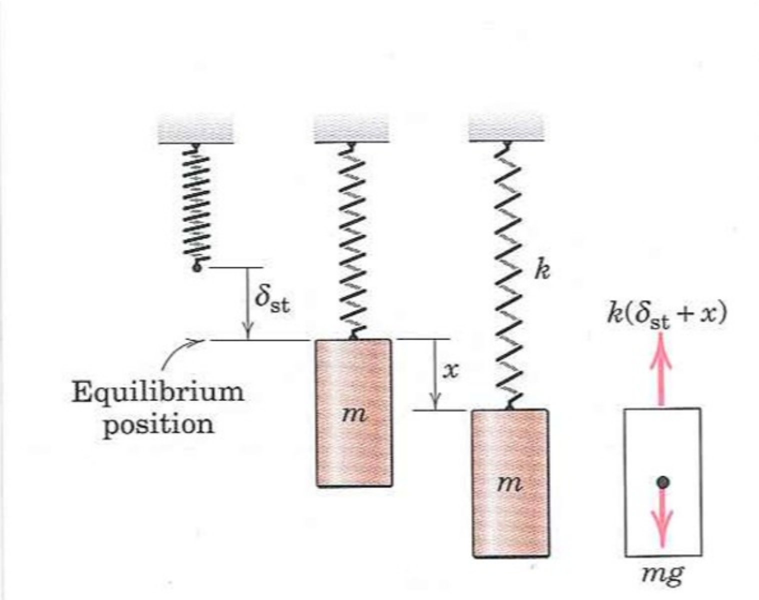


Figure 4: *Spring-Damping-Mass System*

The leg spring and the saddle influence the performance and work load of the horse. A low spring stiffness and low damping of the rider leads to less work load on the horse and lowest impact of the rider. The result would be an extreme jockey seat. There are five joints in the hind limbs and four joints in the forelimbs that act like a spring damping system as well as the torsus of the horse. Because no bones keep the body in a static position, it is oscillating like a spring.

Especially during sitting trot the force load is compared to the other gaits the highest (2112 N), followed by rising trot (2056 N) (Peham et al., 2010). Because of the high load on the horses back and the challenging demands on the horse rider, the data set of the sitting trot is used.

4. Materials and Methods

4.1. Subjects

The study took place in 2017 from april to november. 238 horse-rider-pairs were measured in eight different swiss stables in 30 measurement days. Participants were recruited through horse magazines (SVPS-Bulletin, Kavallo, Pferdewoche, Cavalier Romand) and announcement in newspaper. All horse owner, that were registered in the AGATE-database, were contacted, too. Inclusion criteria for the study were as followed:

- The age of the horse has to be between 5-18
- No physical complaints
- Training at least twice per week
- The rider is the predominant rider (at least 2/3)
- The riders age is at least 18 and does not suffer from any chronic problems
- The examinations were separated into two parts
- Included riding disciplines:

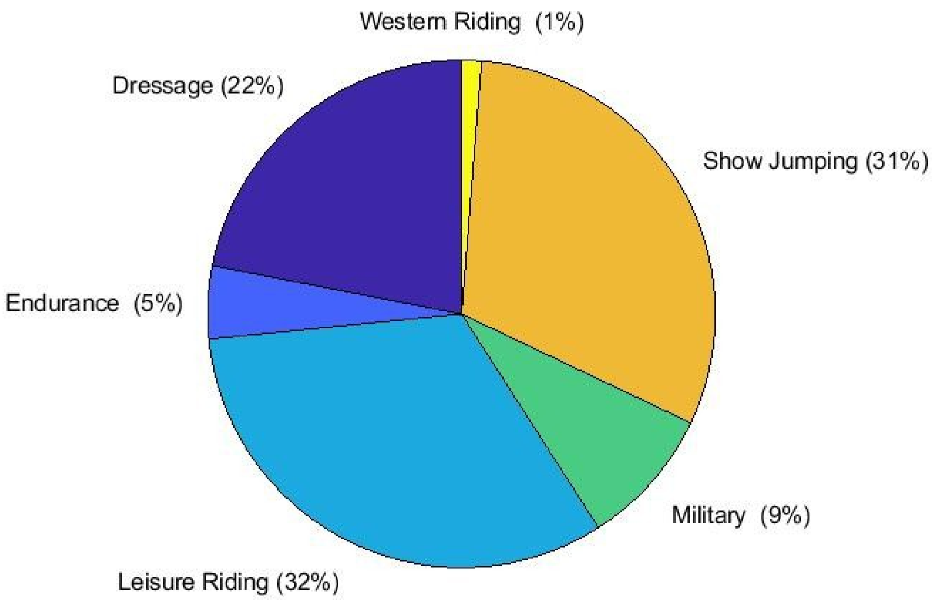


Figure 5: *Riding Disciplines*

Table 1: *Overview Rider*

Parameter		Mean (s.d.)	Range (min, max)
Age Rider [years]		37,34 (+/- 11,37)	18-72 (min,max)
Years of riding experience [years]		25,4 +/- 10,3	4-62 (min,max)
Hours Riding per week [h]		8,09 +/- 4,1	1-30 (min,max)
		Proportion (in %)	
Sex Rider [f,m]	N Females (proportion)	220 (92,8%)	
Competition Rider (in contrast to leisure riders) [n]	N Competition (proportion)	130 (54,9%)	
Licence holders [Yes/No]	N (proportion)	100 (42,2%)	
			Distribution
Competition Frequency	Never 1-5x per year 6-11x per year More than 11x per year 1x per month 2-3x per month		20 (8,4%) 49 (20,65%) 42(17,6%) 1(0,4%) 29 (12.2%) 29 (12,2%)
Frequency training with instructors	1x per week 1x per month 2-3x per month 1-5x per year 6-11x per year often not often		94 (39,7%) 22 (9,3%) 56 (23,6%) 8 (3,4%) 13 (5,5%) 35 (14,8%) 9 (3,8%)
Riding Frequency [per week]	1-2x 3-4x 5-6x 7x +7		8 (3,4%) 58 (24,5%) 106 (44,7%) 43 (18,1%) 22 (9,3%)

***Table 2:** Overview Horse*

Parameter			
Age Horse [years]	Mean +/- s.d.	10,3 +/- 3,4	5-18 (min,max)
Wither Height [cm]	Mean +/- s.d.	163,12 +/- 8,9	134-179 (min,max)

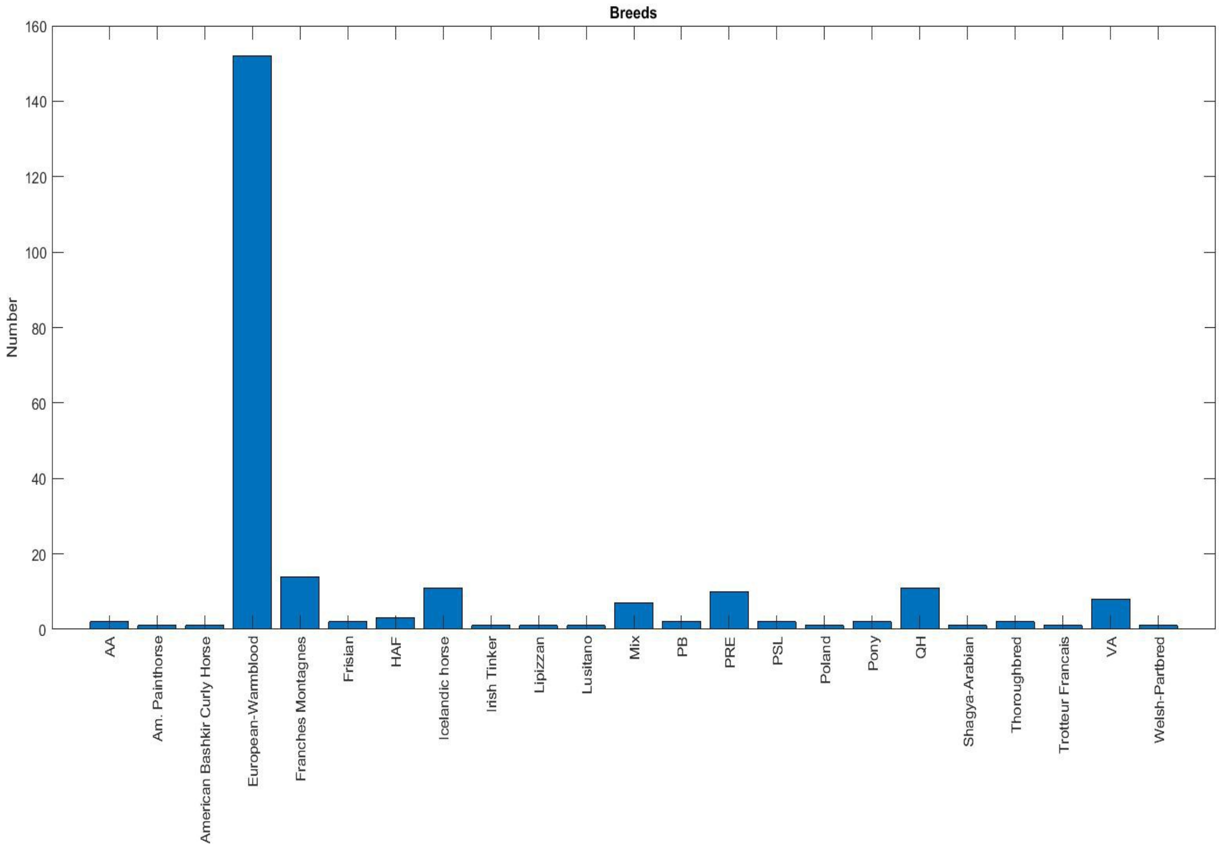


***Figure 6:** Breeds. AA(Anglo-Arabian), HAF(Haflinger), PB(Welsh-Pb), PRE (Pura Raza Española), PSL(Puro Sangue Lusitano), QH(Quarter Horse)*

4.2. Data collection

The rider had to undergo a one hour physiotherapeutic examination to check the physical performance (balance, endurance, flexibility, reaction time, speed, strength) by a physiotherapist. In parallel, two experienced veterinarians examined the horse in respect of motion, back mobility and back pain. The saddle fit was tested as well.

After the clinical evaluation, the Inertial Measurement Units (IMUs) were attached on the horse, rider and saddle. The pressure mat from Pliance system was put underneath the saddle. Each pair had a warm up time for ten minutes. Next, the rider had to follow a riding protocol (see Appendix), including halt, walk, rising and sitting trot and canter at both reins. The riding program was read out loud and recorded by an autofollow-camera (PIXIO ®, MOVE´N SEE, Brest; France). Riding performance was scored by two independent and national judges.

Figure 7: *IMU on Horse´s Sternum*

Figure 8: *IMU on Rider´s Pelvis, Shoulders and Head*

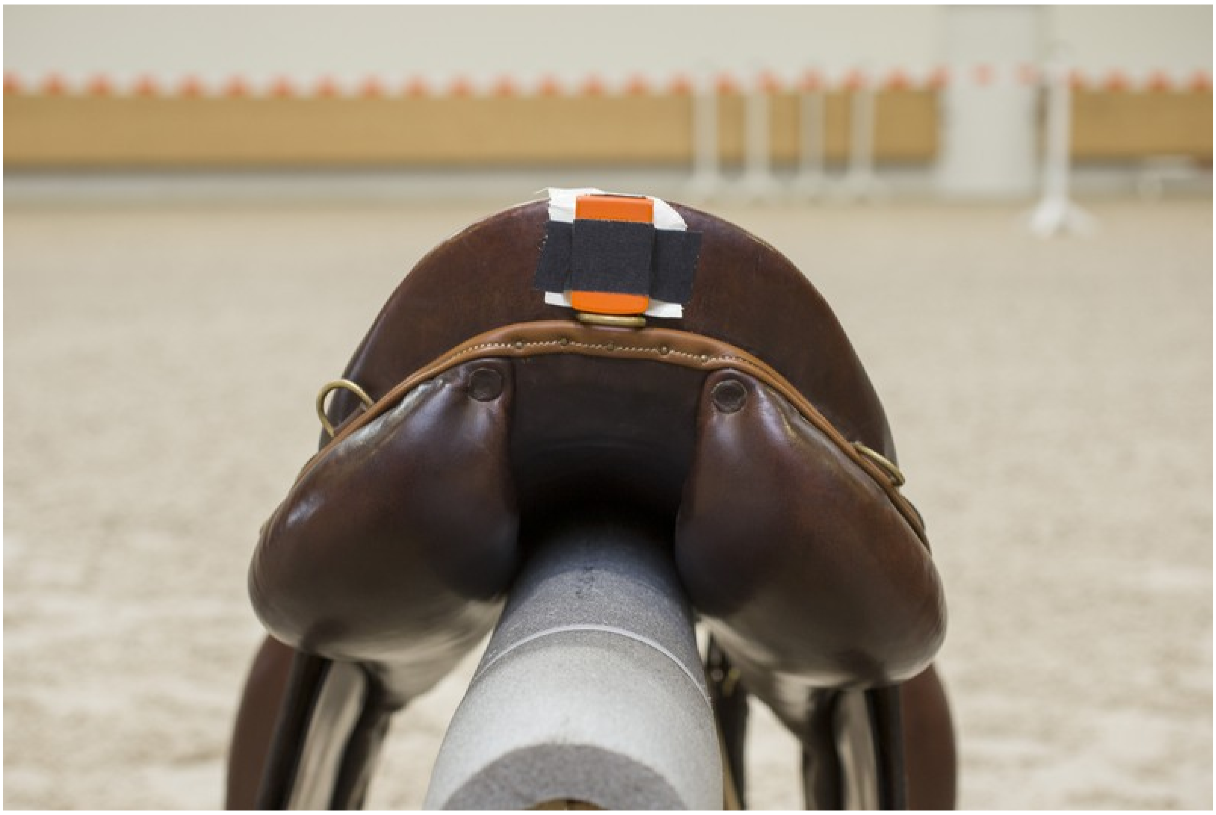


Figure 9: *IMU on Saddle*

4.3. Kinetic Data

4.3.1. IMU

The Inertial Measurement Units are electronic devices to monitor and calculate movements. It is a specific type of sensor that calculates orientation, velocity and measures acceleration by using the integrated accelerometers and gyroscopes The accelerometer provides three axis in transversal direction (x-, y-, z-direction) and the gyroscope three axis in rotational direction (pitch, yaw, roll). The 6 DoF (degrees of freedom) describe the different ways that an object is able to move throughout 3D space. The IMUs were attached on the horse´s sternum, girth, head, the right front leg and saddle.

4.3.2. MVN data

The version of the XSens MVN hardware“AWINDA” is based on single straps that can be easily applied to every human body segment and exists of 17 sensors. Generally, IMUs only measure the acceleration but with the additional software MVN data it is possible to calculate the velocity and position without any extra analysis.

4.3.3. Pliance System

A pressure distribution mat is an objective device to examine the pressure distribution right under the saddle. It is possible to measure not only in a static position but also during riding. The horses often suffer from back pain because of bad saddle fitting. It is used for several studies to survey the effect of the rider on the horses back as well as for clinical investigation. To measure the pressure distribution, the Pliance System incl cable was used. The pad consisted of two two distinct halves.

Figure 10: *Pressure Distribution Mat from Pliance System*

4.4. Data analysis

For the data analysis, the IMUs of the equine´s sternum, the saddle and the rider´s pelvis and head were utilized. In respect of the objectives, these four sensors contain sufficient information. Further studies showed that a small number of IMUs is enough to evaluate the interaction between horse and rider (Münz, A., Eckardt, F., & Witte, K., 2014). The system recorded with a frame rate of 60 Hz. For the analysis MATLAB R2018b was utilized. The full code is attached in digital form.

4.4.1. Fourier Transformation

The Fourier transformation is mostly used to extract the frequency of a time signal. The oscillating movements of the trot can be described by a sum of different sinus curves. The signals can be re written by the sum of sinusoidal functions of different frequencies which can be calculated by the Fourier Transformation. The analysing functions are complex exponentials $e^{j\omega t}$. One disadvantage is that the theory of the Fourier Transformation assumes signals to be stationary. Another point is that it loses localized time-dependent information during the transformation. The results of the Fourier Transformation are the different frequencies, which occur during a movement, and the amplitude of each signal and the phase. The Fourier Transformation was implemented in the analysis as a reference to compare the values with the Continuous Wavelet Transformation to calculate any correlations.

4.4.2. Continuous Wavelet Transformation

The Wavelet Transformation has a basis function as a reference which can have any shape. It is a useful tool especially for abrupt changes in the signal. The Fourier Transformation on the other hand has sine waves as a reference and is smooth and predictable.
(TheMathWorks, n.d).

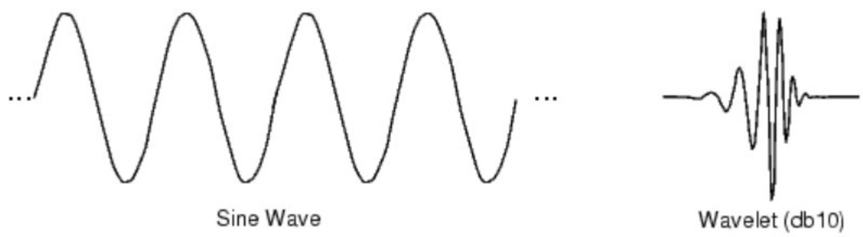


Figure 11: *Sine Wave compared to Wavelet (MathWorks, n.d)*

By comparing the signal to the wavelet at various scales and positions, you obtain a function of two variables. The transformation does not only tell <u>what</u> frequencies are present (as well as the FT), but also <u>when</u> (time) it occurs. The Continuous Wavelet Transformation can be described as “a calculation of a series of pattern correlations between a selected wavelet of a specific size or scale and segments of of the original signal “(Keegan, K. G., Yonezawa, Y., Pai, P. F., Wilson, D. A., & Kramer, J., 2004). Also, the Wavelet Transformation is a useful tool for fore limb lameness evaluation (Keegan, K. G., Arafat, S., Skubic, M., Wilson, D. A., & Kramer, J., 2003).

4.4.3. iHarmonic Ratio

The different frequencies resulting from the Fourier Transformation can be divided into even and odd harmonics. One stride owns two oscillations, one oscillation per diagonal Stance Phase. The second harmonic, also called intrinsic harmonic, is the symmetrical part (even) of the movement (n=2, 4, 6,...). The first harmonic, also called the extrinsic harmonic, reflects the asymmetrical (odd) part of the movement (n= 1, 3, 5,...) (Audigié et al. ,2002). The Harmonic Ratio (HR) is a measure to quantify the smoothness of a motion and describes the harmonic contribution.

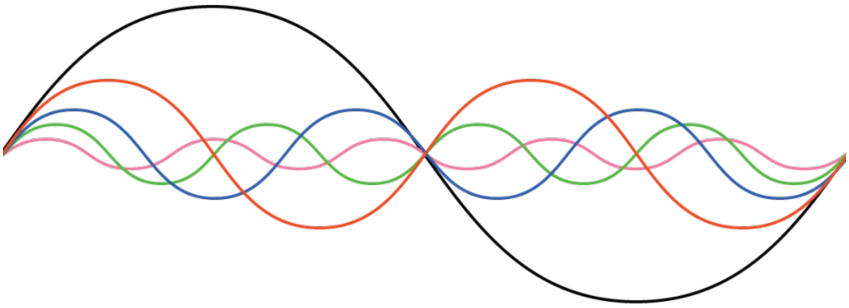


Figure 12: *Harmonics (theDAWstudio, 2016)*

The ratio between the sum of even and odd harmonics gives information about the symmetry of the horse. The greater the value the more symmetric is the gait (Bellanca, J. L, 2013). But the harmonic ratio has limitations: It has a large variability in highly symmetrical gaits due to the small contribution of the extrinsic harmonics. Pasciuto and colleagues introduced an improved model in respect of the harmonic ratio, because of the poor reliability of the HR. Also there is no agreement how many harmonics should be included or over how many strides the statistical distribution must be estimated to be representative.

By using the iHarmonic Ratio, the scale is changed from 0-∞ to a normalised index ranking from 0 to 100%, whereby 100% means absolute symmetry. The iHR relates the power of the intrinsic part(the symmetrical part of the gait) to the total power of the signal for each stride.

4.4.4. Approximate Entropy

The Approximate Entropy (ApEn) is a technique to quantify the predictability of the fluctuations over time-series data. It reflects the probability that same observation pattern will not be followed by additional similar observation. The higher the value the less predictable and regular is the time series. In human science it is a useful method to examine the regularity of certain motion pattern like breathing frequencies during sleep (Burioka et al., 2003). Wolframm and colleagues implemented the ApEn to investigate acceleration data of horse and rider under specific circumstances.

4.4.5.Time differences

Time differences between each strides are taken to measure the consistency of the duration of each stride and to quantify motion pattern stability.

4.4.6. Compression

The forces which are acting on the rider due riding cause a compression of the body. Depending on the vertical acceleration and the stiffness and dampening, the length distance between head and pelvis of the rider changes compared to the initial length when no forces are present. A variety of compensatory movements by the pelvis and the head reduce the vertical impact on the saddle and the horse.

4.4.7. Overview parameters

Table 3: *Overview of all Parameters that are included in the analysis.*

Parameter	Definition	Method	Unit
Synchronicity	- Phase shift between horse and rider	- FT - CWT	- [Radian]
Symmetry	- The ratio between the intrinsic (Symmetric) and extrinsinc (Asymmetric) components of the gait	- iHarmonic Ratio	- [%]
Regularity	- Inter-stride variability	- Approximate Entropy - Time-differences	- [ ] - [sec.]
Frequency	- Individual frequency of horse	- Mean difference of the index of the peak value divided by 60 (Frame rate)	- [Hz]
Wither Height	- Height of the horse measured from the ground to the wither	- Measuring beam	- [cm]
Spring-Damping-Mass-System	- Compression of the riders body	- Length changes in different phases	- [m]

4.5. Coding steps

Kinetic data were processed using Matlab R2018b software. The raw acceleration from the IMUs of the horse and from the XSens “AWINDA” were taken for the analysis. The focus lies on the four sensors to describe the horse-rider-interaction: The horse´s sternum, the rider´s pelvis and head (on the back of the helmet), and the saddle. An error check was conducted to see whether all sensors are recognized. Outliers were excluded. The threshold was set to +/- 10* s.d. to assure that no significant data was left out.

4.5.1. Stride split

Motion cycles was separated into strides based on orientation of the horses leg including a range between -60° (retraction of the limb) and +40° (protraction of the limb), with a minimum distance between two peaks of 15 frames to ensure that no peak is skipped. Although earlier studies used different data points for stride split, we found most accurate results by using the leg orientation (Peham, C., Kotschwar, A. B., Borkenhagen, B., Kuhnke, S., Molsner, J., & Baltacis, A., 2010).

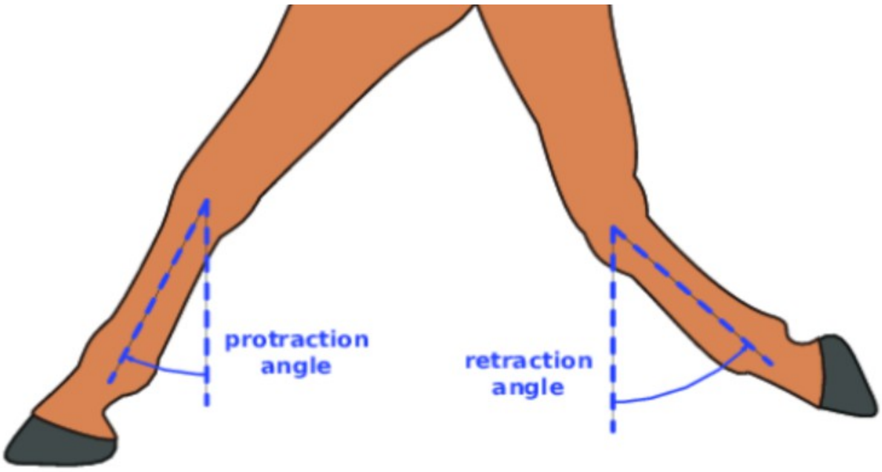


Figure 13: *Protraction and Retraction Angle for Stride Split (Bosch, 2018)*

4.5.2. Biomechanics of the horses locomotion

For the analysis and interpretation of the data it is crucial to understand the biomechanical mechanism behind the locomotion. The Stance Phase can be separated into two parts: the Impact Phase, when the hoof strikes the ground and decelerates. During Mid Stance, the limb is standing vertically to the ground with maximum extension of the tendon and maximum load bearing in the limb. Peak acceleration and the lowest position of the shoulder are reached during Mid Stance. In the later part of stance the limb pushes off, heels leave the ground and the Swing Phase is initiated, where the the limb is at first protracted (pulled forward) and then retracted (pulled backwards) in preparation of ground contact (Clayton, H. M., & Hobbs, S. J., 2017).

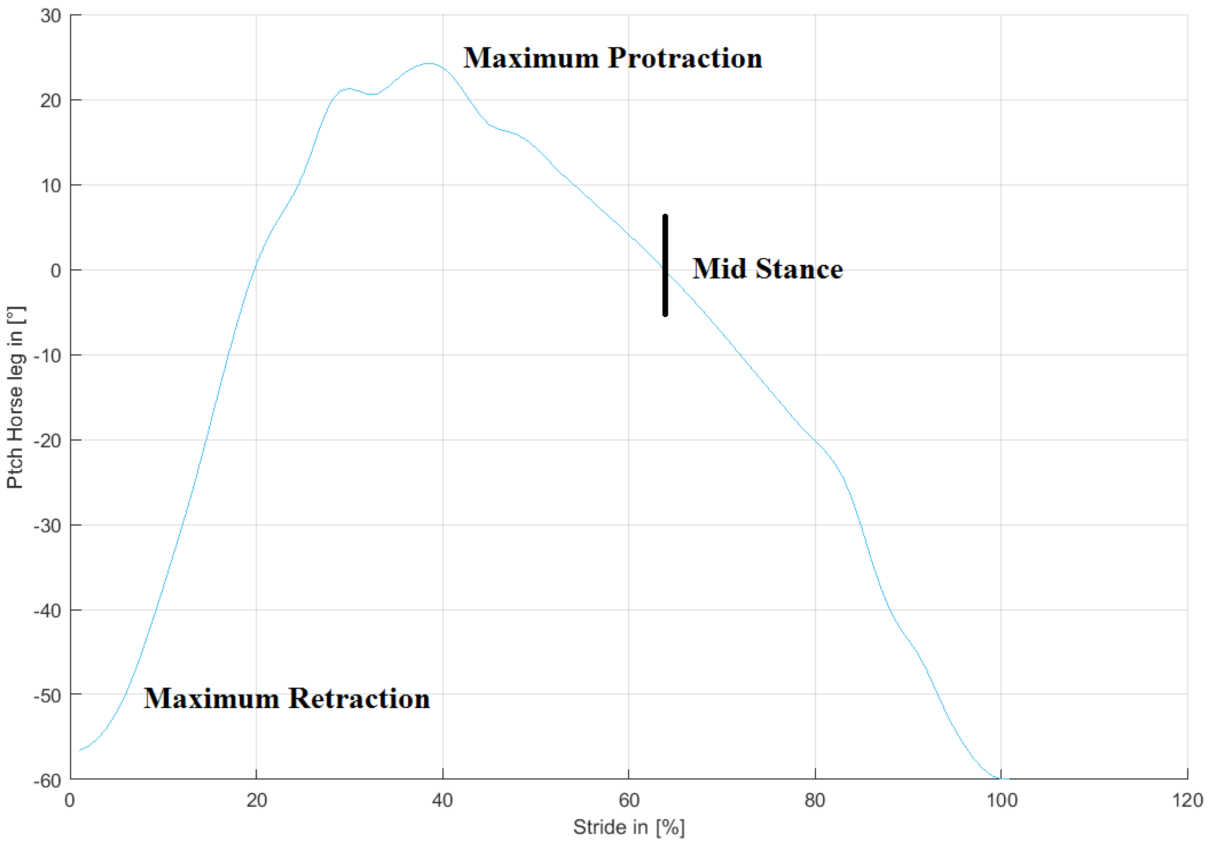


Figure 14: *Pitch Horse leg*

The x-axis ranges from 0-100 %, although there is an overlapping of 20 % of the next step to ensure that the stride split begins at the maximal retraction. Mid Stance is seen at 0°, when the limb stands vertically to the ground.

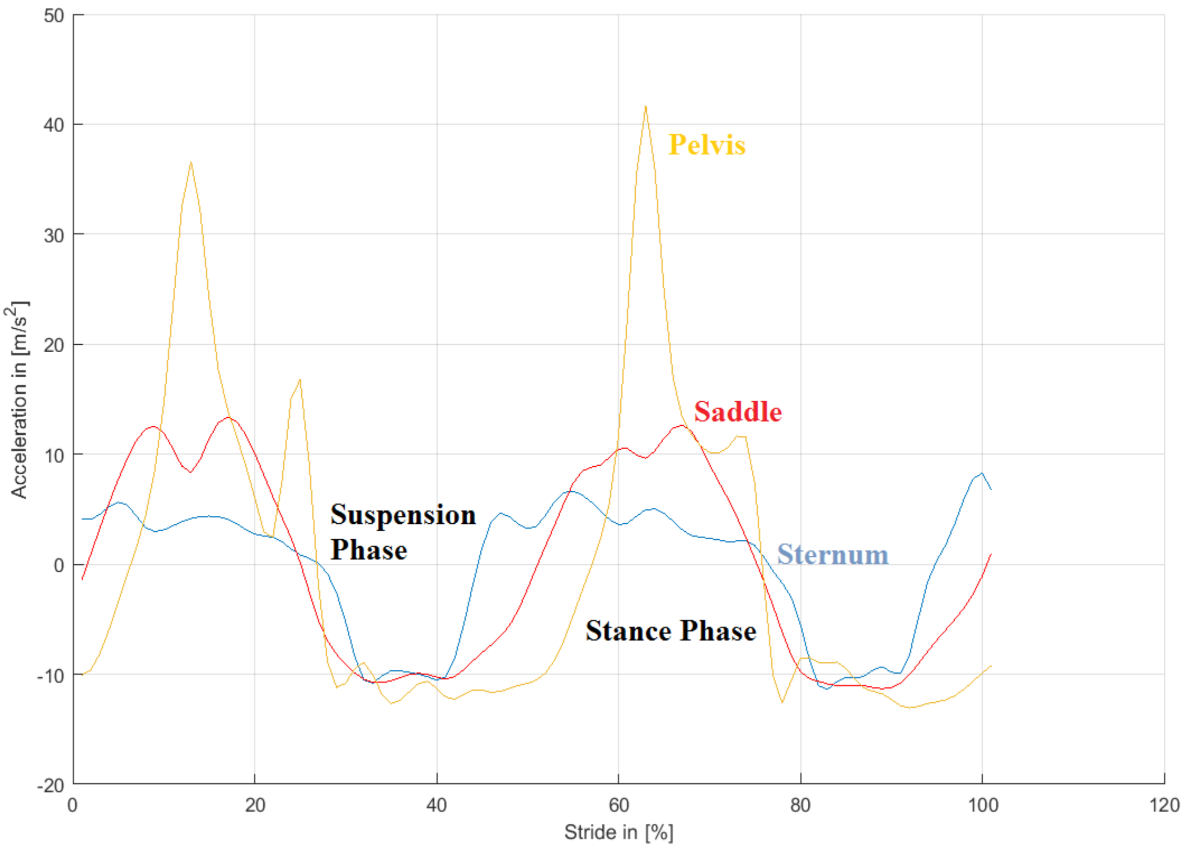


Figure 15: *Stride Split*

The pitch of the horses legs marks the cutting point of the acceleration data for one stride. In each stride cycle, there are two Stance Phases and two Suspension Phases. The highest acceleration of the horse-rider-pair is during Stance Phase, which is the deepest position of the horse and the sensor of the horses sternum. During Suspension Phase, the body of the horse is pushed forward with a partly vertical direction and no limb is in contact with the ground (only gravitational force g= 9.81 m/s^2). The position is therefore the highest when the negative acceleration during the push off phase against the gravity changes into positive acceleration due reaching the peak height and the falling back to the ground. Figure 15 demonstrates the different accelerations of the horse´s sternum (blue), the saddle (red) and the rider´s pelvis (yellow).

4.5.3. FT

The Fourier Transformation of the acceleration data into the frequency domain was done by a pre-coded command. It converts a) the raw data into frequencies and b) contains information about the amplitude, frequency and phase. The number of harmonics is set to 6 (equals three even and three off harmonics). To ensure that only complete strides are used for the analysis, the first and last stride are left out. One stride cycle is from 0-100%.

```
fft_pelvis=fft_decomposition_stride_split(60,index_peak_accel,...
rider_raw.data(:,1),'numOfHarmonics',6,'plot','off')
```

4.5.4. CWT

For the Continuous Wavelet Transformation Matlab offers a Wavelete Toolbox. The program chooses the best fitting Wavelete for the analysing signal by the command *cwt.*

```
[wt_pelvis,f_pelvis]=cwt(mvndata.segments.Pelvis.acceleration(:,3),60);
```

The absolute value (*abs*) is taken from the CWT to get the energy of the signal.

```
cwt_pelvis=abs(wt_pelvis.^2)
```

All complex number are converted to real numbers. The angle is calculated between the Wavelet and the angle of the transformed signal.

```
Phase_pelvis=angle(wt_pelvis);
```

The phase was evaluated at the scales containing most of the energy of the signal (Maxima were found around 40).

```
[M I_Pelvis]= max(cwt_pelvis(1:40,:),[],1);
```

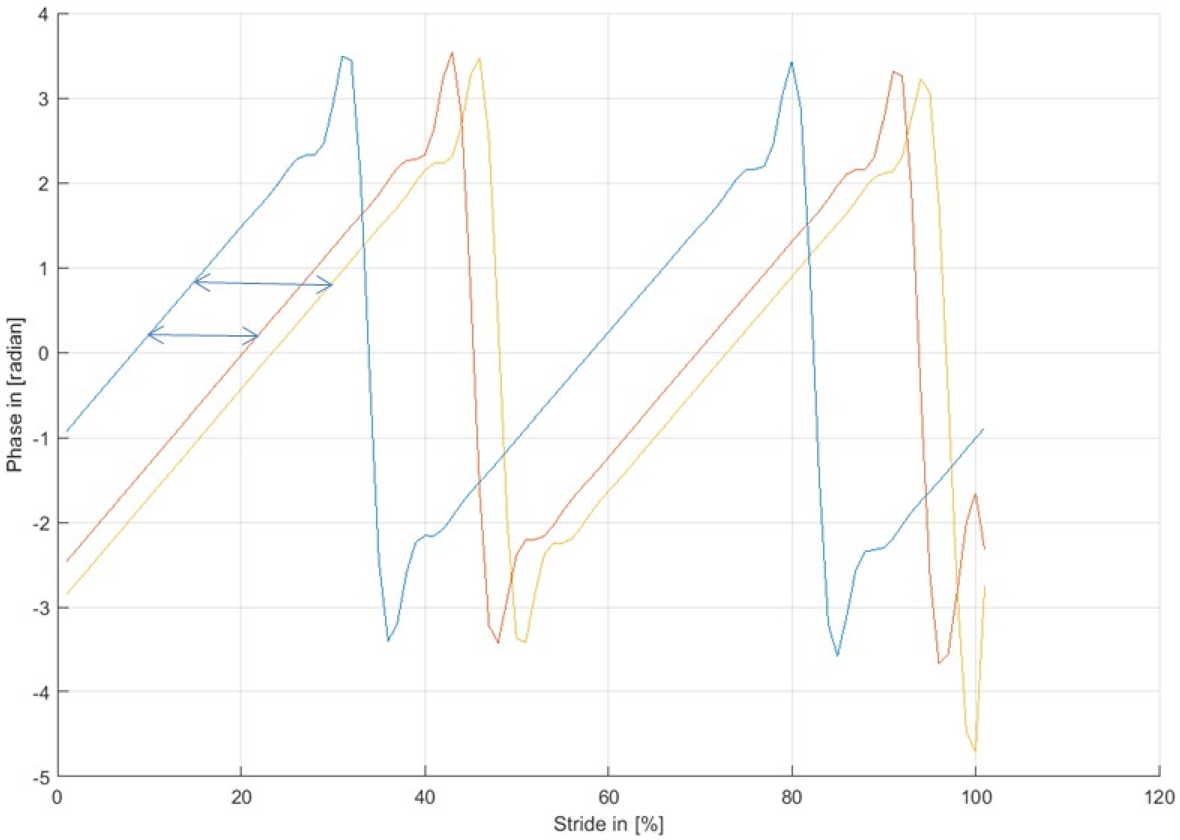


Figure 16: *Phase delay*

The similarity of the three calculated phases (sternum: blue, saddle: red, pelvis: yellow) are a measure for synchronicity, a higher phase shift (blue arrow) indicates less synchronicity. In figure 16, the pelvis would have more phase shift than the saddle.

4.5.5 iHR

The iHarmonic Ratio was calculated based on the advised formula:

$$\frac{\sum_{j=1}^{k}\left(A_I^j\right)^2}{\sum_{j=1}^{k}\left(A_I^j\right)^2+\sum_{j=1}^{k}\left(A_E^j\right)^2}\cdot 100$$

A_I = Amplitudes of the intrinsic harmonics

A_E = Amplitudes of the extrinsic harmonics

k= total number of intrinsic/ extrinsic harmonics

The normalised index ranged from 0% (total asymmetry) to 100%(total symmetry). The complete number of included harmonics is six.

4.5.6. Time-differences

For regularity, all strides of each horse were divided by two to reduce the amount of variance and then the difference between the first peak (`index_accel_peak`) of the first half and the first peak of the second half (following the second peak of the first half and the second peak of the second half...). Measurements were converted from frame rate to the time domain by dividing by 60 (Hz).

```
Number_strides_LO=length(index_peak_accel)
```

Perfect regularity in a horse/rider would result in equal differences between all time points.

```
  If mod(Anzahl_strides_LO,2)==0
% if even
ANS.regelmaessigkeit_time(ii,1)=std(diff(reshape(index_peak_accel(:,1),
[],2),[],2)/((Anzahl_strides_LO)/2))/60;

  elseif mod(Anzahl_strides_LO,2)==1
% if odd
ANS.regelmaessigkeit_time(ii,1)=std(diff(reshape(index_peak_accel(1:end
-1,1),[],2),[],2)/((Anzahl_strides_LO-1)/2))/60;

end
```

4.5.7. ApEn

The complete code is attached to in digital form. Approximate Entropy was pre-coded and added to the script.

4.5.8. Compression

The difference between the maximum head position and maximum pelvis position (Swing Phase) of the rider and the difference of the minimum head position and minimum pelvis position (Stand Phase) were calculated and compared. Forces are acting on the riders back and create a compression when the horse is landing on the ground. In a system without any compression the ratio between both differences would be 1. In reality, the rider tries to reduce the vertical peak force with compensating movements.

```
Diff_Max= Mean_Head_position_Maximum-Mean_Pelvis_position_Maximum;
Diff_Min= Mean_Head_position_Minimum-Mean_Pelvis_position_Minimum;

Diff= Diff_Max-Diff_Min,
```

The position data was taken from MVN data. The double-integrated acceleration data was utilized as a reference to ensure the correctness of the MVN data. Due double-integration the contribution of the noises is raising, therefore the MVN data was used.

5. Results

5.1. Individual Parameter

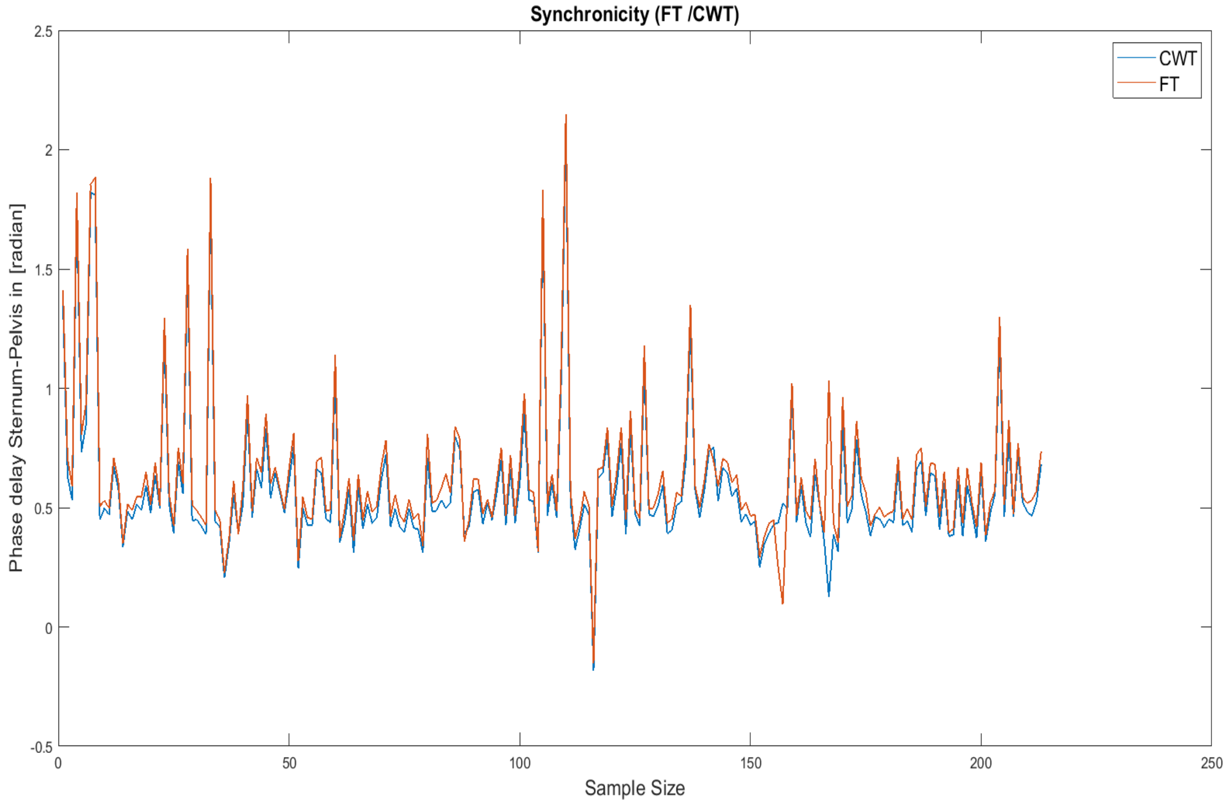


Figure 17: *CWT(blue) and FT(red). Phase delay between the horse´s Sternum and rider´s Pelvis.*

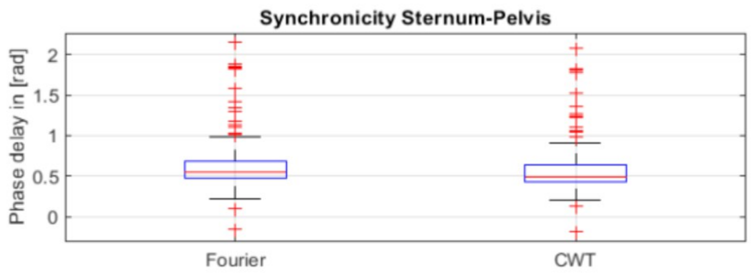


Figure 18: *Analysis of CWT/FT*

Table 4: *Statistics CWT/FT*

Parameter	Mean +/- s.d. (Min, Max)
Fourier	0,63 +/- 0,30 (-0,15/ 2,15)
CWT	0,58 +/- 0,29 (-0,18/ 2,08)

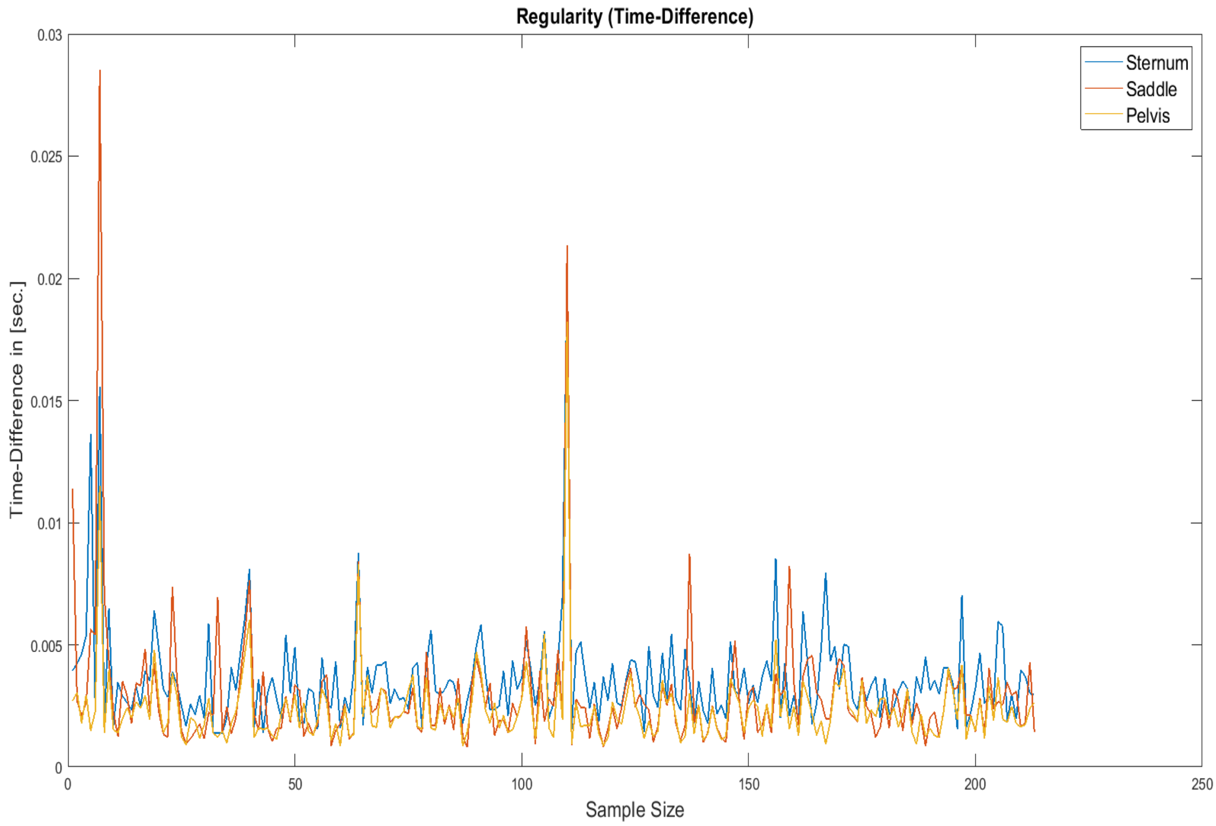


Figure 19: *Regularity calculated by the Time-Difference of the Sternum, Saddle and Pelvis.*

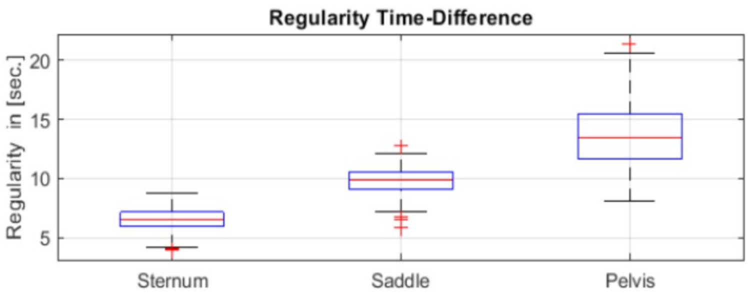


Figure 20: *Analysis of Time-Difference*

Table 5: *Statistics Time-Difference*

Parameter	Mean +/- s.d. (Min, Max)
Sternum	0,0036+/- 0,0021 (0,0014/ 0,0201)
Saddle	0,0029+/- 0,0027 (0,0008/ 0,0285)
Pelvis	0,0024+/- 0,0016 (0,0009/ 0,0182)

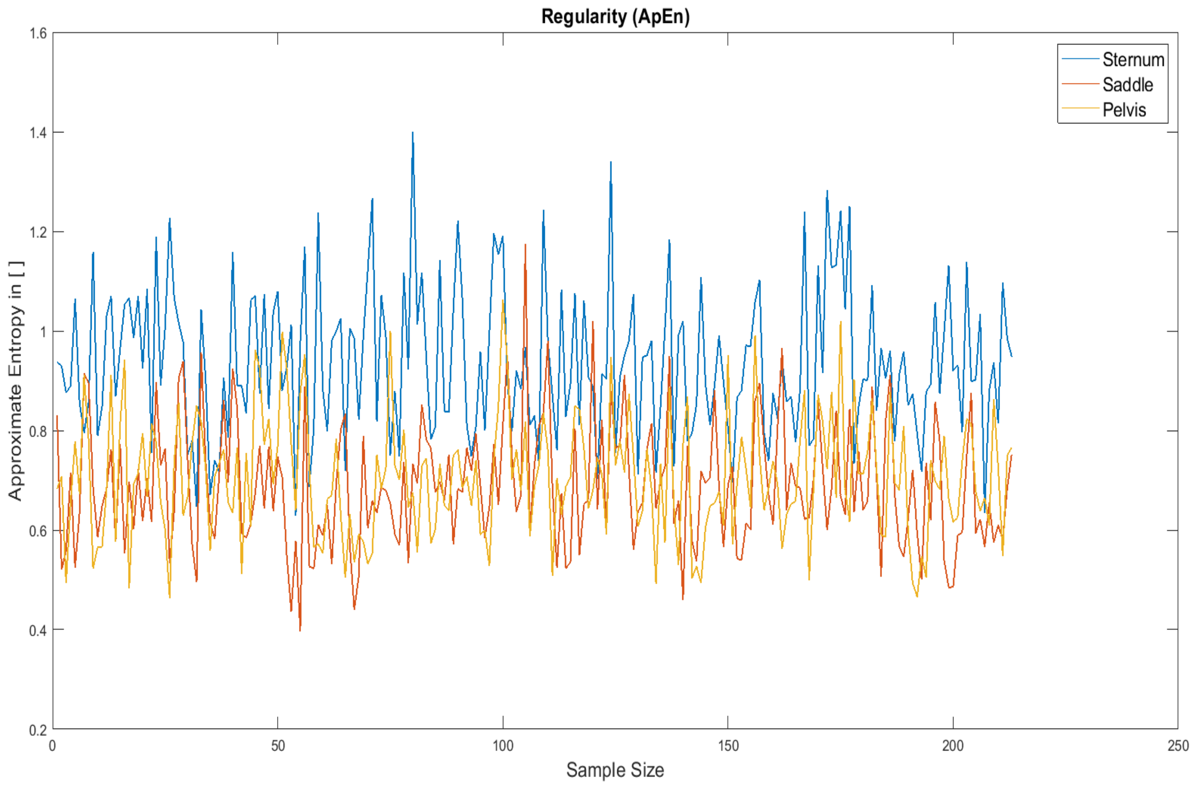


Figure 21: *Regularity calculated by ApEn of the time-series data of the Sternum, Saddle, Pelvis*

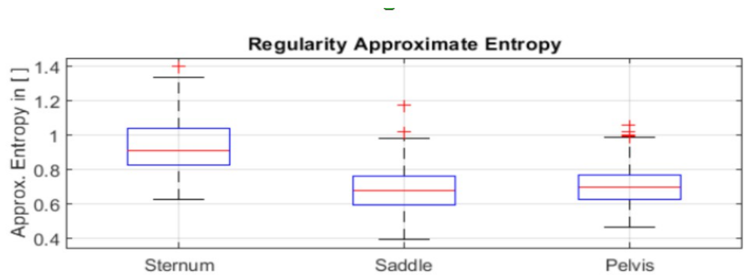


Figure 22: *Analysis of the ApEn*

Table 6: *Statistics ApEn*

Parameter	Mean +/- s.d. (Min, Max)
Sternum	0,94 +/- 0,15 (0,63/ 1,40)
Saddle	0,69 +/- 0,12 (0,40/ 1,17)
Pelvis	0,70 +/- 0,12 (0,46/ 1,06)

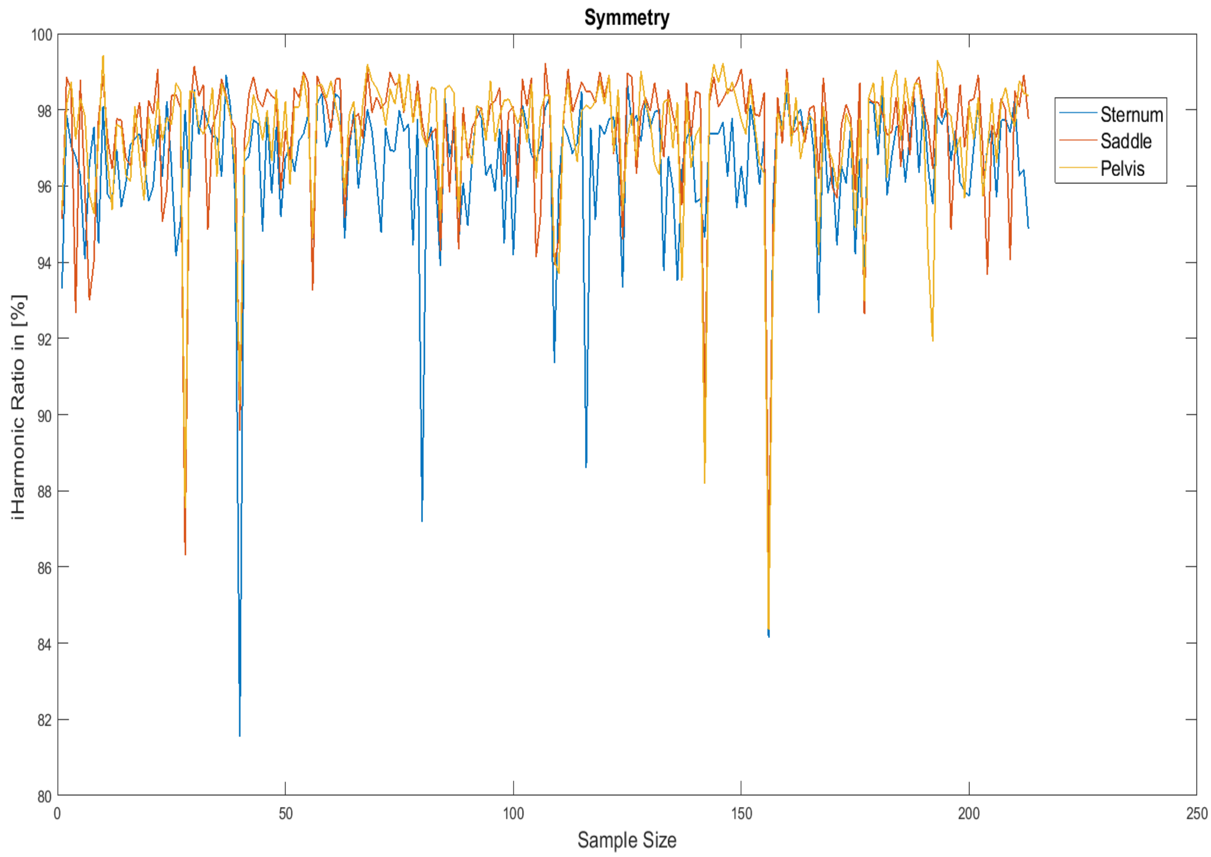


Figure 23:*Symmetry of the Sternum, Saddle and Pelvis by iHR*

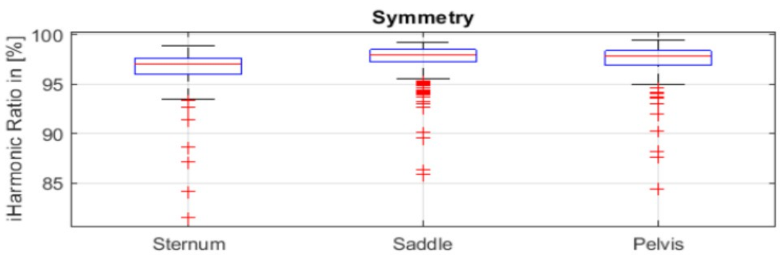


Figure 24: *Analysis of iHR*

Table 7: *Statistics iHR*

Parameter	Mean +/- s.d. (Min, Max)
Sternum	96,55 +/- 2,05 (81,54/ 98,91)
Saddle	97,41 +/- 1,90 (85,89/ 99,22)
Pelvis	97,36 +/- 1,86 (84,36/ 99,41)

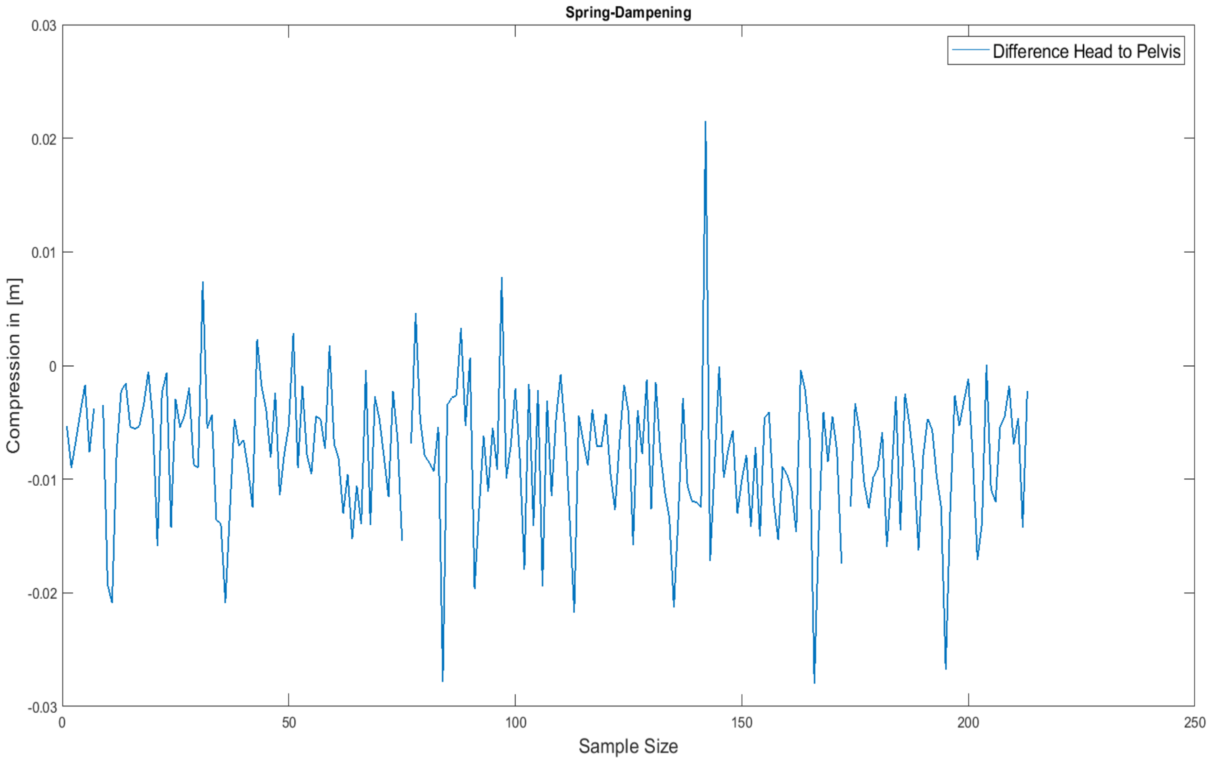


Figure 25: *Compression of the Head and Pelvis of the rider*

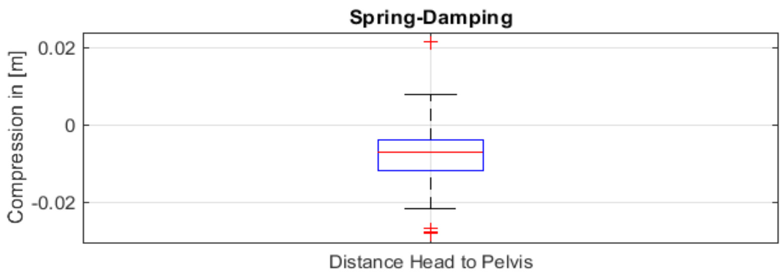


Figure 26: *Analysis of Compression*

Table 8: *Statistics Compression*

Parameter	Mean +/- s.d. (Min, Max)
Head-Pelvis	-0,01+/- 0,01 (-0,03/ 0,02)

5. Results

Obviously, the horse and the rider are a coupled dynamical system which can not be viewed on their own. There are a lot of components that must be noted in respect of defining and quantifying Rider Skills. Especially the interaction of these parameters are dispositive and show sufficient results. The analysis includes data from the left and right rein. The Sample Size represents all horses, where one number stands for one horse.

Synchronicity/Phase shift

Results show that the horses as the locomotion generator prescribed the motion and the saddle and the rider are time delayed. The range of the phase delay computed by the FT (CWT) is from -0,15 (-0,18) to 2,15 (2,08). For calculating the phase shifts between the equine and the rider, the Fourier Transformation and the Continuous Wavelet Transformation were used. Both methods show a high correlation which can be seen in Figure 17 (r=0.9712)

Regularity/Inter-stride variability

The Approximate Entropy and the Time-Difference were used to define Regularity. Figure 19 and 21 demonstrate that the horse (0,0036 +/- 0,0021) is more irregular than the saddle (0,0029 +/- 0,0027) and the pelvis (0,0024 +/- 0,0016). Although a tendency is pointed out, the range of values is comparably small (Sternum: 0,0014 to 0,0201, Saddle: 0,008 to 0,0285, Pelvis: 0,009 to 0,00182). The ApEn underlines the outcome. The average value of the horses sternum (0,94 +/- 0,15) is higher compared to the two other sensors (Saddle: 0,69 +/- 0,12), Pelvis: 0,70 +/- 0,12) which indicates less predictability and therefore less regularity.

Symmetry/ Ratio between even and odd harmonics

The calculated ratio between the symmetric and asymmetric part is ranged from 0 to 100%. The pelvis and the saddle have slightly more symmetrical components in comparison to the sternum, whereby all parts are very close to complete symmetry (Sternum: 96,55 +/- 2,05, Saddle: 97,41 +/- 1,90, Pelvis: 97,36 +/- 1,86).

Spring-Damping-Mass System/ Compression

The distance between the riders head and pelvis increases during Stance Phase and shortens while Suspension Phase. Negative values indicate an elongation of the distance. A minority of the rider shows a compression due horse riding (-0,01 +/- 0,01).

5.2. Correlation between the parameters

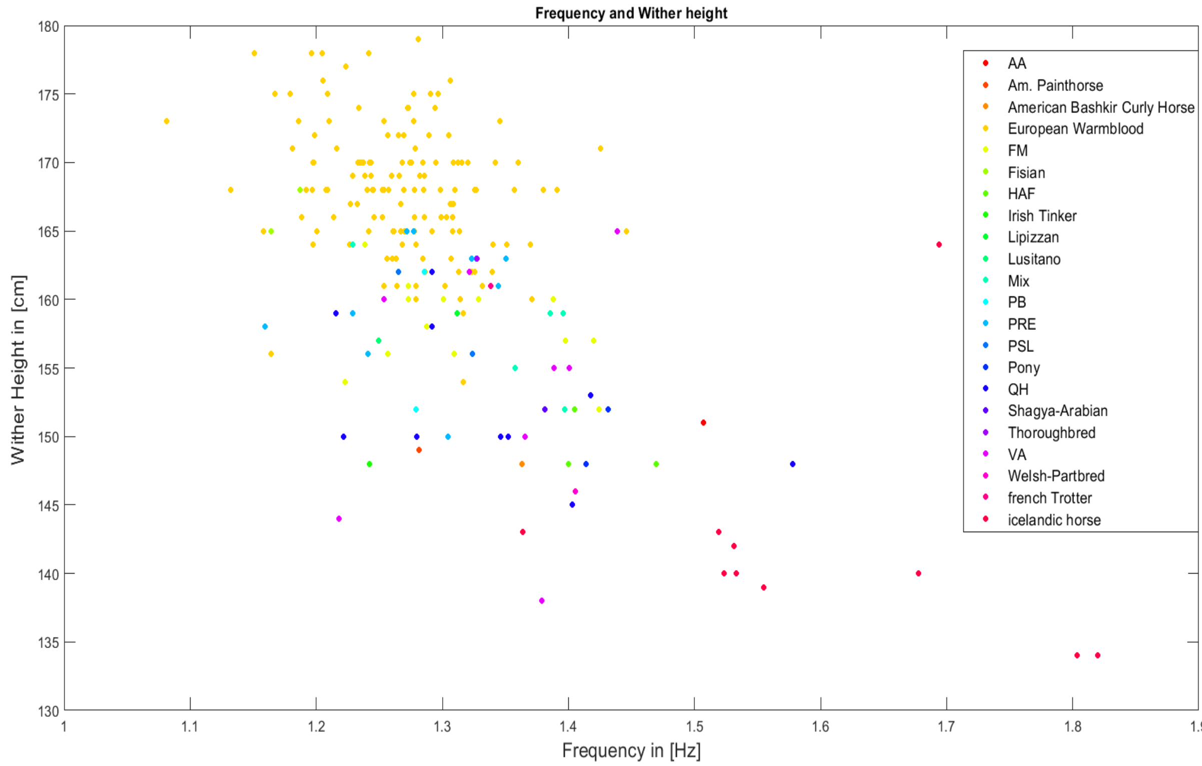
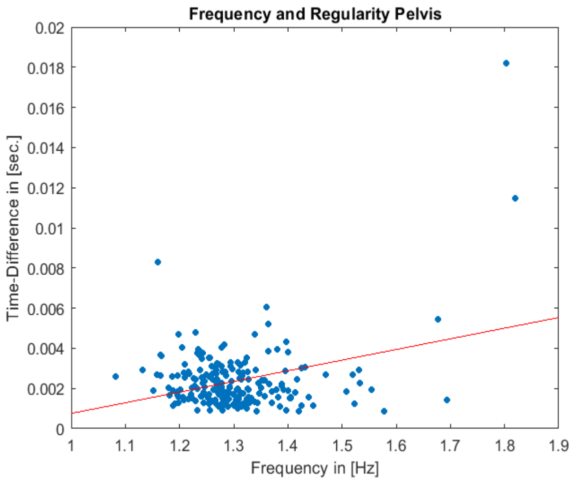


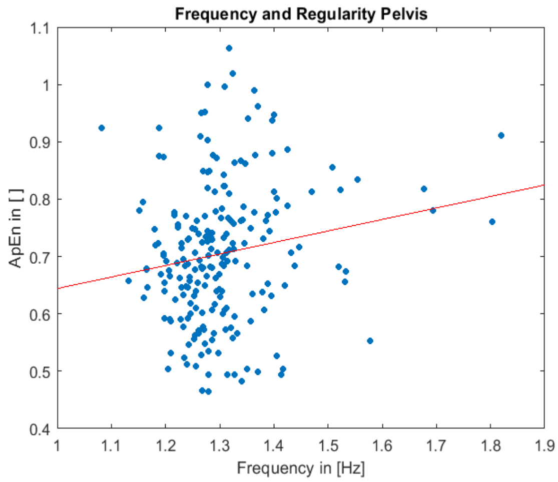
Figure 27: *Breed related wither height and frequencies.*

The relationship between the individual frequency of the horse and its wither height show that a higher frequency (> 1,4 Hz) is mostly associated with minor wither height (<150 cm). Especially the icelandic horses represent the mayor part of the smaller horses and have the tendency to have a higher frequency. The European warmbloods on the other hand have higher wither height and therefore a lower stride frequency (r=0.7084). The relation between stride length, stride frequency and and size has been reported in previous studies.

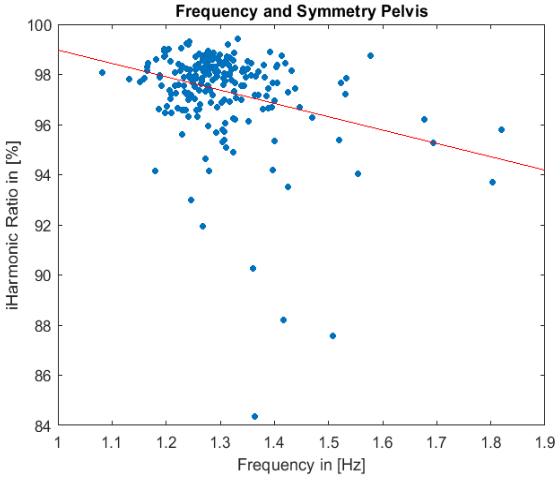
Although these parameters refer to the biomechanical properties of the individual horse, it is an important condition we have to take into account. The unique frequency of each horse has a leading contribution on the Rider Skills and is a given characteristic a rider always has to face with. In the following the relation between the frequency and the calculated parameters is analysed. The acceleration data from the saddle does not let conclude that it has an effect on the horse-rider-interaction, therefore further results will focus on the riders pelvis



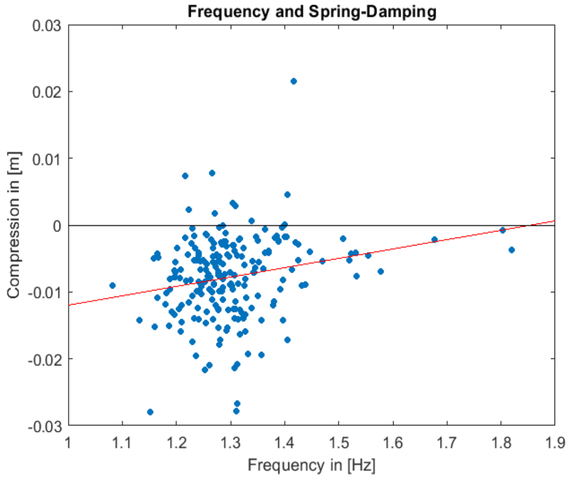
A



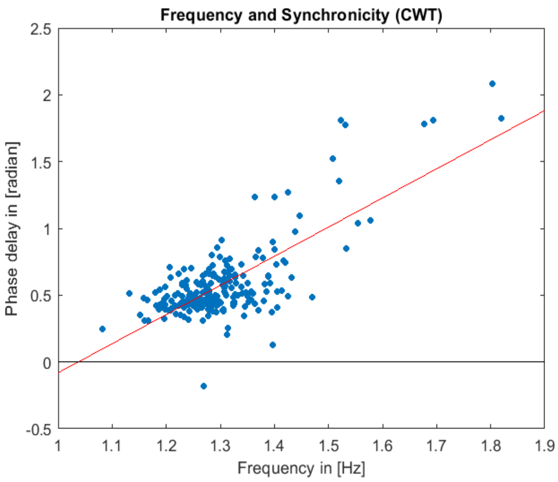
B



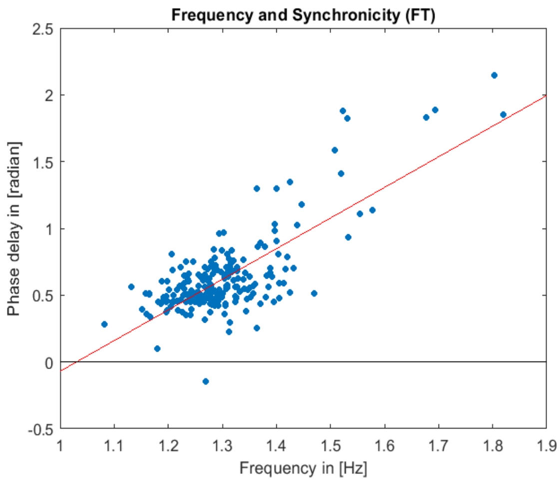
C



D



E



F

Figure 28: *Correlation between Frequency and calculated Parameters.*

The CWT and FT show similar results, therefore in further analysis only the outcome of the FT are used (Figure 28: E and F). The results of the relation between the synchronicity and the individual frequency points that the phase shift between the horse sternum and the riders pelvis is getting bigger with an increased frequency.

The frequency has influence on the symmetry and the regularity (ApEn and Time-Difference). Lower frequencies are likely to have a more regular and symmetrical pelvis (Figure A, B and C).

A correlation matrix was conducted to compare the relation between all parameters (Symmetry, Synchronicity, Regularity and Spring-Damping). The correlation matrix can be seen in the Appendix. Parameters with a higher correlation factor than r=0,23 are presented in the following figures.

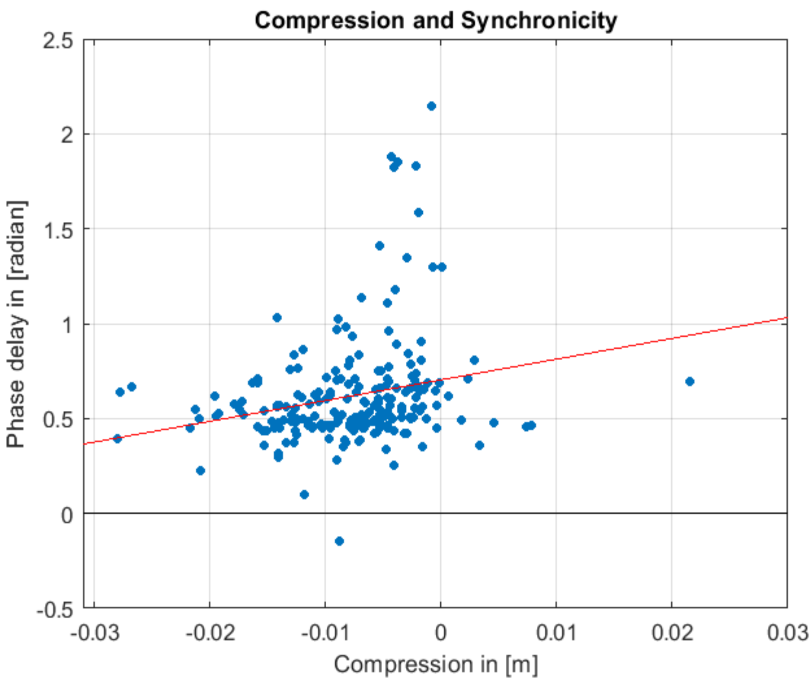


Figure 29: *Correlation Spring-Damping and Synchronicity*

Higher phase delay is associated with a more compressed body posture. An extended distance between the head and the pelvis on the other hand result in more synchronicity. Zero compression, which means no distance change between the two points, is still characterized with a phase delay (figure 29). The correlation value is r=0.23.

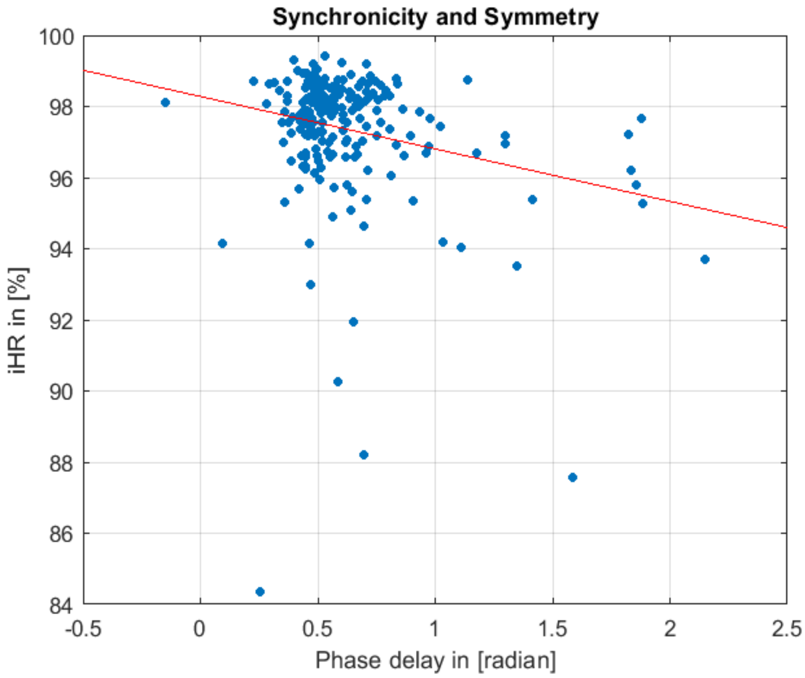


Figure 30: *Correlation Synchronicity and Symmetry*

The iHarmonic Ratio was the ratio between the symmetrical part divided by the sum of the symmetrical and asymmetrical part. The symmetric motion pattern of the pelvis decrease during an extended phase delay (r=-0.24)

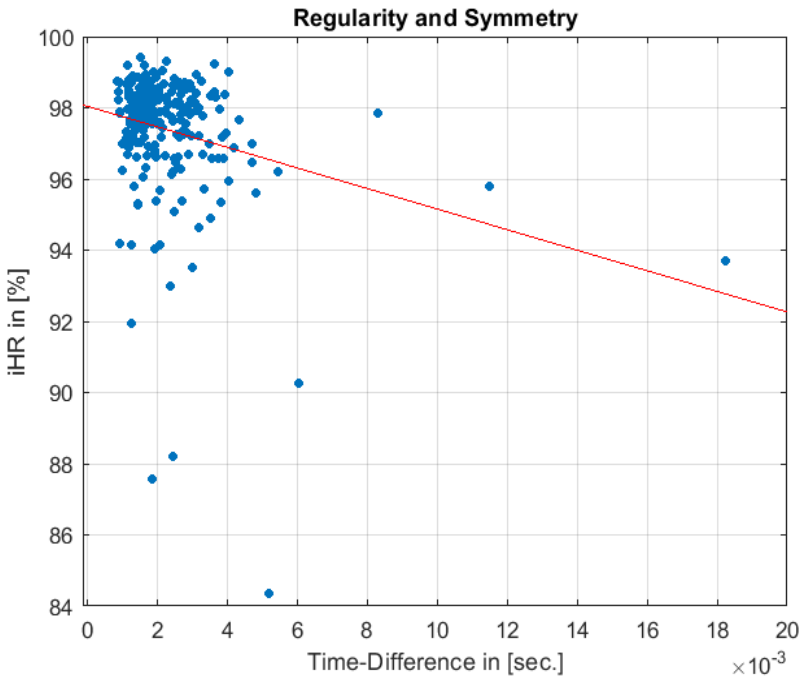


Figure 31: *Correlation Regularity and Symmetry*

In figure 31 it can be seen that a bigger inter-stride time variability leads to lower iHarmonic Ratio value (r=-0,25). Even though a tendency is reported, the riders pelvis shows a high symmetry and regularity.

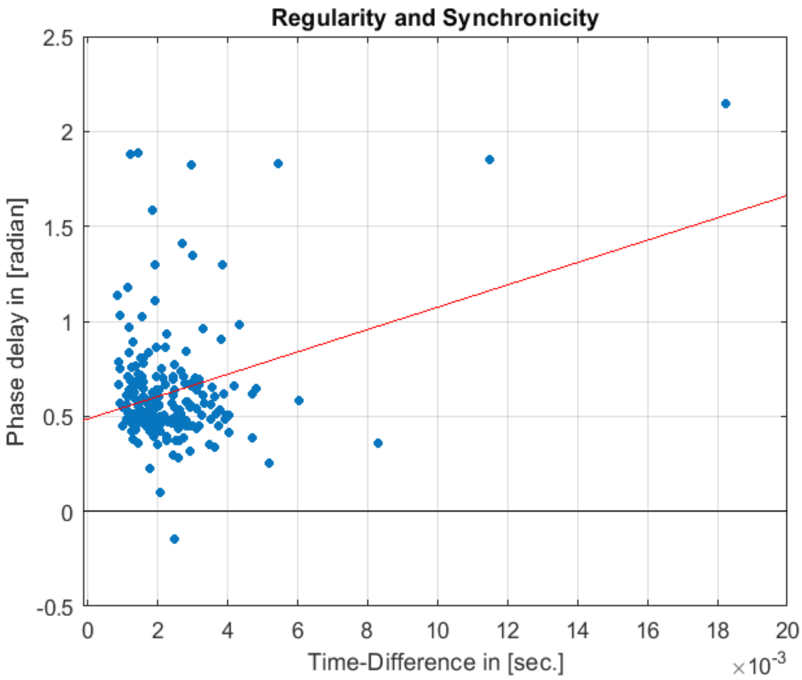


Figure 32: *Correlation Regularity and Synchronicity*

Figure 32 depicts the synchronicity between the horse sternum and the riders pelvis and the regularity of the riders pelvis. The interrelationship has the highest correlation value with r=0,32.

6. Discussion

Equestrianism is an extremely subjective sport. Until now, the quantification of good rider skills remains challenging because of its complexity of the horse-rider coordination system and the big amount of dependent factors. A good physical fitness is the baseline for every horse rider, additionally a good motor coordination and adaptation are demanded for appropriate responses to the horses motion. A lot of research has been done to highlight certain aspects of the relationship between animal and human to better understand how the biomechanical properties of the pair influences each other. But still there is a lack of information concerning a definitely definition of Rider Skills.

The use of Inertial Measurement Units

Since there is a development in the technical area, it is possible to measure under field conditions. The traditional motion capture systems are very expensive, need time consuming calibration and suffer from their limitation of laboratory conditions. The video-based measurements are carried out on a treadmill that creates unnatural circumstances and only provide a prescribed speed. The implementation of light and low-cost IMUs have been done in earlier studies and are also used for data collection in this study. Brighton and colleagues attached IMUs on the rider pelvis to examine the rotation compared to the horses trunk movements. Results indicate sufficient precision (Brighton, C., Olsen, E., & Pfau, T., 2015). In our study, IMUs were attached on the horse´s sternum and saddle and the rider´s wore the “AWINDA” version. The MVN Analyze software calculates the the velocity and position of the sensors. Our self integrated values correlate with the MVN data.

The frequency as baseline

Our results show that the stride frequency and the wither height have an big impact on the ability to adapt the motion patterns. Especially the gaited horses have an increased frequency and rider tend to have a higher phase shift. Even though asynchronicity is an indicator for poor horse riding, we always have to bear in mind the horse and its locomotion properties. The outcome demonstrates that at a certain frequency it seems to be challenging for a rider in general to synchronize with the certain movement pattern. In respect of the different training goals, gaited horses are more often trained in their additional gaits tolt and pace than in normal trot. Therefore it may also be more challenging to have a smooth movement at the same constant velocity.

The Continuous Wavelet Transformation as an alternative to Fourier Transformation

During literature search, the CWT was mentioned to be more accurate in respect of abrupt changes. For reference we also calculated the phase shift with the FT, as it is well established in the analysis of gait locomotion of humans and animals. Keegan and colleagues investigated wavelet transformation to detect forelimb lameness in equines (Keegan, K. G. et al., 2003). Wavelet filtering has also been used to denoise acceleration data (Kruse, L., Salau, J., Traulsen, I., & Krieter, J., 2012). Our results have a strong correlation between the phase shifts calculated by the Wavelet Transformation and the FT. Therefore the CWT is a useful tool for extracting frequencies, especially because it also includes the local time based information about a signal.

The inter-stride time variability and the ApEn as a criterion for regularity

The regularity describes the inter-stride variability that is expressed by a) the time-difference and b) the Approximate Entropy. Concerning the raw acceleration data, the peak vertical acceleration of the rider´s pelvis is much higher compared to the acceleration of the horse´s sternum. The smaller amplitudes are more affected by noises in the signal which can result in an increased ApEn value compared to bigger amplitudes with same noise signals. The higher irregularity of the horse could be explained by technical miscalculation resulting from the noises in the signal.

The potential of the Spring-Damping Systems

We consider all described parameters as important factors to define Rider Skills, nevertheless, further research is needed in the area of spring-damping-mass-systems. We see a lot of potential in the implementation of such models but are also aware of the difficulty and complexity. First studies presented simulated models that examine the stiffness and dampening of the horse-rider-system and compared these with experimental data. Although the model provides insight of the biomechanical requirements of a rider, it demands a lot of investigations. The amount of spring and dampers in a horse make it very challenging to create a realistic model because a lot of biomechanical properties have to be considered. For example the digital flexor tendon of a 500 kg horse stores 1000 J of elastic energy during touchdown. This is achieved by gravitational and inertial forces that extend the metacarpophalangeal joint and stretch the collagenous structures. Studies have shown that a peak tendon strain of 8- 12% during locomotion equates to a tendon elongation of 7 cm (Wilson et al., 2001). The rider itself is a spring-damping-mass system. The vertical displacement is a combination of the riders mass and stiffness. Therefore we implemented compression as a measure to describe the spring-damping system. Interesting results were found regarding to the compression of the riders body due sitting trot. The distance of the head and the pelvis at maximum position and the distance at the minimum position were compared. No compression during the whole motion cycle would lead to zero length change. Surprisingly, the compressions happens in both directions. Negative values indicate an elongation of the head-pelvis distance. Possible causes could be different mechanisms the rider use to reduce the impact. Compensatory movements can whether happen by moving/rotating the pelvis or by nodding the head. It is also depending on the exact location of the IMU on the helmet. Measurements on the front can lead to different results than collected data from IMU that are attached on the back of the helmet. For a better understanding of the different mechanisms and the related biomechanical changes further investigations are needed.

The thesis examined different parameters that are significant for the quality of horse riding. But as mentioned in the introduction there are many other factors that have a tribute to the riders performance.

Horse related factors

To a certain point, the horse is decisively for the Rider Skill. Not only the age, the skill level or the breed specific temperament are significant, but also the body posture. A horse with a high neck position and a lot of tension in the back is more difficult to ride in sitting trot compared to a low neck position. The riding comfort is given to some extent by the horses biomechanical property of the horses locomotion. Equines with a lot of impulsion create a high vertical acceleration and are more exhausting than for example the icelandic tolt, where no Suspension Phase is present.

Saddle related factors

6. Discussion

Acceleration data of the saddle was used to quantify Rider Skills. The saddle fit was checked before to exclude the influence of the saddle because of poor fitting. The analysis of sensors reported less impact of the saddle on the horse-rider-interaction, although we cannot deny a certain effects. Up to a certain point, the saddle can nod up and downwards and exhibit side-to-side movements (Dyson, S., Ellis, A. D., Mackechnie‐Guire, R., Douglas, J., Bondi, A., & Harris, P., 2019)

The environment

The study was carry out in different riding stables. Mostly, sand is used as surface in the arena. But in some cases stables, especially jumping stables, have a mixture of damping material like felt and sand to reduce the high load of the horses limbs during show jumping. During the riding, the surface gets holes and rough. Although the sand was straightened after a certain number of horse-rider-pairs, a change of the surface property can not be excluded.

In order to establish a more detailed understanding of the interrelationship, additional validation of the parameters are needed to . The results of the pressure distribution mat could give a better insight look of the biomechanical properties of the rider. It documents vertical peak forces and the pressure distribution over time. Connected to our findings, it might help to understand the different compression methods and the relation to frequency and synchronicity. Additionally, the different rider could be separated into different skill levels based on their questionnaire and compare our outcome of good and bad horse riding with their expertise.

7. Conclusion

Current findings seem to indicate that Inertial Measurement Units and the included MVN data package provide a sufficient method of mapping the horse-rider interaction. The high number and diversity of the participants reflect a realistic population contribution of breeds, riding disciplines and skill levels. Although it is still challenging to quantify Rider Skills, first steps are made. The four calculated parameter have adequate information about the interaction, but still more research is needed in the Spring-damping system. But nevertheless, the compression, we used as a simplified method to describe spring-damping, let conclude that the rider is using different movement pattern during sitting trot. The CWT and the ApEn are new tools and were successfully integrated into the analysis.

7.1. Limitations

The aim of the overall study was to get overview of the swiss horse population in respect of back health. All participants were aware of the examinations of their horses. We consider that recruited subjects have an interest in the welfare of their horse and routines saddle and health checks. The yearly participation on competition and taking training lessons underline these assumptions.

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10. Appendix

Riding protocol

Dressurprogramm Rückenstudie

A Einreiten im Schritt (am Zügel), X Halt und Unbeweglichkeit
Anreiten im Schritt (am Zügel), C auf rechte Hand
M-F-K Schritt (am Zügel)
K-X-M durch die ganze Bahn wechseln im Schritt (am Zügel)
M-H-K-A-F Schritt (am Zügel)
F-X-H durch die ganze Bahn wechseln im Schritt (am Zügel)
C Arbeitstrab antraben (leichtreiten)
M-F-A Arbeitstrab leichtreiten
A Arbeitstrab aussitzen
K-X-M durch die ganze Bahn wechseln im Arbeitstrab aussitzen
C Arbeitstrab leichtreiten
C-H-K-A Arbeitstrab leichtreiten
A Arbeitstrab aussitzen
F-X-H durch die ganze Bahn wechseln im Arbeitstrab aussitzen
C Arbeitsgalopp rechts angaloppieren über M, F nach A
A auf die Volte (Durchmesser A-X), einmal herum
A geradeaus
K-X-M durch die ganze Bahn wechseln, X Arbeitstrab aussitzen

C Arbeitsgalopp links angaloppieren über H, K nach A
A auf die Volte (Durchmesser A-X), einmal herum
A geradeaus
F-X-H durch die ganze Bahn wechseln, X Arbeitstrab aussitzen
C-B Arbeitstrab leichtreiten
B rechts um, vor X aussitzen, X Halt und Unbeweglichkeit

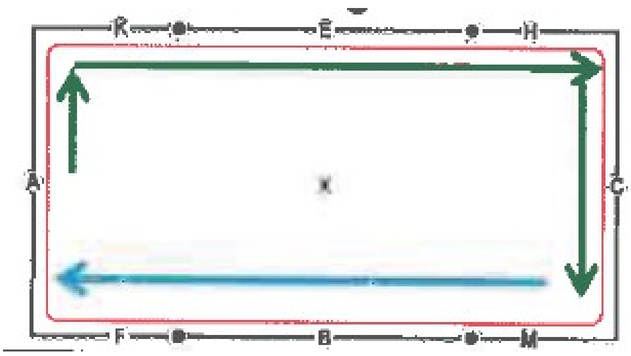

Figure 1: *Riding protocol. Blue arrow indicates measuring line.*

Correlation Matrix

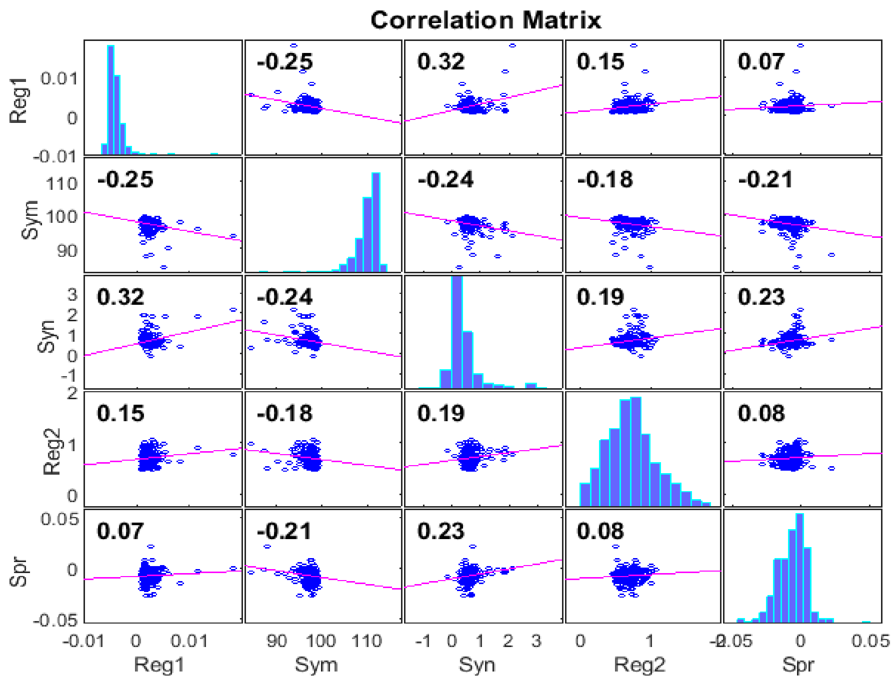

Figure 2: *Correlation matrix. Reg1: Time-Difference, Sym: Symmetry, Syn: Synchronicity, Reg2: ApEn, Spr: Spring-damping. Number indicate Correlation Value.*