Katholieke Universiteit Leuven

Faculteit Bio-ingenieurswetenschappen

Towards objective draught performance measurement in heavy horses

(Naar een objectieve trekprestatiemeting bij zware paarden)

Promotoren: Prof. Dr. ir. Wouter Saeys
Dr. ir. Steven Janssens

Departement Biosystemen
Afdeling Mechatronica, Biostatistiek en Sensoren

Masterproef voorgedragen
tot het behalen van het diploma van
Master of Science in de bio-ingenieurswetenschappen:
biosysteemtechniek
Zhao Ying Cui

Juni 2012

“D*it proefschrift is een examendocument dat na de verdediging niet meer werd gecorrigeerd voor eventueel vastgestelde fouten. In publicaties mag naar dit proefwerk verwezen worden mits schriftelijke toelating van de promotor, vermeld op de titelpagina.*”

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For the technical and sometimes less technical support I would certainly want to mention Frank Mathijs, Soner Akpinar and Dirk Leroy who were always very friendly and willingly to help whenever a problem occurred.

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One person that is not quite related to the thesis development but who had a very big role in my path in becoming a biosystems engineer is Servaas Vochten. Thanks to him and his tutoring I got the chance to catch up with some physics knowledge after high school and so dare to try out for the major within bio science engineering with the most physics.

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Furthermore I would say that I’m morally obligated :p to mention my family: my mommy and my big sis for well yeah being just them, being a helping hand whenever needed and of course for all the delicious food that my mommy made which is highly necessary for basic survival. 妈咪你好牛逼^^! And not to be forgotten, my kung fu Daddy, 罗老师 for being so kungfuwie and caring.

My roomies from house Awesome should not be forgotten! Eano (aka Sam, but who uses that name anyway), Tennis (aka Nina) and Nicora-chan (aka Nicolas) who are just so awesome and by being that awesome they have been my support and smile throughout this wonderful year.

那么我这里再写一段中文吧，反正大家都读不懂，很好奇的人肯定会用字典翻译这一段。但是很抱歉这里真的没写什么。论文吗，也应该有一点搞笑的地方，太认真的话对心脏不好。

Last but not least, special thanks to a special person, 一不. I could write a complete book here but let’s keep it short, thanks for everything ☺.

Abstract

Upcoming reemployment of draught horses in urban tasks on one hand and on the other hand purely subjective studbook inspections both ask for the development of an objective measuring technique to assess draught performance of heavy horses.

In this study the first step is made towards a biomechanical analysis where both force and motion analysis are included. Most importantly the combination of those two and the effect of the horses' dimensions was also studied. Steady state force (ranging from 52.41N – 3598.55N) has a positive relation with the takeoff force (ranging from 159.59N – 6866.80N) which is not surprising. Furthermore larger horses have a lower maximum takeoff force and the variation on the steady state pulling force is also less. This is probably due to the fact that bigger horses can put their weight more into the harness so that they can takeoff with less shocks. The dimensions of the horse are also strongly correlated meaning that a tall horse will also be longer and have a bigger chest circumference. The combined motion and force analysis did not give conclusive results probably due to the non optimal experimental set up and the low degree of standardization of the different set ups where the most important factor was the different types of load (cart, plough and sledge) which gave forth a big difference in force profile against expectations.

An improved experimental set up is suggested at the end of this thesis study. The suggested motion parameters all showed significant difference among individual horses which means that they can be used as valid individual parameters in a more standardized experiment. This should include a standard load to pull, the same soil and a predefined track in addition to the experimental set up used in this thesis. With regards to the motion analysis the lowering of the hind quarters would be a good additional parameter. Since this was an experimental study the number of observations was rather limited, this should certainly be avoided in future experiments so that outliers can be averaged out more.

Samenvatting

Opkomende hergebruik van trekpaarden in de stedelijke taken aan de ene kant en aan de andere kant zuiver subjectieve stamboekkeuringen vragen allebei naar de ontwikkeling van een objectieve meetmethode om de prestaties van trekpaarden te beoordelen.

In deze studie wordt de eerste stap gezet naar een biomechanische analyse die zowel kracht- als bewegingsanalyses omvat. Het belangrijkste is de combinatie van deze twee en het effect van de paardenmaten die eveneens worden bestudeerd. Steady state kracht (variërend van 52,41N tot 3598,55N) heeft een positieve relatie met de aanzetkracht (variërend van 159,59N tot 6866,80N) wat niet verrassend is. Verder hebben ook grotere paarden een lagere maximale aanzetkracht en de variatie op de steady state trekkracht is ook minder. Dit is waarschijnlijk doordat grotere paarden hun gewicht meer in het harnas kunnen zetten en zo minder schokkend kan vertrekken. De afmetingen van het paard zijn sterk gecorreleerd wat betekent dat een groter paard ook langer zal zijn en een grotere borstomvang zal hebben. De gecombineerde beweging en krachtanalyses gaven geen uitgesproken resultaten wat te wijten is aan de niet optimale experimentele omstandigheden en de lage mate van standaardisatie van de verschillende opstellingen waar de belangrijkste factor de verschillende soorten belastingen (kar, ploeg en slee) was. Deze gaven namelijk een groot verschil in kracht profiel.

Op het einde van deze thesisonderzoek werd een voorstel gemaakt naar een verbeterde experiment in de toekomst. De voorgestelde bewegingsparameters verschillen allemaal significant tussen individuele paarden waardoor ze gebruikt kunnen worden als geldige individuele parameters in een meer gestandaardiseerd experiment. Dit omvat een standaard te trekken belasting, dezelfde bodem en een vooraf aangelegde route bovenop de experimentele set up die gebruikt werd in deze thesisonderzoek. Met betrekking tot de bewegingsanalyse zou het zakken van de achterhand een goede extra parameter zijn om op te volgen. Omdat dit een experimentele studie was, waren het aantal waarnemingen vrij beperkt. In de toekomst zou dit best worden vermeden, zodat uitschieters uitgemiddeld kunnen worden.

List of abbreviations

SSF = Steady state force

TOF = Takeoff force

SSDEV= Steady state force deviation

minNW = minimum distance between the nose and the withers

AH = angle of the head relative to the horizontal line of the withers

minWH = minimum distance between the withers and the hind leg

maxWH = maximum distance between the withers and the hind leg

minAF = minimum angle of front leg relative to the horizontal line of the withers

maxAF = maximum angle of the front leg relative to the horizontal line of the withers

AF = angle difference between the maximum and the minimum

c = cart

p = plough

s = sledge

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1 Introduction

For centuries horses have been a loyal partner for human kind in labor and war because of their enormous power capacity, stamina and speed. On the country sides they were used for agricultural operations, on the road as transportation mean and during war as brothers in battle. Horses were often considered more than just a pet. For some nobles the horse was a sign of wealth and status and for the common farmer he was a part of the family. Decennia's later the industrialization introduced huge machines capable of power generation over hundred times more than that of a horse, speed faster than any horse could run and this hour after hour, day after day without needing to rest. So the horse gradually lost its function and usefulness in society. The draught horse in particular, bred for plowing lands and puling carts was one of the first that had to resign from the work he was bred to do. Horses were now merely kept for fun and recreational ends.

Nowadays with the rising issue of global warming people are trying to find alternatives to replace internal combustion engines in all the domains of life. Urban duties where speed is of underlying importance (such as garbage collecting, watering plants,…) are opportunities to reemploy horses. They have the advantage of low emission, production of renewable energy,… The reemployment of horses also asks for a method for objective draught performance assessment which is not available yet so that people have to rely on personal experience and 'urban knowledge' in their search for the proper horse. Next to that, in the hobby sector, draught horses are bred for their looks according to exterior standards that have lost their functional meaning. So the development of an objective draught performance test could also be used during studbook inspections as a test towards their work capabilities. The aim of this thesis is to set the first step towards the development of such a test.

The second section describes the usage of draught horses throughout the ages and the domains where draught horses are present. Next section gives a multidimensional perspective on the usage of these horses covering harness, exercise physiology, exterior, character and biomechanical aspects where the latter will be of biggest importance for this study. The fourth section will describe the scientific aim of this thesis followed by the materials and methods section. After that the results and discussion are handled in section six and the last section formulates the general conclusion and the suggestion for an objective measurement technique for the assessment of draught performance of heavy horses.

2 Historical perspective of usage of draught horses

2.1 Past

Cooperation between man and horse began due to the ability of horses to work and respond to human commands. Selective breeding over many centuries resulted in the appearance of different breeds within the same species. The heavier horses whom are suitable for draught work are a product of many centuries of breeding war horses. They needed to be bigger to carry the armored knights and with this increased weight also came bigger power capacity. (Smil, 2000)(Peerlings, van der Weerden, & van Hoof, 2008)

Selective breeding of draught horses had the aim to produce animals capable for long sustained sub maximal exercise at low speeds against high external forces. Horses are excellent draught animals because their front ends are heavier than the back which is a great advantage in inertial motion. Compared to cattle horses live longer and have greater endurance which make them more suitable for the work than cattle. Due to the large nutritional needs of horses and the use of wooden ploughs, which generates enormous friction compared to steel ploughs, it still took a while before horses became the dominant source of labor on the field. (Potard, Leith, & Rog, 1998)(Smil, 2000)

The early stages of industrialization were also characterized by the presence of the horse. The 19th century was marked by the advent of the big stationary steam machines and horses were used for transporting the commodities and products to and away from the factory. Other means of transportations were also facilitated by the draught horse such as transportation at harbors where they had to drag the shiploads, travelling where they pulled carriages and covered wagons for the transportation of multiple persons or for the work in mines.(De Brauwer, 2004)(Peerlings, van der Weerden, & van Hoof, 2008)

During the second half of the 19th century the tillage sector also underwent big changes. The industrialization made it possible to produce better working instruments which lead to improved production methods. This meant that for the same amount of time bigger areas and new crops could be cultivated, at the same time there was a rising population and a mainstream moving out from the country side to work in the city. All these facts made the horse a key factor for achieving more work and results. Next to that the plough was also greatly improved but also became bigger and heavier at the same time so the demand for bigger and stronger horses rose, especially on heavy soils. The result was horses with heights ranging from 1m60 up to over 2 meters at withers and a body weight between 700kg and 1500kg. (De Brauwer, 2004)(Peerlings, van der Weerden, & van Hoof, 2008)

Later on, due to further industrialization, the real horsepower was gradually being replaced by steam engines, internal combustion engines and electric motors. (Smil, 2000) (De Brauwer, 2004) (Peerlings, van der Weerden, & van Hoof, 2008)

2.2 Present

The original breeding purpose of draught horses no longer matches the current usage of these giants anymore although there is a movement towards reemployment of draught horses in daily life. Even with the obvious advantages that machines have compared to horses there are still areas where the horse is used untill today.(De Brauwer, 2004)(Peerlings, van der Weerden, & van Hoof, 2008)

One of the best examples is the forestry where the horse is sometimes prefered above machines because of their agility so they can reach places that are very hard to access for heavier machinery. Land owners often prefer horses because they do less damage to the forest than the machines due to their lower weight. One horse can tow away about 25 to 100 m^3 a day depending on the soil, size of the trees and his training. Other advantages of the usage of horses in the forestry are less soil compactation, no pollution, lower investements, preservation of the profession and renewable energy. (De Brauwer, 2004)(Peerlings, van der Weerden, & van Hoof, 2008)(Talpe, 2011)(Odeur, 2011)

In the tillage, the usage of horses is not that common anymore. The ones who still use these giants do it for hobby purpose or because of their religion (Amish people in Amerika). The latest intrest in bio food and eco-way of producing all kinds of food make it possible for some farmers to reuse horses on the land. (Peerlings, van der Weerden, & van Hoof, 2008)

The biggest reason why draught horses are still kept, is for hobby purposes. The Power Horse competition held in Belgium and the Netherlands is a very good example. During this competition a wide variety of disciplines are being held such as dressage, obstacle track, obediance tests, etc. . There is a tendancy to not only measure the usefulness of horses in the sport sector but also as labour animal. Other examples of the usage of draught horses for pleasure are the schrimp fishing at the seaside, touristic carriages or trams for sightseeing, processions on horseback,…(De Brauwer, 2004)(Peerlings, van der Weerden, & van Hoof, 2008)

Traditionally, studbooks rely on visual inspections of breeding animals. A lot of competitions are organised where horses are being inspected and given a score on which other breeders or consumers base themselves upon to match their horses. Originally these competions were held by the governement to approve or dissaprove the horses for breeding. They would provide the owners of the approved horses with a certain amount of money, in this way they hoped to encourage breeders to use the better horses for breeding programs. Nowadays the competitions have evolved into a sport where breeders invest lots of effort and time in, hoping for a victory. The disadvantage of these events is that horses are mainly judged by exterior or conformation and a little bit on their gaits but the traits where the draught horses were originally being bred for has lost its importance in these competitions. (De Brauwer, 2004) (Peerlings, van der Weerden, & van Hoof, 2008)

2.3 Future

The draught horse will mainly be used for recreation purposes in the future and not so much for useful purposes. However! Emergy analysis gives a quantitative comparison of how one source of energy can be transformed and used directly or indirectly for the production of the final product. This analysis takes into account all the different kinds of energy needed in a process for obtaining a product or service, it brings everything to the same denominator so that efficient comparisons are possible. The downside of horses is the maintenance requirements, which are still present even when the horse is not deployed for work. On the other hand the horse is also a source of renewable energy since it can bring forth foals that can be used for many ends and its feces can be used as fertilizers. Furthermore the tractor represents higher investment and insurance costs. With the ever rising environmental pollution issues the re-establishment of draught horses for certain urban tasks is gaining in popularity again. In certain countries such as France, Belgium and The Netherlands horses are already being used for collecting garbage. This task is very well suited for horses because it needs to be done at low speed so that a motorized vehicle does not have any surplus value. The advantage here for the usage of horses is of course far lower emission which is better for the environment. In the forestry the horse will keep on playing a role due to the advantages mentioned above. So although the power output of a tractor can exceed five times the possible power output of a draught horse and the difference in working speed is also very pronounced, according to emergy analysis, the efficiency of the horse is not that far behind the tractor so that under strict conditions, rising fuel prices and ecological considerations, the reemployment of draught horses for draught work is not that farfetched. (De Brauwer, 2004) (Peerlings, van der Weerden, & van Hoof, 2008) (Beckwé, Leen, Nuyts, Oorts, Taillieu, & Van Aggelen, 2011)(Talpe, 2011)(Odeur, 2011)

3 Multidimensional perspective on the usage of horses

3.1 Harness

The general design of a draught harness consists of a part that transfers the horse pushing power to the attached load and a bridle for managing the horse.

Two types of commonly used harnessing for draught work are the breast band and collar harness. The breast band harness shown in Figure 2 applies the load against the horse's breast by means of a wide strap often made of leather, whereas the collar harness shown in Figure 1 rest on the entire shoulder. The latter is more suitable for pulling heavy loads but has the disadvantage that every collar can only used for one particular horse to assure proper fit whereas the breast band can be easily adjusted by means of straps to bring the band to the right height. Another disadvantage of the collar harness is that it limits the freedom of movement because of its size and weight, this is why the breast band harness is used in disciplines where speed and agility are of higher priority. Displacement of the load is ensured by the force that is transferred to the swingletrees through the traces which on their turn are loaded because of the pushing force that the animal exerts against the collar or breast band. (Miller, 1985)(Campbell, 1990)(Schroll, 2009)(Talpe, 2011)

For governing the horse the most common used gear is the bridle with two conventional reins where each one is attached to one side of the bit. In some cases the 'kordeel' where both rings of the bit are connected to only one rope, is implemented so that the handler only needs one hand to manage the horse.(Campbell, 1990)(Talpe, 2011)

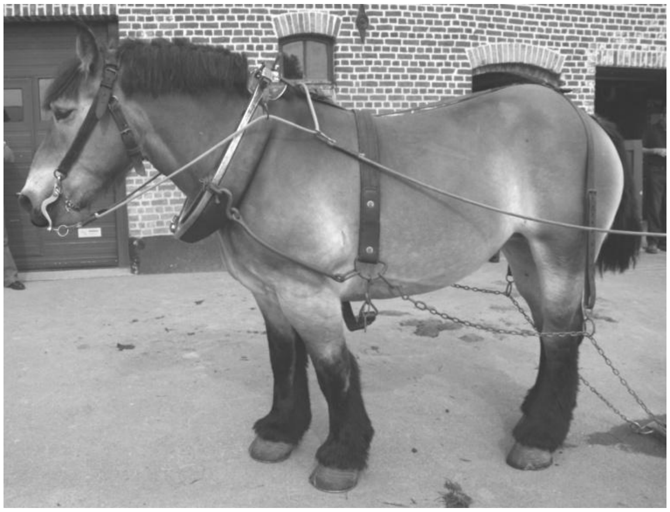

Figure 1: Collar harness with kordeel

Figure 2: Breast band harness with conventional reins

3.2 Exercise physiology

Exercise can be defined as a transition from rest condition to movement due to energy consumption which leads to muscle contraction that enables movement. This can either be acute or chronic. Related to sport we are more interested in the acute exercise type. We can characterize acute exercise by biochemical variables, muscle variables and locomotion variables. There is a wide variety of components that have an influence on the mechanical and metabolic behaviour of the muscle. This is represented schematically in figure 1. (Lippincott & Lippincott, 2006)

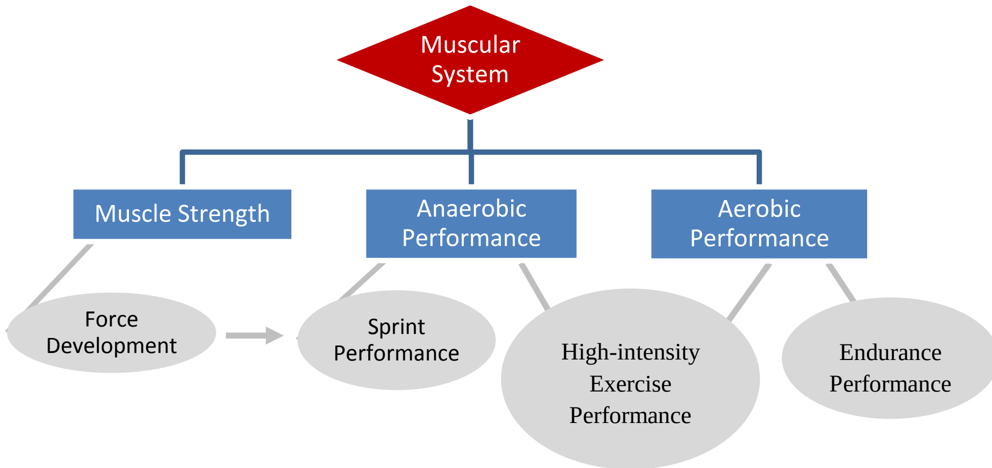

Figure 3 Influencing factors on the mechanical and metabolic behaviour of the muscle.

The smallest unit of muscle tissue is called the myofibril. This unit consists out of actin and myosin filaments. These two filaments can interact with each other which results in a contraction of the muscle on macroscopic level. Without going to deep into the biochemistry of this contraction it is known that ATP is required for the interaction between actin and myosin filaments. (David Jones, 2005)

3.2.1 Biochemical variables of energy metabolism in blood or plasma

The major fuel distributors of the body are carbohydrates (glycogen and glucose) and fats, though proteins also have some contribution especially in long lasting and intensive exercise. Phosphagens is the intramuscular energy source which is available as adenosine triphosphate (ATP) and phosphocreatine (PCr). The ultimate substrate that is used by the muscles for energy production is ATP, this is why all the energy pathways finally produce ATP. The choice of pathway depends on the energy demand and availability of substrate. It needs to be pointed out that all the energy pathways are always active and running simultaneously, but their kinetics are variable. The quantity of intramuscular phosphagens greatly influences the ability to generate "all-out- energy" for brief durations. For long duration efforts other energy sources need to refill the muscles' phosphagen stores continuously. This can be done in two different systems namely the lactic acid system and the aerobic system. At start of the exercise, energy demand will rise, as will oxygen intake (oxygen is necessary for het aerobic breakdown of the fuel substrates). This intake will rise rapidly during the first minutes and reaches a plateau between four or six minutes. At this plateau a steady rate of aerobic metabolism occurs. However the steady rate is never reached immediately and the difference between this theoretical demand and the true oxygen rise is quantified as the oxygen deficit. This is shown in Figure 4.

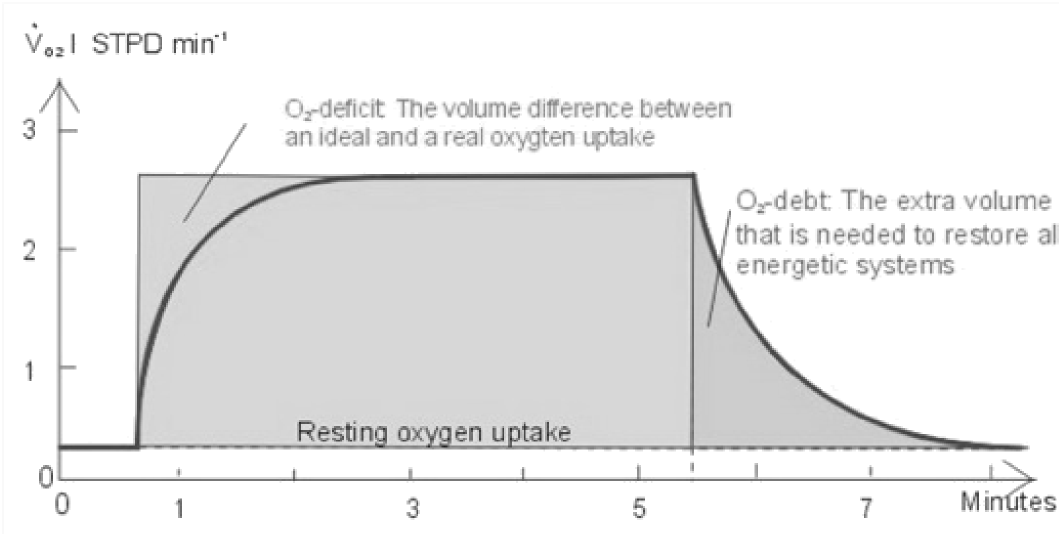

Figure 4: Oxygen uptake during steady state exercise with STPD (Standard Temperature and Pressure, Dry) the standardized dry oxygen uptake at 0°C and 101,3kPa. (Zubieta-Calleja & Paulev, 2004)

Energy provided during the deficit phase is generated by the anaerobic system. With rising training intensity the oxygen uptake will rise too until the point of maximal oxygen uptake is reached. This limit describes the region where oxygen uptake reaches a plateau and does not increase anymore despite an additional increase in exercise intensity. The maximal oxygen uptake is an indication for an individual's capacity to re-synthesize ATP aerobically. (Lippincott & Lippincott, 2006)

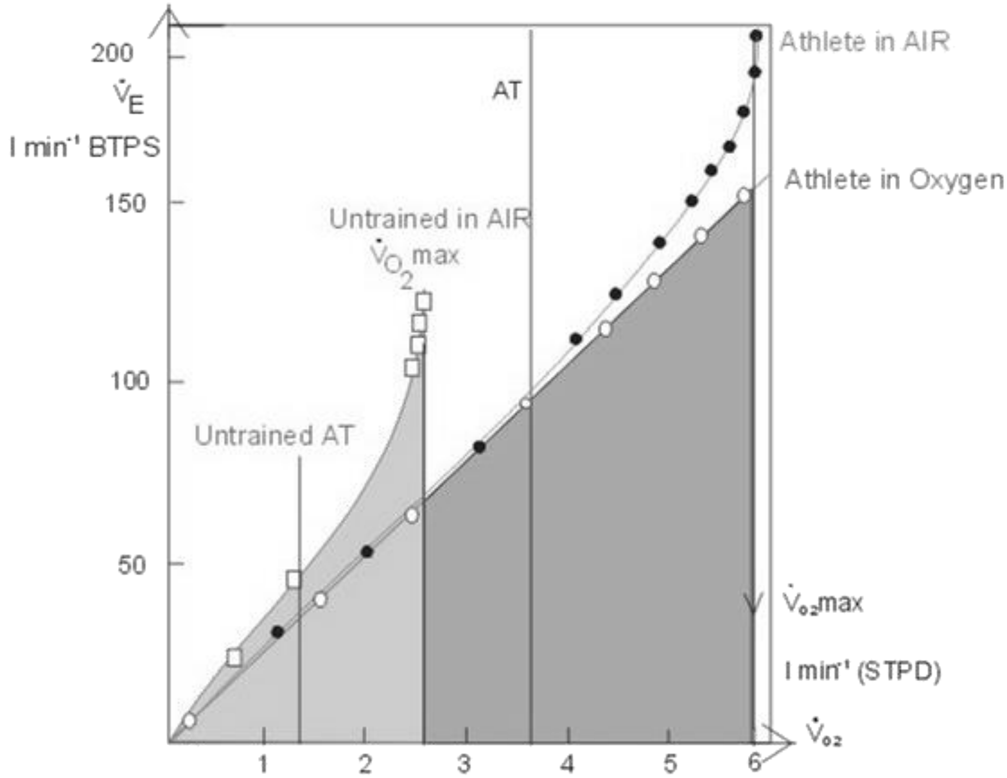

Figure 5: Ventilation and oxygen uptake in an untrained person with a maximum oxygen uptake of 2.7 l per min. Results from a top athlete, with a VO_2max of 6 l min-1 breathing air (•) or oxygen (o) is shown for comparison. (Zubieta-Calleja & Paulev, 2004)

Energy requirement above this level can only be met through the anaerobic system. Anaerobic glycogenolysis then provides the energy source to phosphorylate ADP: muscle glycogen is broken down to produce glucose, which undergoes glycolysis. Due to a lack of oxygen supply to accept the hydrogens formed, pyruvate is converted to lactate. Note that lactate is formed even under resting conditions but is removed simultaneously by heart muscle and nonactive skeletal muscle. Only when the production exceeds the removal, lactate is build up. Aerobic training can increase the capacity for lactate removal so that accumulation occurs on higher exercise intensity. Well trained individuals can generate higher lactate levels in all-out exercise compared to less well trained athletes. For the same sub maximal exercise a well trained horse will show a lower blood lactate concentration. In rest the blood lactate concentration in horses is usually below 1,5 mmol/l. During endurance riding this can rise up to 10 mmol/l while in gallop and trot/pace races or multi days eventing the blood lactate concentration can reach values higher than 20 mmol/l.

(Barrey, Fazio, Ferlazzo, Linder, & Luis López Rivero, 1997) (McArdle, Katch, & Katch, 2000) (Faria, Parker, & Faria, 2005)

The maximum oxygen uptake is partially innate and partially trainable whereas the maximum lactate level is very much depended on physical condition of the athlete (taken into account the physical limitations of maximum bearable lactate level). Since the lactic acid system is a source of energy, the maximum lactate concentration represents the maximal exercise intensity the athlete can take. (Deldicque, 2011)(Coyle, 1999)(Barrey, Fazio, Ferlazzo, Linder, & Luis López Rivero, 1997)

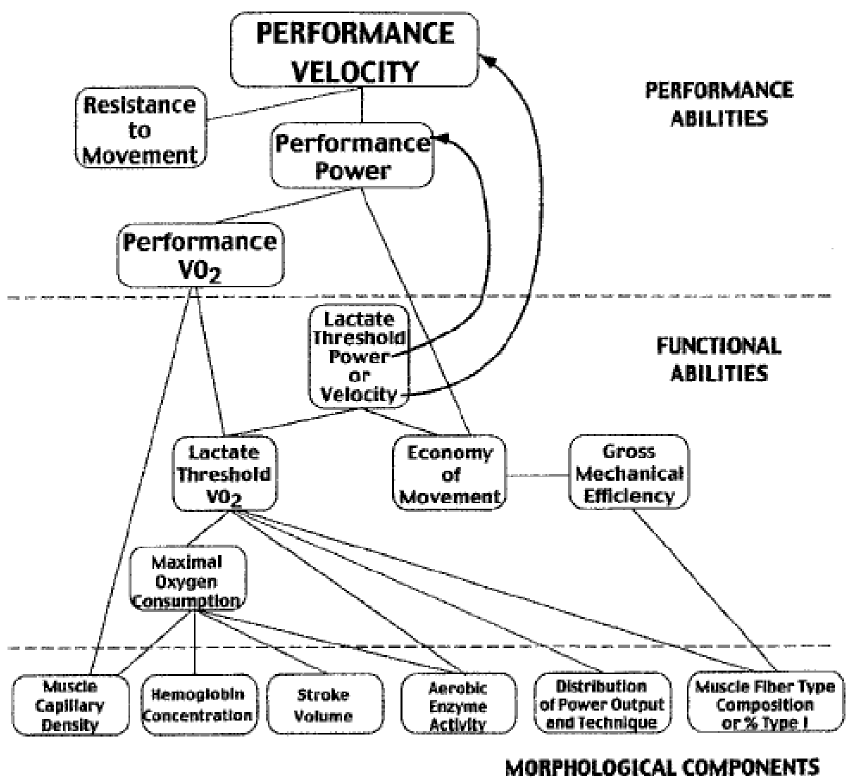

Figure 6: Interrelationships of the physiological factors determining performance ability (Coyle, 1999)

Compared with other species horses are outstanding elite athletes. They owe this remarkable athletic potential to their incomparable aerobic capacity. Similar lactate and VO_2 max tests have been developed for horses as for humans to determine their performance characteristics which in turn can be related to performance power. (van Erck, Votion, Serteyn, & Art, 2007)

3.2.2 Muscle variables

The diversity of skeletal muscles is one of the horses' unique characteristics. This is due to the fiber composition and heterogeneity of the individual fibers which leads to a great functional plasticity. Muscle fibers can be divided in two groups, type 1 and type 2 which are also known as the slow twitch and fast twitch muscles respectively. Slow twitch fibers are slow oxidative which makes them more suitable for sustaining slow repetitive movements and sustaining isometric force. The type 2 fibers posses a type of myosin and other contractile protein that enables them to develop force rapidly. Type 2A have more mitochondria and a greater oxidative metabolism capability which leads to the fact that type 2A muscle fibers can attain high power over a relative long period whereas type 2B muscle fiber have more myosin protein which enables them to contract faster than the type 2A. The recruitment of muscle fiber is than very straight forward. Slow twitch fibers, type 1, are recruited for longer period of time because their oxidative capacity enables them to release energy continuously. When power is needed fast type 2 muscle fibers are addressed. The muscle fiber composition can differ according to the breed. A thoroughbred will most likely have more type 2 fibers compared to draught horses.

Depending on the training the recruitment of the different kinds of muscles types will be different modifying the metabolic profiles of the muscle. The limitation of performance is fatigue. Increased aerobic capacity and greater proportion of type 2A/2B fiber muscle result in more fatigue resistant fibers. This improved performance is most sensible at speeds or effort at which the onset of blood lactate accumulation occur. Downside of this adaptation is that type 2B fibers also become smaller in size, this will lead to lower contractile speed and reduction of maximal force output which is not desirable with draught horses. It is shown that the proportion of type 1 and 2 fibers are highly heritable, implying a marked influence on the performance. (Barrey, Fazio, Ferlazzo, Linder, & Luis López Rivero, 1997)

3.2.3 Lactate levels

Next to heat lactate is a main by product for intense and prolonged oxidative metabolism. The presence of high lactate values is a sign of muscle acidosis which can limit performance remarkably. Lactate level is a good indication for the ability to maintain prolonged aerobic ATP production. In practice, endurance performance ability can be very well predicted by the exercise intensity electing the blood lactate threshold. (Coyle, 1999)

For draught horses lactate values during resting conditions are around 0,5 mmol/liter, during mild exercising it could rise to 5,1 mmol/liter and reach extreme values of 25-30 mmol/liter during exhaustion exercises. (Pastoret, Laurant, Courtois, Collard, Tinchi, & Hachez)(Art, 2011)

3.2.4 VO_2 max

The lungs contain a certain volume of air, during normal inspiration and expiration the moved volume of air is called the tidal volume. During maximal inhaling or exhaling a reserve volume can be moved respectively the inspiratory and expiratory reserve volume. After a maximal exhalation a certain volume will always remain, this volume is known as the residual lung volume. An increase of the maximal lung capacity will allow the individual to have an increased uptake of oxygen for its aerobic metabolism. (Lippincott & Lippincott, 2006)

Research has shown that draught horses have a smaller volume each inhalation (7,5ml/kg) compared to the thoroughbred horses (11,9ml/kg). Combined with also a lower yield draught horses have a maximal oxygen consumption (72ml/kg/min) that is inferior to that of the thoroughbred (134ml/kg/min). (Pastoret, Laurant, Courtois, Collard, Tinchi, & Hachez)(Potard, Leith, & Rog, 1998)

3.2.5 Heart rate

Heartbeat is another important parameter in training especially the heartbeat reserve, this is the difference between maximal heartbeat and heartbeat in rest. While the latter is dependent on physical condition the maximal heartbeat is innate. For draught horses heartbeat can vary from 45beat/min during rest up to 200 beats/min at maximal power output.(Pastoret, Laurant, Courtois, Collard, Tinchi, & Hachez)(Coyle, 1999)(Deldicque, 2011)

3.3 Exterior

On studbook inspections or shows the horses are evaluated on a desirability scale compared to an ideal. Some of these traits are based on performance characteristics whereas others are purely exterior ideals.

The shoulder would preferably have an angle of 45° because it is correlated with the length of the stride. The longer the pace the longer the horse can maintain contact with the ground to exert his force. Additional to that the pace itself should be firm and powerful. A shorter back is also linked to a bigger power output capacity. Regarding the chest the judges will look for a broad and deep chest. This is considered to provide indications of the volume of the lungs and as mentioned before the bigger the lung volume, the more oxygen uptake that is possible which is on its turn correlated to the power output. (Deboitselier, 2011)

Presented horses at shows will also be subjected to gait inspection. For every gait there are desired standards such as wide and secure walk, flexible and powerful gallop. (Deboitselier, 2011)

It needs to be pointed out that the visual judgment of these parameters is very subjective to the judge and his own skills and preferred beauty standards. (Trekpaard)

A less subjective method has been developed by the French institution for horses and equestrian sport "Les Haras Nationaux". "Le Pointage" is a linear scoring method used for optimizing breeding procedures. Very large quantities of horses are subjected to the investigation for differences in conformation and gait traits by scoring parameters determined in advance such as the clearness of the eyes, length of the back, head, muscle development, amplitude of the walk and trot, souplesse,… For every trait a score is given from 0 to 10 with 0 the less desired form of the regarded trait and 10 the most desired. A score of for example 9 for the head means the horse has a very expressive head. The aim of this method was to investigate heritability of the horses and the effect of age, sex, jury,… so the pedigree of the scored horses had to be known. Based on this information breeding values of all traits were calculated. This should help the breeders in their choice for coupling their mares to the appropriate studs. (Danvy, Doubre, Bois, Hemery, & Ricard, 2008)(Sabbagh)(Richard & Danvy, 2009)

3.4 Character: Horsonality

Temperament of the horse can be related to performance and is crucial for its usage by man. Objective measuring of a horse's character could help the layman to choose the right horse for the right job, handler, housing or management.

To avoid mismatches it's important to have horses with a temperament suited for the work that needs to be performed. Temperament is defined as the individual's response towards continuing changes and challenges in its environment. With regards to work performance the horses' learning abilities, emotionality and reactivity to man are the most important aspects of its temperament. To be able to perform well the horse must trust and respect the person who's handling it and have the willingness to work for them. The ultimate goal of a matching temperament is for the horse to have the same objectives as the human. This cooperation can be tested through a handling test where the presence or absence of the above mentioned aspects as trust, respect, and willingness to work are tested. Learning is the change of behaviour due to experience. This can be achieved by either rewarding a good behaviour where the horse will associate a certain rewarding cue with the desired performance, or by applying an aversive stimulus until the desired response is performed. It should be taken into account that learning abilities and emotionality influence one another. (Visser, 2002)

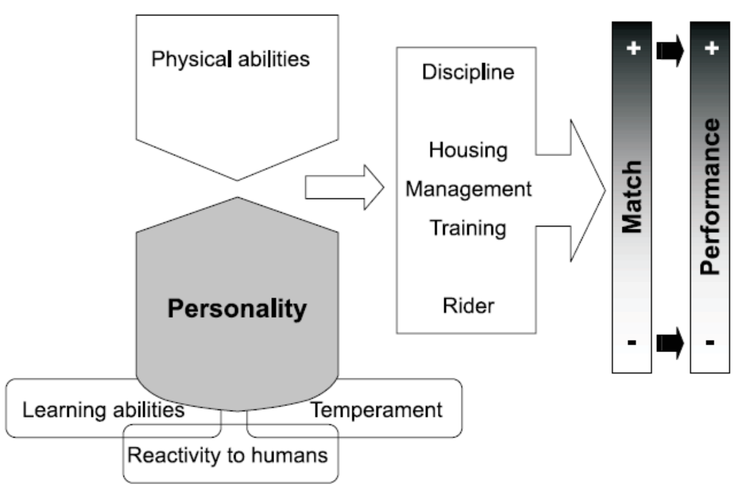

Figure 7: A schematic overview of how performance is affected by personality and its interaction with environmental influences (Visser, 2002)

With regards to the performance prediction it is common assumed by horse trainers that an emotional horse will perform worse in stressful situations and a horse with good learning abilities will be easier to train.

In the thesis of Prof. Kathalijne Visser at the University of Wageningen she described the concept of Horsonality.

3.4.1.1 Quantifying aspects of young horses' temperament: consistency of behavioural aspects

To map an individual's full temperament you need a wide variety of distinctive behavioural variables. These variables were selected from different behavioural classes such as postural expression, locomotor activity, latency times and vocalizations. For this research young horses were submitted to (1) a novel object test where their response to an open umbrella was investigated and (2) a handling test were they were lead by a human over a bridge. The novel object test related these behavioural classes to 'flightiness' and 'sensitiveness' of the horse whereas the handling test related them to 'patience' and 'willingness to work'. It could be concluded that these behavioural test were reliable enough to identify individual behavioural variables and temperamental traits in young horses. However, it must be pointed out that whether these behavioural variables and temperamental traits can be used to predict future temperament. This still needs to be investigated so long term consistency is yet to be confirmed with future tests. (Visser, 2002)

3.4.1.2 Heart rate and heart rate variability during a novel object test and a handling test in young horses

The objective of this part of the research was quantification of temperamental traits on the base of heart rate and heart rate variability measurements. The heart rate is controlled both by the parasympathetic nerves which slows it down and the sympathetic nerves which accelerate it. This balance can be shifted due to external or internal changes. In stress situation for example it is shown that the body suppresses the parasympathetic activity. The level of suppressing is different between different individuals though, this can be due to differences in temperament. Horses that are easily stressed emotionally have a lower degree of parasympathetic nerve activity. Both the handling as the novel object tests showed an increase in mean heart rate and decrease of the heart rate variability. This increase was not completely due to the change of activity (only 30% - 40%) and was dependent on level of training and age of the horse. It was suggested that the remainder of the change (nonmotor heart rate) is connected to the horses temperament especially emotionality. Trained horses encountered more new things during their training which resulted in a lower increase in heart rate during the tests. In Visser's experiment there was no convincing evidence though to support this theory.(Visser, 2002)

It needs to be pointed out that the behaviour of the horse is highly dependent on its rider or handler. A mismatch can result in lower performance or even more accidents. Besides temperament the learning ability is also important personal trait. (Visser, 2002)

During the selection of riding horses in Europe the judges try to assess information about personality traits such as "character", ”temperament", ”willingness to work" and "constitution". There are however some drawbacks about the conventional ways of determining these traits. For starters there is no clear definition about personality traits and consequently there is lack of universally accepted guidelines for its evaluation. This leads to a low variation in the scores so that most horses end with similar scores. Another drawback relates to the fact that personality traits are scored during performance tests on station. (Visser, 2002)(Uta König von Borstel, 2011)

3.5 Biomechanics of locomotion

Compared to visual scoring a biomechanical approach of locomotion has the advantage to be objective, reproducible, accurate, not altering the function that they are measuring and often exceeding the diagnostic capability of a skilled clinician. Biomechanical analysis can be of added value due to a higher possible temporal and spatial resolution. (Oosterlinck, 2011)

3.5.1 Skeleton

The skeleton of the horse has two purposes being the framework for the body on one hand and providing mechanical advantage to the horse in motion on the other hand.

Due to the natural conformation of the skeleton in combination with the muscles a various combinations of levers are present which account for the mobility and strength of the animal. The first lever of great importance is the one where the weight and power are on both sides of the hinge point. An illustration of this lever is the propulsive motion of the hind leg where the hip represents the power, the foot and lower limb being the weight (through the contact with the ground) and the hock functions as hinge point. A second lever has the power at the end and the hinge points are at the two ends and the weight in the middle. This principle is displayed at the front foot when the horse is moving forward. (Miller, 1985)

Furthermore, due to the natural slope of the shoulder the optimum draught angle is 90° of point of draught to the contact point with shoulder relative to shoulder angle as shown in Figure 8. If the point of draught would be higher it would cause the collar to rock forward and press against the horse's windpipe as illustrated in Figure 9. The optimal angle of draught depends on the slope of the shoulder, the height of the horse and the weight of the load. (Spruytte & Allen, 1983) (Miller, 1985)

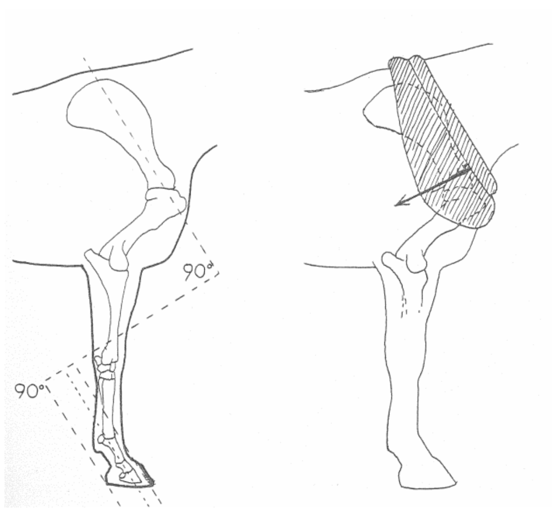

Figure 8: Natural slope of the shoulder (Miller, 1985)

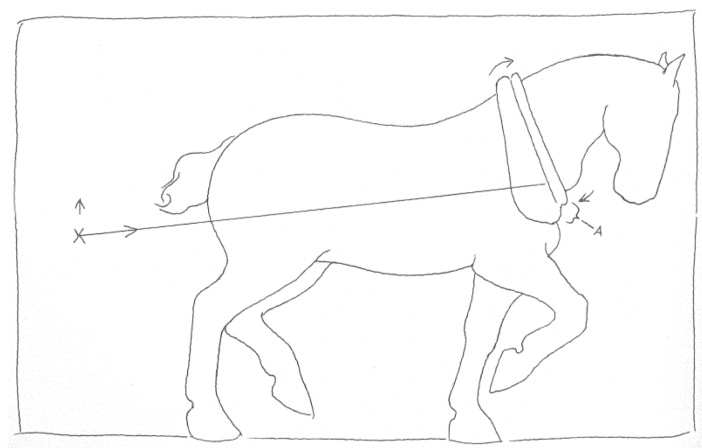

Figure 9: Choking effect when draught point is too high (Miller, 1985)

3.5.2 Locomotion variables

The locomotion is the final and mechanical expression of the exercise activity which allows many combinations of sequence of limb movements. The different gaits of the horse can be classified according to their linear and temporal characteristics. The walk and trot are symmetric gaits whereas the gallop is asymmetric. One complete cycle of limb motion is called a stride which is characterized with a stance and swing phase and its frequency and length. The stride length appears to be more related to blood lactate and heart rate than does the stride frequency. So when increasing velocity induces high cardiac and metabolic response this is mostly due to increase in stride length rather than higher stride frequency. (Barrey, Fazio, Ferlazzo, Linder, & Luis López Rivero, 1997)

3.5.3 Locomotion analysis

Biomechanics studies the mechanical properties (structure and function) of biological systems by means of the methods of mechanics. The body of the horse is composed of a set of rigid segments articulating with one another and consequently follows the laws of mechanics as a series of inanimate objects. For the study of locomotion there are two complementary methods. The first one is kinetics or dynamics, it explains the cause of the motion by analyzing the forces that work on it. Kinetics deals with forces, energy and work which can be related to the variables of the second method i.e. kinematics. The second method, kinematics, describes the motion of the body segments in space and time and is based on image analysis to require information about the body segments' trajectories, angles, velocities and accelerations. Kinetic analysis can be preformed quickly whereas kinematic analyses are time consuming but they can provide visually details of the movements. Combination of both methods allows for the calculation of variables like work, power and momentum. (Hinchcliff, Kaneps, & Raymond, 2004)(Spaepen, 2010)(Oosterlinck, 2011)

3.5.3.1 Kinetic analysis

This method studies the biomechanics of locomotion by measuring external forces applied to the body or acceleration of the center of gravity of the body segments. (Hinchcliff, Kaneps, & Raymond, 2004)

External forces can be measured upon impact of the hooves with the ground. The ground force measured is according to Newton's third law equal and opposite to the force exerted by the hooves on the ground. Different measuring instruments are available for these analyses. The most common known is the force plate which is capable of measuring the amplitude and orientation of the ground reaction force, the three components of these forces are displayed in the picture below.

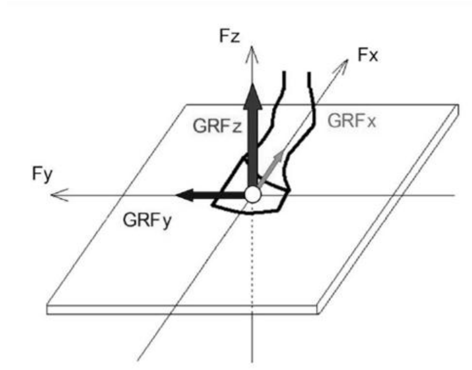

Figure 10: Forces acting at the hoof-ground interface. The Ground Reaction Force (GRF) is divided in its 3 orthogonal components (F_x = medio-lateral component, F_y = cranio-caudaal component, F_z = vertical component) (Oosterlinck, 2011)

An important drawback however is the fact that the force plate cannot distinguish simultaneous impacts and they can only measure a limited number of strides. Other means of measuring the external forces are instrumented horseshoes that were developed to overcome the drawbacks of the force plates and so they are able to measure successive strides even on different substrates. The discussion remains whether or not the thickness of the shoe affects the horses' locomotion. For the measurement of acceleration a simple accelerometer can be used and according to Newton's second law, if the mass of the horse is known, the force can be calculated by multiplying the mass with its acceleration. For equine locomotion analysis the accelerometer should be placed as near as possible to the body center of gravity. The main advantage of this measuring method is its simplicity whereas the disadvantage is the fact that it is hard to calculate the acceleration, velocity or displacement with respect to a set of ground axes. Another measuring instrument is the pressure plates. Due to their high number of sensors that are distributed uniformly it is possible to simultaneously measure different hooves. Downsides of this method concern durability, calibration issues and limited dimensions. (Hinchcliff, Kaneps, & Raymond, 2004)(Ortiz-Laurel & Cowell, 2007)(Oosterlinck, 2011)

For draught work the walking gait is of main importance. A typical force profile along the y and z axis for a normal walk is shown in the figure below where it is shown that in normal walk the first part of the stride has a negative load in the y direction i.e. in a direction opposing to the forward movement of the horse. Once the body has moved over the foot, point of maximum vertical force, the force along the y axis becomes positive so changing from a braking to a propulsive function. The forces in the x direction follow a similar pattern. The forces along the z axis reach their maximum when the whole leg is perpendicular to the walking surface. (Hinchcliff, Kaneps, & Raymond, 2004) (Ortiz-Laurel & Cowell, 2007)(Oosterlinck, 2011)

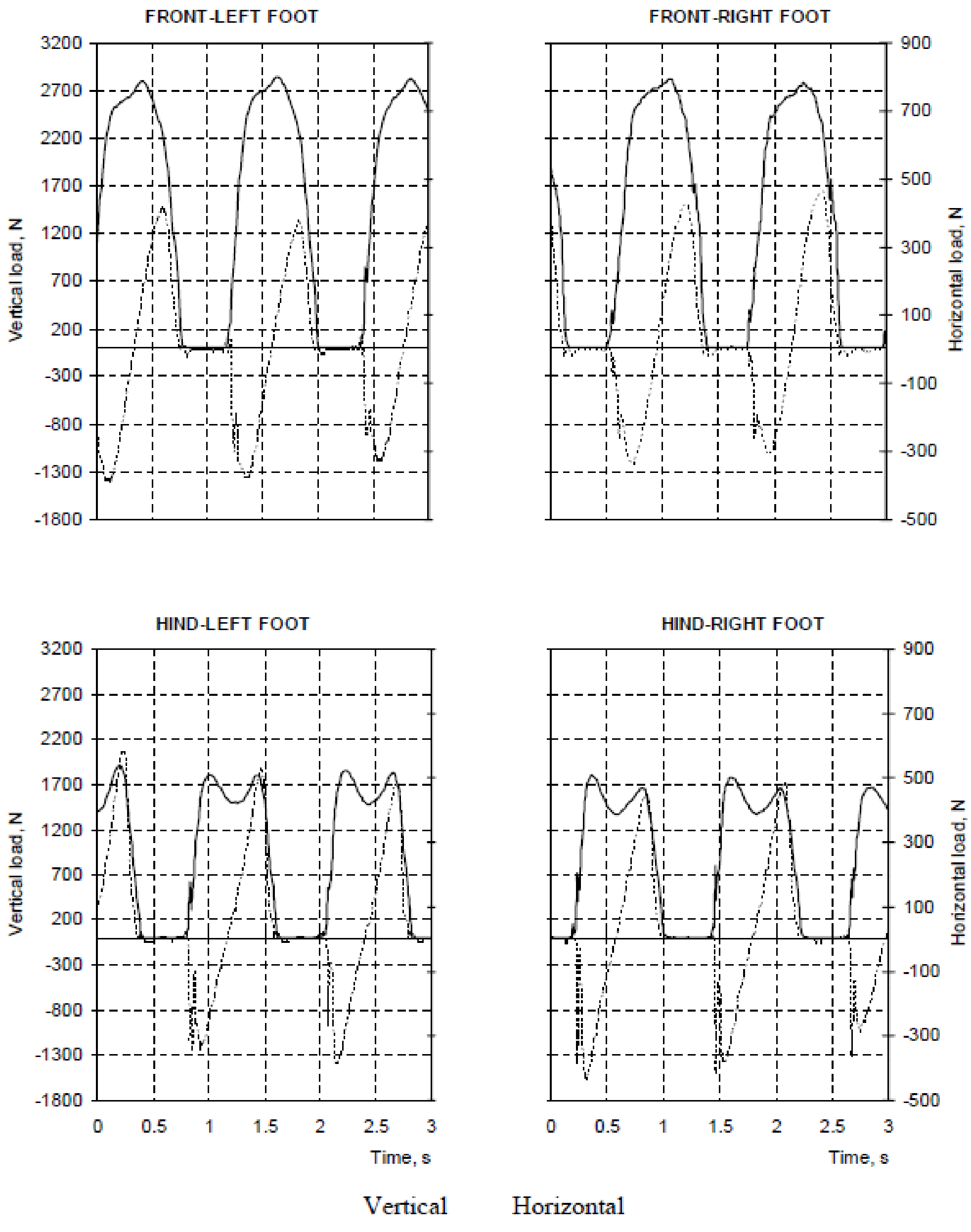

Figure 11: Ground reaction force in the y and z direction on each of the feet (Ortiz-Laurel & Cowell, 2007)

However when the horse is pulling a certain load the conversion from braking to propulsion occurs before the maximum vertical load as shown in the figure below. Another effect is a partial shifting of the body weight distribution from the front legs to the hind legs. ***(Ortiz-Laurel & Cowell, 2007)(Beckwé, Leen, Nuyts, Oorts, Taillieu, & Van Aggelen, 2011)***

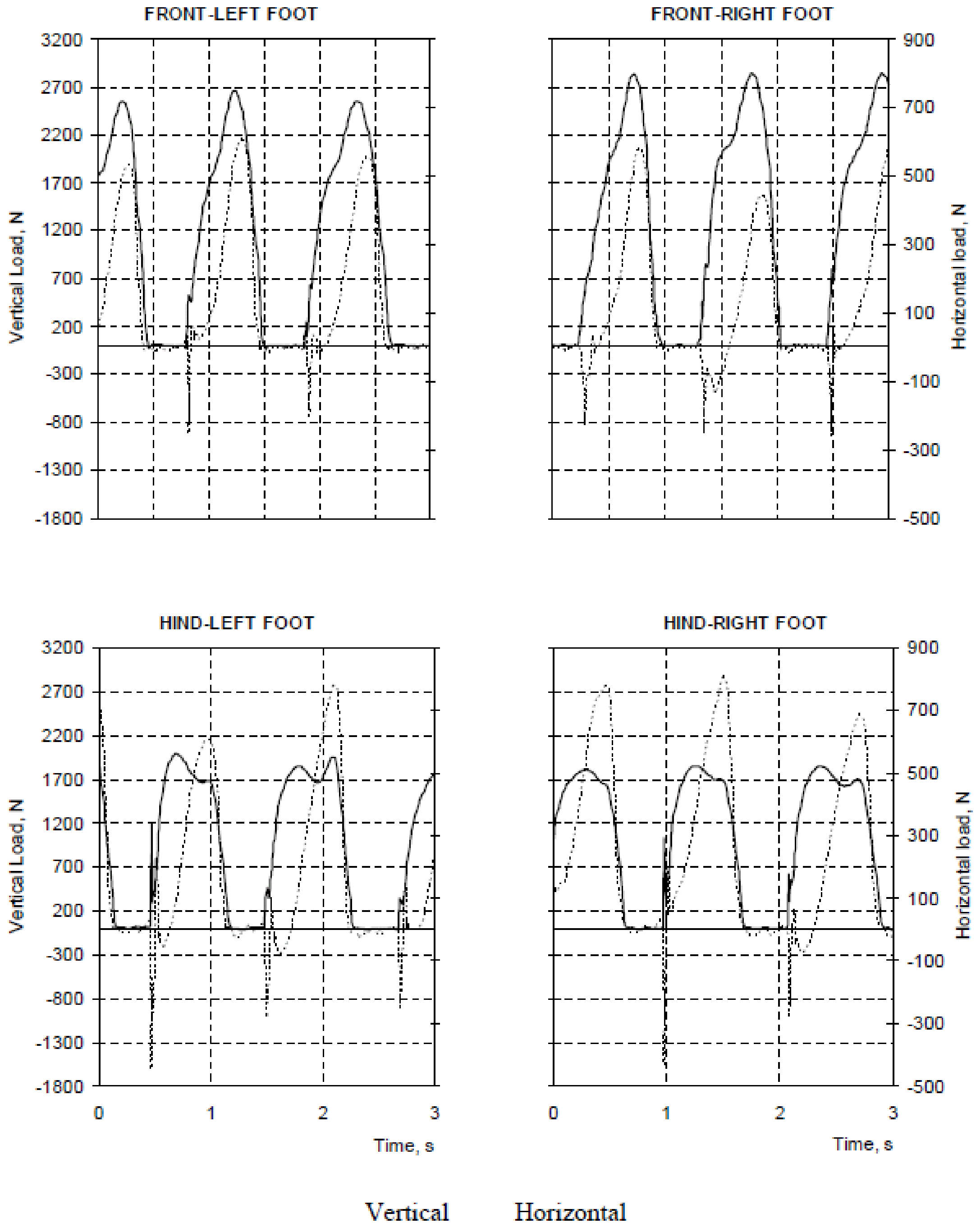

Figure 12: Force profile when pulling a load of 710N (Ortiz-Laurel & Cowell, 2007)

3.5.3.2 Kinematic analysis

Another approach is the analysis of locomotion by means of two or three dimensional measurements of linear and angular displacements as function of time also known as chronophotography. Depending on the technique both qualitative and quantitative analysis are possible. In practice, high speed cameras combined with markers, indicating the approximate instantaneous center of rotation of the joint, are used for locomotion analysis. However the relative displacement of the skin over the skeleton can create artifacts. The markers used can be passive or active ones. The former only detects or reflects a signal while the latter transmits signals. When using passive markers, after filming, they need to be tracked. This can be done manually, semi automatically or automatically. A big disadvantage of kinematic analysis however is the restricted field of view so that only a low number of strides can be analyzed. (Hinchcliff, Kaneps, & Raymond, 2004) (Oosterlinck, 2011)

The number of body segments used for the analysis depends on the nature of the movement and the objective. Knowing that one body segment has three degrees of freedom in a two dimensional fixed coordinate system (two translations and a rotation) the total degrees of freedom equals 2 x n with n the number of body segments. This number can however be reduced if the length of the segments are constant and known and they move with respect to each other in hinge points that are fixed points of both adjacent segments giving a reduced total degrees of freedom of n + 2. (Spaepen, 2010)

Many locomotion variables of foals are closely related to that of the adults so that kinematic values in foals can give an indication of the quality of movement of the adult horse. This way it would be possible to predict the quality of a draught horse in an early stage. (Back, Schamhardt, Hartman, Bruin, & Barneveld, 1995)

4 Scientific aim

With the upcoming reemployment of draught horses in daily life the assessment of their performance is also of rising importance. Current studbook inspections are based on exterior and gait evaluation through which they hope to get an idea of the performance level. The main goal of these inspections however are merely scoring according to a beauty standard which used to be derived from characteristics that ensured better draught performance but in time has evolved to purely personal taste. Other tests such as obstacle track mainly attempts to assess character traits such as workability and obedience.

If the draught horse will be used again for urban tasks the development of an objective scoring test is not an excessive luxury. Although very important, character is difficult to measure objectively so it will be hard to use this in a scoring test. Since the main concern is the work performance of the horse it is better to assess locomotion and physiological parameters rather than exterior since they are less direct related to work performance. As mentioned before VO_2max and lactate levels are two interesting parameters as indication for performance level. The drawback of VO_2max measurements is that it needs a mask and a non mobile measuring device which is not practical for this goal. Furthermore it is very hard to get draught horses up to the exercise level where VO_2max is reached (Art, 2011). Lactate measurements would require blood samples and lab analysis before giving any results. Since the aim here is to develop a measuring technique that can be used on site and with online results both VO_2max as lactate measurements are not ideally. For the same reason conducting a biopsy, where tissue can be sampled to determine the muscle composition, wouldn’t be able to give immediate results. Next to that a biopsy result is very dependent on the area and dept of sampling which makes it very hard to take comparable samples (Art, 2011). So the choice for the development of a biomechanical measuring technique seems the best choice here since it can be performed objectively, quick, on site and with online results. In the literature there has already been biomechanical studies but more often they described the forces at the hooves. Traction force in function of rising load has been an unstudied domain so far. Kinematic analysis of horses have already been conducted in thoroughbreds to analyze their motion but there are no known studies for draught motion analysis. This study will use kinetic traction force analysis combined with draught motion analysis which will be a whole new area of study towards draught horses.

The first step will be the search for relevant performance parameters so that they can be used to define an ideal pulling mechanism. As mentioned above this thesis will focus on biomechanical analysis using force profile (kinetics) and posture variables (kinematics) to set the first steps towards the development of a total objective performance analysis. The investigation of changing parameters with increasing pulling load is the main goal.

4.1 Parameter proposal

For the draught force profile the parameters of interest are the maximum takeoff force defined as the first relative maximum of the profile after takeoff. A low takeoff force is considered desirable since this is more favorable for the horse and equipment. Sudden force peaks will produce a shock to the horse and its equipment so that more damage will occur in the long term. The steady state force will be an indication of the amount of force needed to maintain movement of the load. Peak to peak variation in the force profile will show how consistent the horse pulls. This variation is better kept small to reduce the shocks to the horse and its equipment. (Talpe, 2011)(Van de Vijver, 2012)(Coen, 2012)

Important parameters from the video analysis will be the posture of the head which gives an indication of the degree of collection and elevation. The stride length is another important feature to follow. Assumption is that a horse that is pulling a heavy weight will have a longer stride length (especially in the hind legs). This goes together with a lowering of the hind quarters of the horse which is a more stable situation since the centre of gravity is closer to the ground. Since the front legs function as a lever and balances the horse during motion the angle at the front is expected to change too. (Miller, 1985) (Talpe, 2011)(Van de Vijver, 2012)(Coen, 2012)

Expectations are that these parameters will change in function of the effort the horse has to exert. That's why every horse will be pulling three different weights: easy, medium and hard. Where easy is the load at which little effort has to be done and consequently having limited influence on draught posture. Hard load is near the maximum load the horse is still able to pull. Medium load is in between. Every process will be monitored during takeoff and at least three steps of steady state pulling. During that time both force and posture are measured.

5 Materials and Methods

5.1 Materials

5.1.1 Draught horses

The selected horses must have good health. The absence of lameness is obligated since this could affect the results. A lot of Belgian breeds struggle with certain chronic diseases. The Belgian draught horse for example is known for its lymphedema.

Table 1: Horses used for the experiments. BDH = Belgian Draught Horse, FDH = Flemish Draught Horse (in America known as the Belgians)

	Breed	Sex	Age	Training level	Type load
Horse 1	BDH	Mare	10	Regular	Cart
Horse 2	BDH	Mare	10	Regular	Cart
Horse 3	BDH	Mare	3	Regular	Cart
Horse 4	BDH	Mare	10	Occasional	Sledge
Horse 5	BDH	Mare	8	Occasional	Sledge
Horse 6	FDH	Stallion	7	Regular	Sledge
Horse 7	FDH	Stallion	5	Regular	Sledge
Horse 8	FDH	Stallion	13	Regular	Sledge
Horse 9	BDH	Mare	8	Regular	Sledge
Horse 10	BDH	Mare	6	Regular	Sledge
Horse 11	BDH	Mare	2	Regular	Sledge
Horse 12	BDH	Mare	2	Regular	Sledge
Horse 13	BDH	Mare	10	Regular	Plough
Horse 14	BDH	Mare	11	Regular	Plough
Horse 15	Boulonnais	Mare	10	Regular	Plough
Horse 16	BDH	Mare	7	Regular	Plough
Horse 17	BDH	Mare	3	Regular	Plough
Horse 18	Hybrid	Mare	6	Regular	Sledge
Horse 19	Hybrid	Mare	15	Regular	Sledge
Horse 20	Norman Cob	Mare	10	Regular	Sledge

5.1.2 Data acquisition

5.1.2.1 Force

The force profile is determined by means of a load cell, the Vishay Tedea-Huntleigh S-Type Stainless Steel Load Cell model 620 which has its maximum capacity at 1000kg. This device is a transducer that converts small deformations due to external forces into an electrical signal which is sent to the SG-3016 load cell signal amplifier supplied by a 12V battery. The amplifier is then connected to a National Instruments USB-6009 data acquisition (DAQ) device which reads out the data and sends it to the laptop that runs LabVIEW 2011. The whole experiment is done at walk so a sampling rate of 100Hz is used. The material used for the force data acquisition is shown in the figure below.

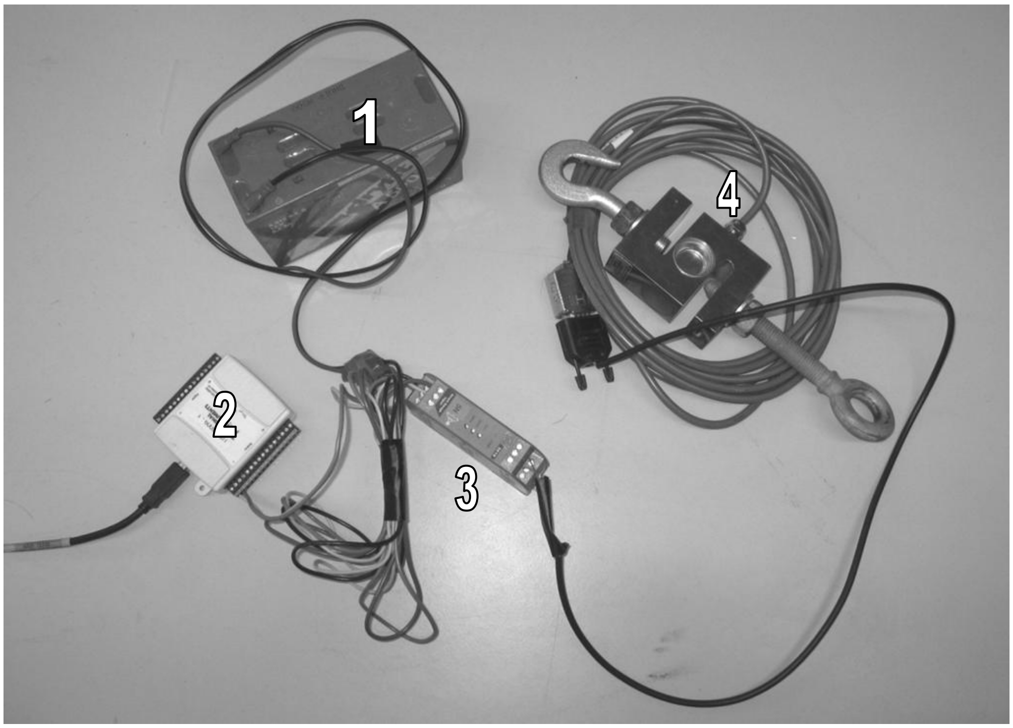

Figure 13: 1: 12V battery, 2: DAQ device, 3: Signal amplifier, 4: Load cell

5.1.2.2 Motion

Image acquisition was done by means of a Mini-DV camera, type Sony HDR-HCE9 with a sampling rate of 30 frames per second. The horses have to pull according to a predefined track so that the line of movement is perpendicular to the camera's filming direction. In this way image distortion is minimized also due to limited track length followed and the small camera range we can assume that the distortion to be negligible. (Spaepen, 2010)

5.2 Methods

For kinematic analysis of the draught movement we consider the body (parts) as nearly undeformable rigid bodies. The skeleton and moreover the muscles and organs are subjected to a certain amount of deformation during locomotion but these deformations are relatively small compared to the displacement of the whole body (part) so that the assumption is valid. (Spaepen, 2010)

5.2.1 Preparations

For kinetic analysis the pulling force is registered by means of the load cell that is attached between the swingletree and the load to pull. For horses 1 till 3 these loads were carts of different weights. Horses 13 till 17 had to pull a plough with adjustable plowing dept that ensured an increasing resistance. All the other horses pulled a sledge where the weight was increased by putting peoples or heavy material on the sledge.

Kinematic analysis was done by locomotion filming. Certain preparations were in order to allow correct data processing afterwards. First of all a length reference is needed for calibration later on. In this experiment the reference will be a part of the harness as shown in the figure below and will be measured for each horse. Passive, light reflecting markers were attached to the horses. The marker positions are shown in the picture below. These points are chosen so allowing the calculation of several locomotion parameters as mentioned above. The explorative experiment has shown that yellow reflecting material is easier to track than other bright colored materials such as sponges (as shown in the picture below). So during the real experiments yellow reflecting cloths are used as shown in Figure 15: Experimental set up.

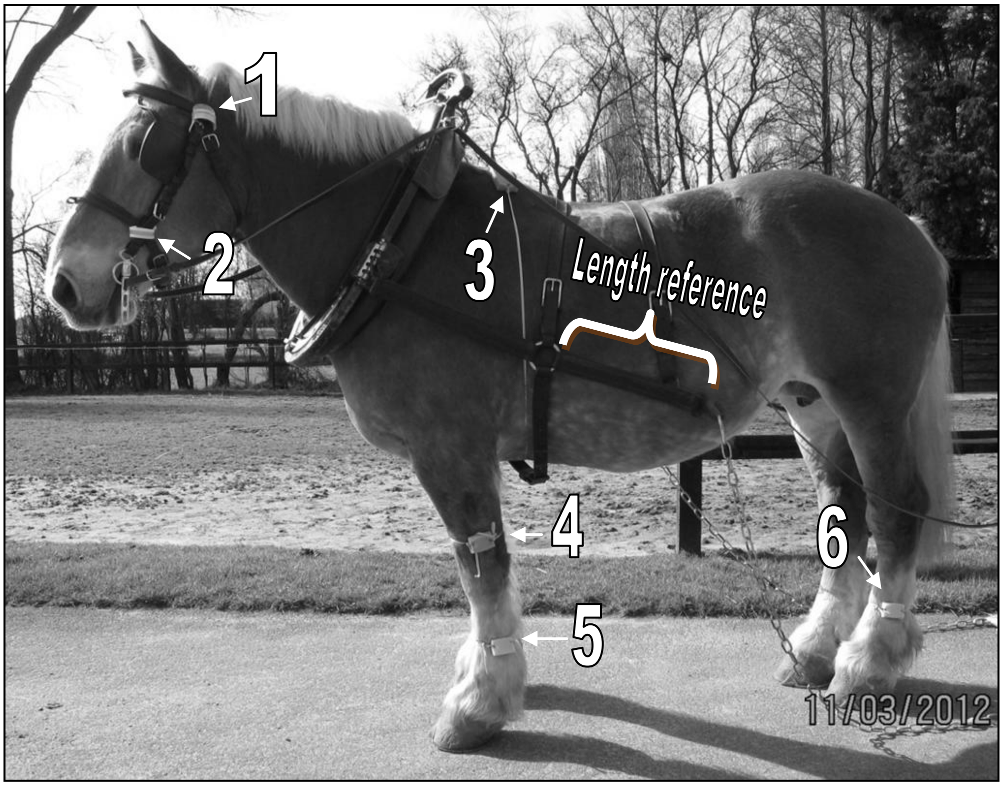

Figure 14: markers 1: intersection crownpiece-browband, 2: intersection cheekpiece-noseband, 3: withers, 4: radius, 5: metacarpus, 6: metatarsus

The camera is set up in such a way that there is good image filling and the optical axis of the camera is perpendicular to the motion's plane, this way minimal image distortion can be achieved as mentioned above. The horse will pull on a track that is predefined by means of a ribbon to ensure equal distance and orientation with respect to the camera. The horses were first guided through the track a couple of times for habituation.

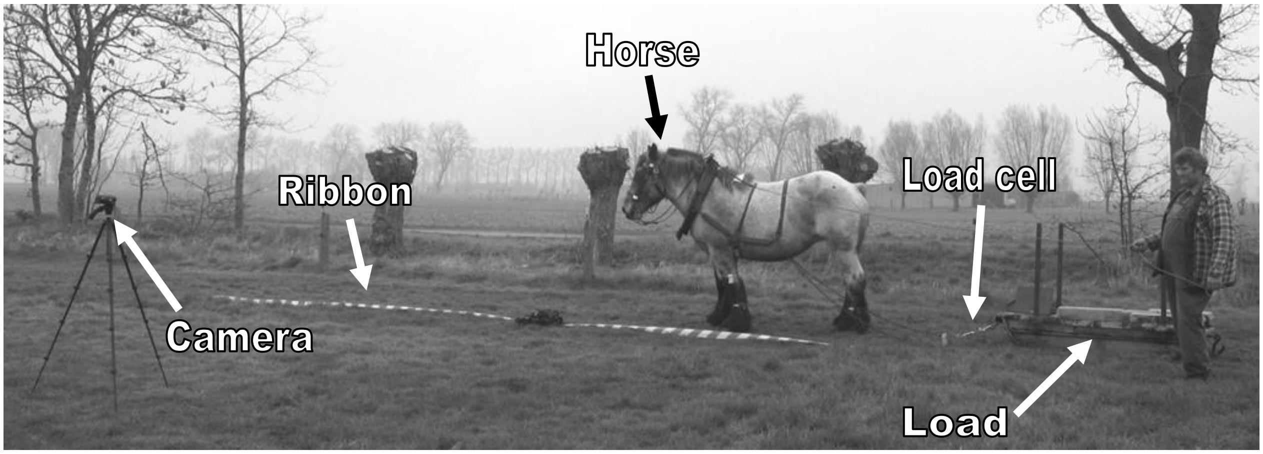

Figure 15: Experimental set up

5.2.2 Data processing

Both kinetic as kinematic analysis will be done separately first. The kinetic analysis will relate force parameters to the increasing load whereas kinematic analysis will relate the motion parameters to the horses' dimensions. Afterwards the force and motion analysis will be combined to see what the effect of higher loads will be on the motion parameters. In the end the difference between the individual horses will be investigated.

Parameters of interest in the force profile are initial takeoff force (TOF), steady state pulling force (SSF) and peak to peak variation. To reduce the noise of the load cell read out a low pass filter is used (forward and reverse digital filtering to obtain a zero phase shift of the signal). By performing a fourier transformation on the signal the useful frequencies were found beneath 4Hz so this frequency was then used as the filters frequency. After calibration the mV read out is multiplied with a factor 145.5942 to convert to the desired Newton output. This analysis is done by MATLAB 2010a.

Definition of the initial takeoff force is the maximum peak within the first three seconds. Furthermore, the peak to peak variation is quantified by means of the standard deviation of the steady state region of the signal (SSDEV).

For the image data the elevation can be measured as the angle and height of the head and stride length can be calculated in both front and hind legs. The video material is imported in Kinovea 0.8.15. and the markers are indicated, afterwards the software will track them semi-automatically leaving opportunity for manual correction if the software loses track of the marker. After indicating the coordinates' system origin, every marker will be situated in the same coordinates system. The coordinates of every marker for every frame can be exported to an excel file and then imported with Matlab 2010a for further analysis.

In order to obtain a reference a regression line is fitted through the withers' marker position over the time frames (approximately 5 seconds depending on the video) as illustrated in Figure 16. The angle of the head is defined as the angle between the line through point 1 and 3 and the line through the withers' coordinates (A). The amount of elevation can be assessed i.e. when both this angle (B) and the distance between point 2 and 3 (C) is minimal. For a measure of the stride length of the front legs the difference between maximum and minimum angle between the line defined by point 4 and 5 and the withers' regression line is taken (D). At the hind legs we take the distance between point 3 and 6 as an indication for the stride length (E). When stride length increases we expect the operating angle of the front legs to increase and the length between point 3 and 6 at the hind legs to increase too.

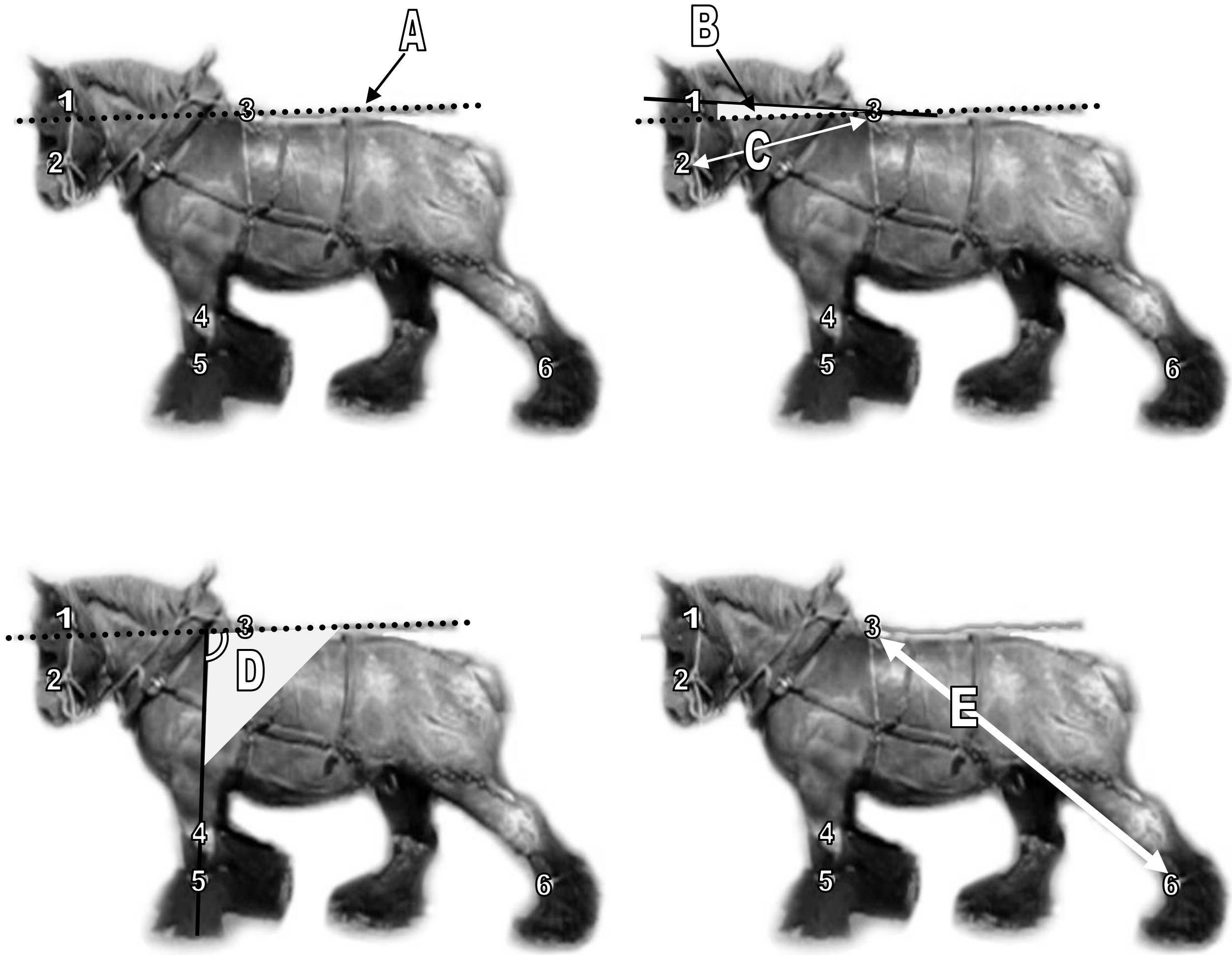

Figure 16: A: Regression line through the withers' coordinates, B: angle of head as a measure for elevation C: Distance between nose and withers, D: angle of front leg, E: Distance between withers and hind leg

Statistical analysis are done in Microsoft excel (calculation of minima, maxima, averages, standard deviations and regression coefficients) and R (linear regression modeling with ANOVA analysis, linear mixed effects modeling and calculation of correlations coefficients).

6 Results and discussion

6.1 Force analysis

A characteristic force profile is shown in the graph below where the filtered and calibrated data is shown. Area 2 represents the steady state region, i.e. the time that the horse followed the track along the ribbon. The average value of this steady state level, 1886 Newton in this example, is used as a representative value for the load and its deviation which represents the peak to peak variation has a value of 320.78. The takeoff force (1) in this example is 4523.40 Newton. The rest of the signal comprises the turning of the horse and placing itself back to the beginning of the track. This part of the signal is not used for analysis.

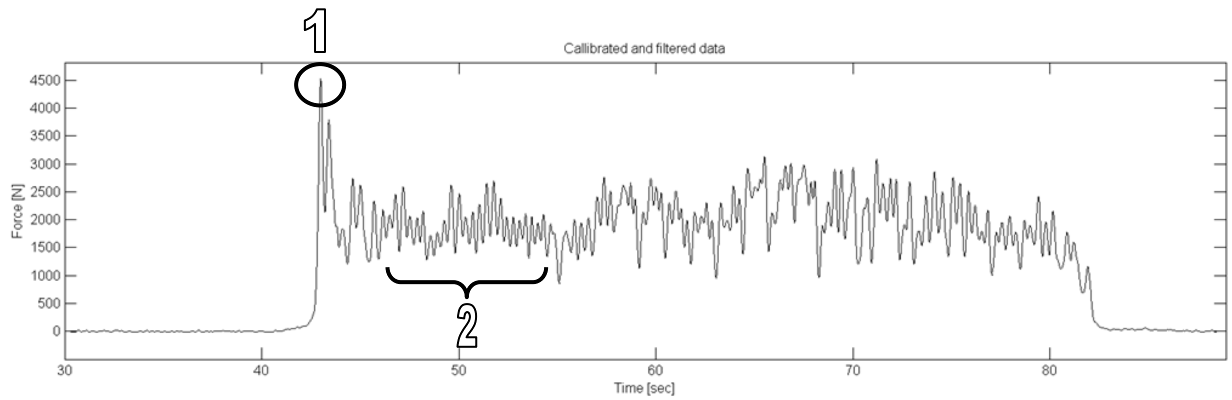

Figure 17: Force profile: 1: Takeoff force, 2: Steady state region

A summary of the force analysis data is given in Table 2 showing the number of data points, their averages, minima, maxima and standard deviation. Two potentially interesting ratio's were also calculated i.e. TOF/SSF and SSF/SSSDEV.

Table 2: Summary of force measurement data

	N	Average	Min	Max	Standard Deviation
TOF (N)	103	2504.11	159.59	6866.80	1339.52
SSF (N)	103	1256.98	52.41	3598.55	790.22
SSDEV	103	213.20	14.18	530.70	110.91
TOF/SSF	103	2.56	1.19	14.34	2.09
SSF/SSDEV	103	6.09	1.76	14.44	3.14

After a first inspection of the data it was clear that the force profiles for the different types of loads (cart, plough and sledge) showed big differences as shown in Figure 18 and Table 3.

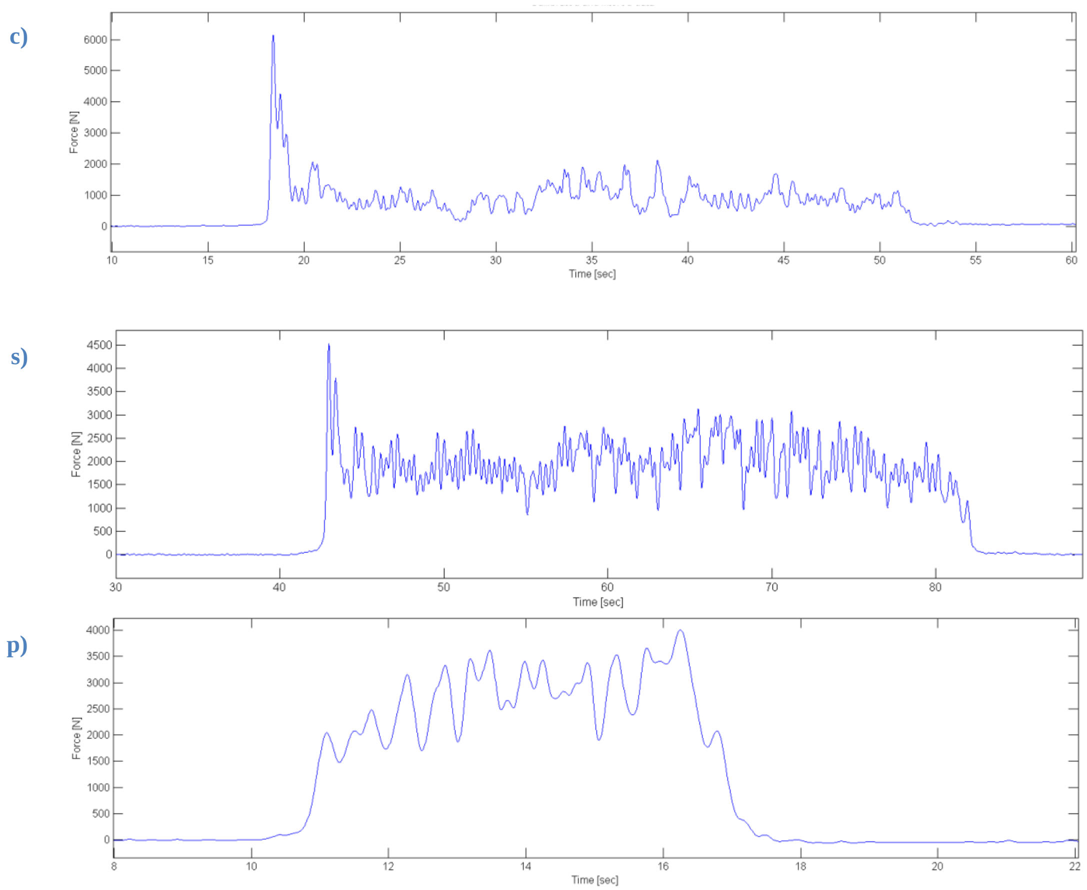

Figure 18: Force profile of a c) cart, s) sledge, p) plough

Table 3: Summary of force measurement data per type of load

	N	Average	Min	Max	Standard Deviation
Cart					
TOF (N)	18	3618.28	1571.55	6866.80	1877.75
SSF (N)	18	857.30	211.49	1867.84	589.02
SSDEV	18	283.70	97.89	530.70	142.42
TOF/SSF	18	5.95	1.48	14.34	4.00
SSF/SSDEV	18	2.78	1.76	4.32	0.83
Sledge					
TOF (N)	28	2160.67	159.59	4521.70	1104.02
SSF (N)	28	1077.20	52.41	2727.40	667.39
SSDEV	28	179.00	14.18	351.33	96.88
TOF/SSF	28	2.23	1.29	3.13	0.55
SSF/SSDEV	28	6.32	2.42	14.44	3.48
Plough					
TOF (N)	57	2642.58	971.85	5203.10	1208.15
SSF (N)	57	1853.67	590.86	3598.55	837.99
SSDEV	57	248.53	140.26	462.02	98.36
TOF/SSF	57	1.45	1.19	1.73	0.17
SSF/SSDEV	57	7.36	3.89	10.65	1.64

As seen in Figure 18 the cart has a much higher TOF/SSF which means that for the same TOF the cart has a lower SSF. The corresponding boxplot is shown in Figure 19 and ANOVA analysis confirmed a significant difference between the cart and the other two type of loads but not significant difference between the plough and the sledge. This difference can be due to the rolling mechanism. Once the load is pulled into motion, the force needed to keep a cart in motion is much lower compared to a sledge. Since a plough is pulled 'into' the ground you can even see an increasing force in Figure 18c. The SSF/SSDEV is also higher for the cart, visualized in Figure 20 and ANOVA analysis confirming a significant difference between the cart and the other two. This means that for the same SSF the cart has a higher SSDEV. This phenomenon seems contradictory to the explanation above. Expectations are that once a cart is pulled into motion it is easier to keep it in motion so that the force needed during the successive step is lower than compared with the sledge or plough. Another reason might be that due to the heavier load the cart will swing more back and forth causing a higher SSDEV.

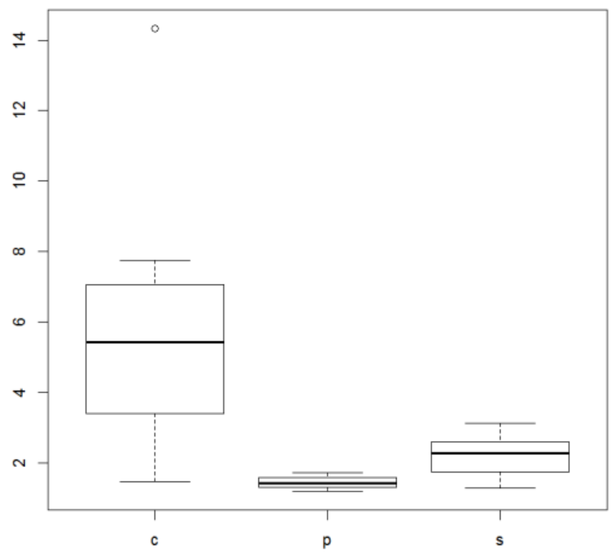

Figure 19: Boxplot of TOF/SSF for the different type of loads

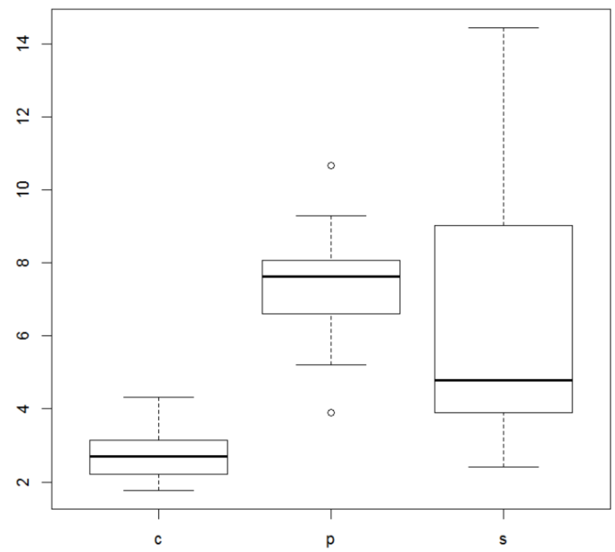

Figure 20: Boxplot of SSF/SSDEV for the different type of loads

Furthermore some potentially relevant relationships are studied. First of all the effect of increasing SSF on the TOF for the different type of loads is studied and the results are shown below where significant p-values (< 0.05) are indicted with a ‘*’.

Table 4: Linear regression models between TOF and SSF for the 3 different type of loads

	TOF	
	Estimate	*p-value*
SSF		
Cart	2.47	< 0.01 *
Plough	1.00	< 0.01 *
Sledge	1.21	< 0.01 *
R^2	0.52	

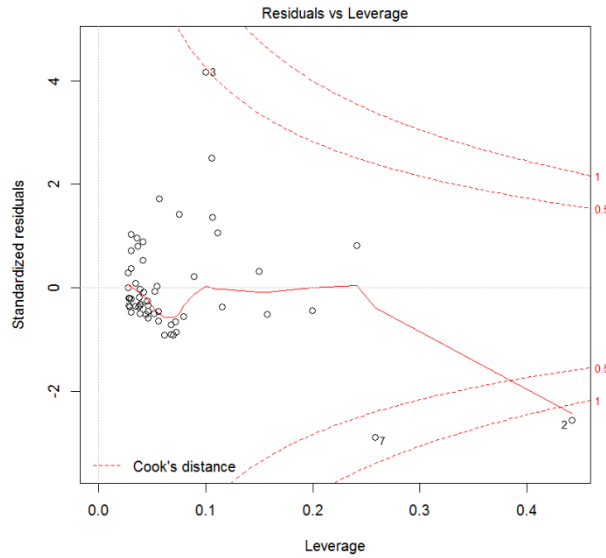

Figure 21: Residual vs leverage plot of TOF vs SSF

It's clear that the SSF has a significant effect on the TOF for the 3 different type of loads. The scatter plot in Figure 21 shows the present of three outliers. When leaving these out we get a new model as shown in Table 5 and Figure 22.

Table 5: Adjusted linear regression models between TOF and SSF for the 3 different type of loads

	TOF	
	Estimate	*p-value*
SSF		
Cart	4.80	< 0.01 *
Plough	1.16	< 0.01 *
Sledge	1.46	< 0.01 *
R^2	0.80	

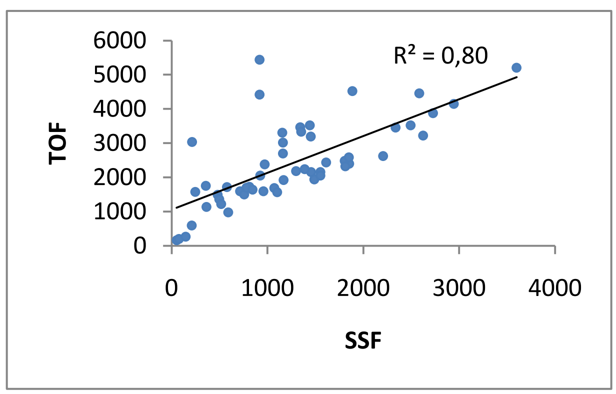

Figure 22: Scatter plot of SSF vs TOF

This means that for all 3 types of loads the TOF is significantly influenced by the change of SSF which is not surprising. The force needed to pull an object into motion equals the normal force multiplied with the friction coefficient. So whenever the weight is increased, independent of the type of load, both the force needed to pull the load into motion and the force needed to keep it into motion will increase. Since the static friction coefficient is higher than the dynamic one the TOF will be higher than the SSF.

Next the change of SSDEV is studied. The effect of both SSF and TOF on SSDEV is studied as shown below.

Table 6: Linear regression models between SSDEV and SSF and TOF for the 3 different type of loads

	SSDEV	
	Estimate	*p-value*
SSF		
Cart	0.22	< 0.01 *
Plough	0.09	0.53
Sledge	-0.10	< 0.01 *
TOF		
Cart	0.02	< 0.01 *
Plough	0.02	0.06
Sledge	0.12	< 0.01 *
R^2	0.89	

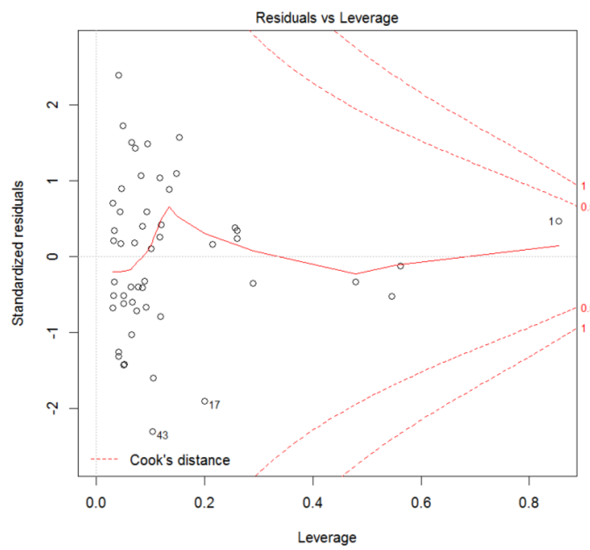

Figure 23: Residual vs leverage plot of SSDEV vs SSF&TOF

Table 6 shows that the total variation of the SSDEV can be predicted for 89% with this model. For the influence of the SSF only the cart and sledge have a significant influence. However the SSF of the cart and the sledge have an opposite influence on the SSDEV where the cart has a positive coefficient, the sledge has a negative one. This means that for increasing SSF of the cart the SSDEV will increase too. An increase of the SSF of the sledge will cause the SSDEV to decrease. Furthermore the TOF of the cart and the sledge both have a positive correlation with the SSDEV. The effect of the sledge seems quite surprising since the SSF and TOF have opposite effects on the SSDEV whereas for the cart both SSF and TOF are positively correlated with SSDEV, so next the TOF/SSF to SSF for the different type of loads will be studied.

Table 7: Linear regression models between TOF/SSF and SSF for the 3 different type of loads

	TOF/SSF	
	Estimate	*p-value*
SSF		
Cart	< 0.01	0.71
Plough	-0.001	< 0.01 *
Sledge	-0.001	< 0.01 *
R^2	0.26	

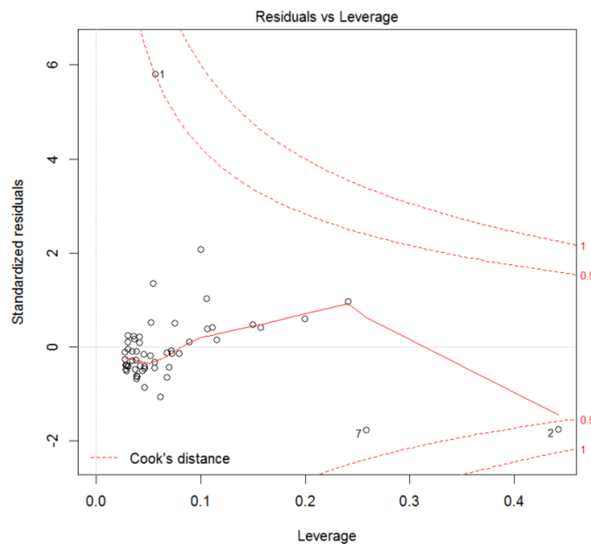

Figure 24: Residual vs leverage plot of TOF/SSF vs SSF

Table 7 shows significant effects of increasing SSF of the plough and sledge on the TOF/SSF. Leaving the data point 1 and 2 out as outliers result in a new model with R^2 of 0.47 as shown in Figure 25 (the hollow dots are the data points of the cart). The negative correlations between SSF and TOF/SSF indicate that when the load increases the horse has to generate less TOF relative to the SSF. Every horse has a maximum deliverable force so initially the TOF will increase with increasing load but it will reach its maximum even if the SSF increases.

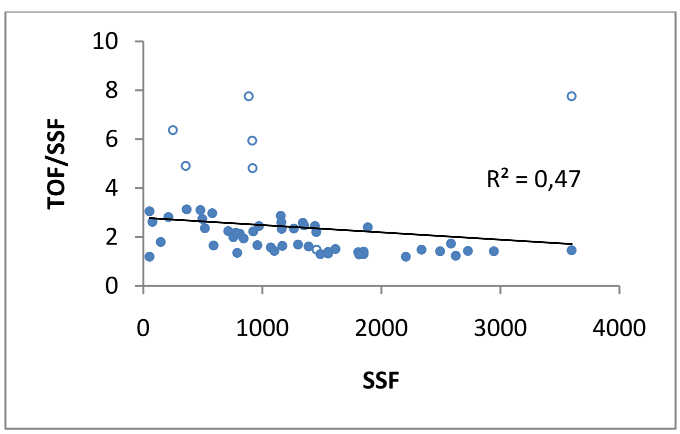

Figure 25: Scatter plot of SSF vs TOF/SSF

Next the influence of the horses' dimensions on the force parameters is checked. The results are shown in Table 8.

Table 8: Linear regression models between TOF, SSDEV and the horse's dimensions

	TOF		SSDEV	
	Estimate	*p-value*	*Estimate*	*p-value*
Withers' height	-62.26	< 0.01 *	-3.97	0.03 *
Length	17.12	0.38	1.08	0.52
Chest's circumference	16.33	0.36	0.36	0.81
R^2	0.16		0.09	

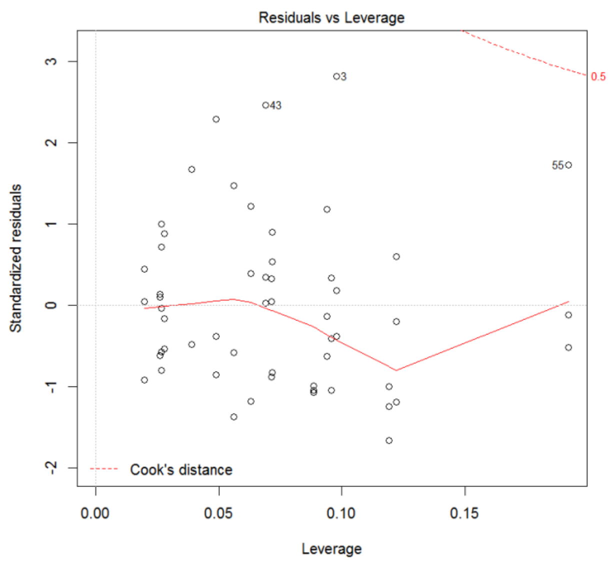

Figure 26: Residual vs leverage plot of TOF vs horse's dimension

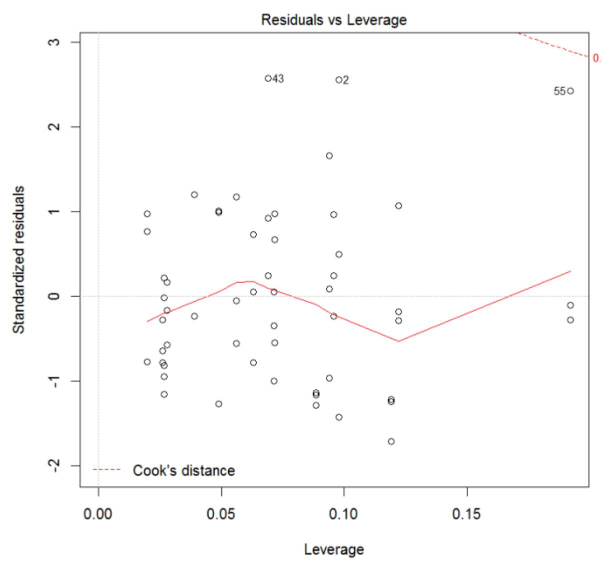

Figure 27: Residual vs leverage plot of SSDEV vs horse's dimension

Figure 26 and Figure 27 shows that both models do not have any significant outliers. Furthermore Table 8 shows that only the withers' height is negatively related to the TOF and SSDEV meaning that horses with higher withers will have a lower TOF and SSDEV. It is possible that bigger horses are able to use their entire body weight more so they can put their weight 'into' the harness for pulling instead of 'launching' themselves so that the TOF will be lower. For the SSDEV the explanation is similar. Due to the discontinue nature of the walk there will be a point where a minimum of pulling force can be carried out. During this phase the load will also decelerate more (due to inertia). You could compare the moment after every deceleration phase with a small takeoff so again, smaller horses will need to 'launch' themselves every time so that the SSDEV is larger for them.

Correlations between the horses dimension parameters are checked in Figure 28 with the matching Pearson's coefficients, which are displayed in Table 9.

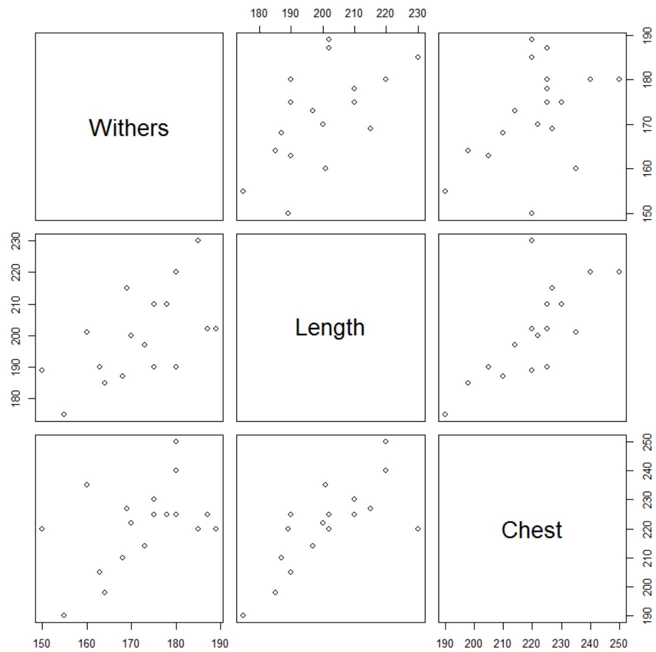

Figure 28: Scatter plots between the dimension parameters

Table 9: Correlations between horses' dimensions

	Withers' height	Length	Chest's circumference
Withers' height			
r		0.60	0.46
p-value		< 0,01 *	< 0,01 *
Length			
r			0.72
p-value			< 0,01 *
Chest's circumference			
r			
p-value			

This shows that the length of the horse is rather strongly correlated with the circumference of the chest of the horse. The correlation between the height of the withers and the length and chest's circumference is also present but less clear. This could be important for the interpretation of the data since strongly correlated parameters, if significant, could be predicting the same part of the variation of the data. So rather than seeing them as completely separate parameters it's better to see them as a set of related parameters.

6.2 Motion analysis

The motion parameters are minimum distance between the nose and the withers (minNW), angle of the head relative to the line of the withers (AH), minimum distance between the withers and the hind leg (minWH), minimum angle of front leg relative to the line of the withers (minAF), maximum angle of the front leg (maxAF) and the angle difference between the maximum and the minimum (AF). A summary of the motion analysis data is given in Table 10 showing the number of data points, their averages, minima, maxima and standard deviation.

Table 10: Summary of motion measurement data

	N	Average	Min	Max	Standard Deviation
minNW (cm)	55	84.18	52.78	105.85	12.26
AH (°)	55	24.04	5.75	88.53	12.34
minWH (cm)	55	133.72	97.41	165.75	15.35
maxWH (cm)	55	185.63	138.78	230.45	20.90
minAF (°)	55	59.92	42.49	69.91	5.85
maxAF (°)	55	116.31	105.86	142.32	7.68
AF (°)	55	56.39	41.71	99.83	10.03

To make the different locomotion parameters comparable between the different horses the dependency of these parameters on the horses' dimensions was studied. In the first step we see if horses' dimensions have an individual effect on the locomotion parameter. Table 11 shows the individual correlations between the different force represented by the Pearson correlation coefficients (r) with its p-values. Pearson correlation coefficients (r) of 0.7 and higher (absolute value) means that there is a strong correlation between the two variables. Between 0.3 and 0.7 the correlation is rather weak whereas under 0.3 there is only little or no association. The significant correlations have p-values below 0.05 (indicated with a * in the table above), will be discussed individually.

Table 11: Linear regression models between horses' dimensions and motion parameters

	minNW	AH	minWH	maxWH	minAF	maxAF	AF
Withers' height							
r	0.51	0.12	0.54	0.38	0.22	0.02	-0.12
p-value	< 0,01 *	0.40	< 0,01 *	< 0,01 *	0.10	0.89	0.40
Length							
r	0.54	-0.14	0.15	< 0,01	-0.02	0.25	0.20
p-value	< 0,01 *	0.32	0.28	0.96	0.89	0.07	0.14
Chest's circumference							
r	0.48	-0.03	0.12	-0.04	0.14	0.28	0.14
p-value	< 0,01 *	0.86	0.39	0.79	0.32	0.04	0.32

This table shows that the withers' height is associated with the minWH. This means that for a smaller horse the minWH will also be smaller. This seems logical since larger horses tend to have a longer neck so that the distance between the nose and withers will also be larger. Furthermore it seems that both the minimum and maximum distance between the withers and the hind leg are also correlated with the withers' height. This means that the distance between the hind leg and the withers will be larger both at its minimum and its maximum with increasing withers' height. When a horse is taller the distance from its withers to its hind leg will be automatically larger then with smaller horses so that the minimum distance will be larger for larger horses. Finally both the length and the chest's circumference are also correlated with the minWH probably for the same reason as mentioned for the withers' height.

Next a multiple regression analysis between the horses' dimensions and the motion parameters is done for the different type of loads. Results are shown in Table 12.

Table 12: Multiple regression models between the horses' dimensions to motion parameters (Est = Estimate, p = p-value)

	minNW		AH		minWH		maxWH		minAF		maxAF		AF	
	Est	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*	*Est*	*p*
Withers' height														
Cart	0.75	0.25	0.44	0.56	1.87	0.02 *	2.26	0.065	0.14	0.68	0.40	0.36	0.26	0.63
Plough	0.36	0.47	-0.75	0.20	1.04	0.07	0.82	0.38	-0.06	0.83	-0.07	0.83	-0.01	0.97
Sledge	0.24	0.21	0.39	0.09	0.86	< 0.01*	1.15	< 0.01*	0.23	0.03 *	-0.11	0.38	-0.34	0.04 *
Length														
Cart	-1.02	0.39	-0.40	0.78	-0.41	0.77	-1.91	0.39	-0.85	0.19	-0.11	0.90	0.74	0.46
Plough	0.17	0.53	0.03	0.92	-0.19	0.55	< 0.01	0.99	-0.04	0.76	0.05	0.80	0.09	0.69
Sledge	0.09	0.75	-0.26	0.45	-0.15	0.67	-0.44	0.43	-0.27	0.10	0.35	0.09	0.62	0.02 *
Chest's circumference														
Cart	0.79	0.24	-0.001	0.99	-0.28	0.72	0.53	0.66	0.65	0.07	0.05	0.91	-0.60	0.29
Plough	0.06	0.77	0.53	0.05 *	0.11	0.67	-0.12	0.77	0.10	0.40	0.23	0.12	0.13	0.47
Sledge	0.21	0.45	-0.08	0.82	0.28	0.38	0.07	0.89	0.08	0.58	-0.01	0.96	-0.09	0.69
R^2	0.41		0.19		0.49		0.29		0.25		0.30		0.37	

Also here there is a significant relation between the minWH and the height of the withers but only for the cart and the sledge. Furthermore the sledge also shows a significant relation between the maxWH and the wither's height. Different than the results in Table 11 is the significant relation for the sledge between the minAF and the withers height, the AF and wither's height and length. The reason that there are more significant relations for the sledge could be due to the number of data points which are higher for the sledge than for the cart and plough. The minAF is positively related with the height of the withers whereas the AF is negatively related. This means that taller horses will have a bigger minAF so the front leg will remain on the ground for a shorter period of time and consequently the total angle covered by the front leg (AF) will be smaller too. Since the front legs have a stabilizing function and taller horses are further away from the ground they cannot afford themselves to have a too large angle on the front leg because they need the stabilization more than smaller horses. The length of the horse is positively correlated with the AF which means that longer horses will cover a wider total angle with their front legs than compared with smaller horses.

6.3 Combined force and motion analysis

To investigate the effect of higher loads on the locomotion parameters the force and motion analysis need to be combined.

The relationships between the force and motion parameters are studied taken into account the physical dimension parameters. Moreover the effect of the individual horse will be taken into account as well.

The analysis is made by means of linear mixed effects models where the dependent variables are the motion parameters and the physical dimensions and force parameters are considered as fixed effects and the effect of the horse as a random effect. This means that random variation of each horse is expected which could not be controlled during the experiments.

Table 13: Linear mixed effects models between force and motion parameters (minNW and AH)

	minNW		AH	
Fixed effects	Estimate	p-value	Estimate	p-value
Dimension parameters				
Withers' height	0.33	0.17	0.38	0.08
Length	0.14	0.53	-0.31	0.09
Chest's circumference	0.06	0.78	0.12	0.47
Force parameters				
SSF				
Cart	< 0,01	0.02 *	< 0,01	0.93
Plough	< 0,01	0.67	0.03	0.02 *
Sledge	0.02	< 0,01 *	-0.01	0.06
TOF				
Cart	< 0,01	0.30	< 0,01	0.79
Plough	-0.001	0.82	-0.02	0.02 *
Sledge	-0.01	< 0,01 *	< 0,01	0.02 *
Random effect	Lower	Upper	Lower	Upper
Horse	5.42	9.15	9.12	14.04

First of all a significant relation between the SSF and the minNW is detected for the cart and the sledge. This means that when the load gets heavier the horse will collect himself more at the front. It's possible that this goes together with a total collection at the hind quarters too but this was not studied here. For the plough the SSF is related to AH which means that for a higher load the horse will elevate his head more. Minimizing the distance between the shoulders and the head could be a way of the horse to save power. Supporting the head needs a certain amount of power and this is proportional to the distance of the head to the shoulder (where the neck muscles are attached). For this reason exerting force for pulling should be more economical to minimize other power expenses.

Next the table shows a negative relation between the TOF and the minNW for the sledge, which is against expectations. With an analogue way of thinking we would expect the horse to collect more when takeoff force is higher but the opposite is seen here. The TOF of the sledge however does show a positive relation with the AH which means that with great takeoff force the horse will have a bigger elevation at the front end which is conform with the expectations. Then again the TOF of the plough is also against the expectations since it shows a negative relation with the AH which would mean that for a plough the horse would sink his head more when the loads gets higher instead of rising it. It might be possible that this is due to the loose soil that was present on the field for the experiments where the plough was used. So the horses sank more into the ground making it harder for them to assume a proper posture. Last the random effect of the horse shows a confidence interval with 0 excluded every time which means that the individual horse has an effect on the parameters studied.

Table 14: Linear mixed effects models between force and motion parameters (minWH and maxWH)

	minWH		maxWH	
Fixed effects	Estimate	p-value	Estimate	p-value
Dimension parameters				
Withers' height	1.10	< 0,01 *	1.17	0.04 *
Length	-0.28	0.33	-0.48	0.35
Chest's circumference	-0.05	0.84	-0.29	0.53
Force parameters				
SSF				
Cart	-0.009	0.02 *	-0.01	0.05
Plough	-0.002	0.84	< 0,01	0.63
Sledge	0.02	< 0,01 *	0.03	< 0,01 *
TOF				
Cart	< 0,01	0.49	-0.0003	0.86
Plough	-0.002	0.66	-0.005	0.49
Sledge	-0.01	< 0,01 *	-0.02	< 0,01 *
Random effect	Lower	Upper	Lower	Upper
Horse	6.36	10.87	10.26	17.61

As discussed before this table also shows a significant relation between the height of the withers and the distance between the withers and hind leg. For the relation between SSF and minWH the analysis shows a different effect for the cart as for the sledge. A negative effect of the cart SSF on the minWH would mean that with heavier loads the distance between the withers and the hind leg would become smaller. The effect of heavier loads on the minWH however is opposite with the sledge.

The effect of the sledge's SSF on the maxWH is within expectations i.e. bigger maxWH with increasing SSF which means that the maximum distance between the withers and the hind leg increases when the load increases. Since the back leg is the propulsive power it's quite logical that it will remain longer on the ground to exert more force when the load gets heavier. This explanation is however countered by the negative relation between the TOF of the sledge and the maxWH. Which would mean that for higher takeoff force the distance between the withers and hind leg gets smaller. For the minWH there is a negative relation between the TOF and the minWH for the sledge. This is also contradictory to the positive relation between the SSF of the sledge and the minWH. This table confirms some hypotheses but also has quite some results opposing them which makes it hard to make a final conclusion. Finally the effect of the individual horse is again confirmed here as was in Table 13.

Table 15: Linear mixed effects models between force and motion parameters (minAF, maxAF and AF)

	minAF		maxAF		AF	
Fixed effects	Estimate	p-value	Estimate	p-value	Estimate	p-value
Dimension parameters						
Withers' height	0.14	0.28	-0.06	0.75	-0.21	0.40
Length	-0.18	0.12	0.14	0.44	0.31	0.17
Chest's circumference	0.12	0.24	0.11	0.52	< 0,01	1.00
Force parameters						
SSF						
Cart	-0.0006	0.85	< 0,01	0.62	< 0,01	0.74
Plough	-0.003	0.62	-0.0003	0.97	< 0,01	0.93
Sledge	< 0,01	0.44	0	1.00	-0.003	0.62
TOF						
Cart	-0.0007	0.43	< 0,01	0.23	< 0,01	0.20
Plough	< 0,01	0.77	-0.0003	0.95	-0.0001	0.99
Sledge	-0.003	0.14	< 0,01	0.93	< 0,01	0.30
Random effect	Lower	Upper	Lower	Upper	Lower	Upper
Horse	4.53	7.02	4.96	8.31	6.83	11.01

This table shows no significant relations meaning that the angle of the front leg is in no way dependent of the force parameters. The effect of the individual horse is however again confirmed.

In general the combined force and motion analysis could not bring forth a hard and conclusive confirmation of any hypothesis.

6.4 General experiment discussion

In the previous sections it is shown that some parameters are significantly correlated with the application of higher loads, though the number of parameters is limited. It’s possible that other parameters are also of significant importance (f.e. lowering of the hind quarters) but have not been discovered during this experiments due to a non optimal experimental set up. In general there were a lot of variables that we could not control during the experiments. The weather for example. Horses tend to be more jumpy when there is a strong wind and in this way are not always listening properly to the commands that have been given to them. The soil on which the experiments were done was not always the same neither. This could vary from wet grass to sand to heavy dirt soil. This was due to the fact that the experiments had to be done on the site of the horse owner leaving little room for choice of different kinds of soil. Another very important factor is of course the horse-handler interaction. The way the horse is governed has a big influence on its performance. All these uncertainties could have influenced the experiments so that it was not executed in an optimal way.

Regarding the force analysis the biggest drawback was the difference in the load to pull. The type varied from sledge, cart till plough which give a very clear difference in pulling pattern as discussed before. This difference was far greater than expected so consequently had a very large influence on the experiments. This led to the splitting up of the analysis for the different type of loads. A big drawback here was that some subsets of the data became rather small which makes it hard to draw conclusions.

For the kinematic measurements both the difference in soil and load had an influence on the draught posture. Horses plowing in heavy dirt soil have more grip on the ground so that they will be allowed to assume a different posture. Furthermore the markers were attached to only one side of the horse. In some cases the first pull motion was done by the other leg without marker so that this information was missed, this was discovered visually during the video analysis. The same problem was found for the croup. Due to difficulties for attaching markers there, a potentially interesting body part was not monitored.

For a first exploring experiment it might have been better to have more standardized environments to dismiss the effect of a lot of variables. Also, more repetition would make it possible to remove extreme data.

7 General conclusion

Nowadays draught horses are mainly kept as hobby animals. Studbook inspections try to judge the horse by its exterior and gait but lack a way to assess draught performance. Furthermore, for the upcoming reemployment of horses in urban tasks such as garbage collecting, it is of economical importance to find the right horse for the right job. This thesis worked towards the development of an objective measuring technique that can be performed quickly and easily to assess the draught performance of heavy horses.

The force analysis showed a negative relation between increasing steady state force level (representing the load) and the takeoff force to steady state force ratio which means that for increasing load the takeoff force peak becomes lower relative to the steady state level. This could be due to the presence of a maximum deliverable takeoff force. Once this is reached, the takeoff force will not increase anymore despite rising steady state forces.

The second part of the force analysis showed that the height of the withers had a negative relation with both the steady state force variation as the takeoff force which means that for the same steady state force level, taller horses generate a lower takeoff force and have a smaller variation on the steady state level. This could be due to the fact that an increased height of the withers implies a heavier body weight so that taller horses can put their body weight more into the harness. In this way a lower extra force needs to be delivered to pull the load into motion or maintain this motion.

The three different types of loads that were used (cart, plough and sledge) brought forth a very interesting difference in force profile. The characteristic profiles for each type of load were clearly distinguishable. If the force profile of the sledge is taken as standard it was clear that the cart had a much lower steady state force level relative to the takeoff force needed. This can be explained by the rolling mechanism where a load on wheels need less force to maintain movement compared to a sledge. The plough on the other hand does not have a takeoff force peak since it is been pulled into the ground. The force gradually increases until steady state force level and will maintain this level as long as it’s being pulled forward.

Motion analysis first of all showed that there is a strong correlation between the different dimensions of the horse meaning that large horses in height will also be longer in length and wider around the chest. Furthermore both multiple as individual regression analysis has shown that the maximum and minimum length between the withers of the horse and its hind leg is dependent of the height of the withers of the horse.

Combined force and motion analysis showed quite some contradictory results. Since the steady state force and the takeoff force are positively related with each other, expectations are that if one of the two has an effect on any motion parameter, the other would have the same effect. The analysis however often showed a positive relation of for example the steady state force with the angle of the head whereas the takeoff force had a negative relation with this parameter. A closer look at the video material revealed some less optimal aspects on the experimental set up that could be the cause of this non conclusive analysis. Points for improvement are the low number of data points so that outliers could not be averaged out. Experimental environment could be more standardized so minimal influence of environmental changes could be achieved. Different types of loads are certainly not ideally as proven here. However the combined force and motion did confirmed the chosen motion parameters to be horse dependent. This means that if they would be also draught performance dependent then they can be used for individual performance measurement.

Finally some suggestions will be made towards future research on this topic.

First of all it would be better to construct a sledge or cart so that a standardized load can be used for every horse. The harness should be of the same type for every horse, either breastband or collar harness, since the draught mechanics will most probably be different for the two types (this would however be an interesting study to do too).

Another environmental factor to control is the type of soil. This could be achieved by doing all the experiments at the same location. Furthermore the horse should be left alone as much as possible so that it can assume the most natural posture as possible. Only the departure and stopping commands should be given and the direction in which the horse should walk should be indicated by a predefined track.

Next, additional markers could be applied, one on the croup to quantify the lowering of the hind quarters. The motion should ideally be tracked from both sides of the horse so that any characteristic posture change during takeoff is not missed since the videos showed that sometimes the first and most characteristic step is made by the leg that was not tracked. A sampling rate of 30 frames per second showed to be enough to track the draught movement.

Heart rate and heart rate variability measurements would be a good addition to the experiment since it would be easy to conduct, the results can be interpreted quickly and easily and they are good indications of the performance level.

Finally it's better to do the same experiment multiple times with the same horse and load so that any outliers could be averaged out. From this large scaled experiment a population average of every parameter for every particular load can be calculate. This average will be considered as the ideal value and can be used as a standard. Deviating values are then an indication of non optimal draught performance.

Once this test is developed it would be interesting to study the effect of the level of training, effect of the handler, age, sex,… In addition the current subjective scoring techniques such as visual inspections could be compared and validated with the objective scoring method.

In contrary to physiological, exterior and character tests, the development of this suggested test has the advantage to be objective, quick, easy and with optimization of the computer models it can be performed with direct results. This could then be used during studbook inspections or other selection procedures to find the right horse for the right job.

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