Student: Karen Goedknegt
Supervisor: Ben Gorissen
Examiner: Claudia Wolschrijn
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Pressure plate analysis in Dutch warmblood foals; the relation of peak vertical force, imbalance and development of balance with radiographic OCD scores.

Abstract

This study tried to determine the correlation between the peak vertical force, balance and the development of balance and the OC(D) score in the hock of 11 foals. The Dutch warmblood foals were clinically sound and were walked and trotted across a pressure plate during the first 6 months of their lives. At 6 weeks radiographs were made of all the foals, 6 foals were found to be OC(D) positive. After the second set of radiographs made at 6 months, the OC(D) positive group consisted of only 2 foals. It was found that the peak vertical force corrected for the weight of each foal (nPVF) was significantly lower in the group of foals diagnosed with OC(D) at 6 weeks of age. No significant difference between the OC(D) positive and negative group could be found at this age. Asymmetrical indexes were calculated to obtain values about the symmetry of the foals. No significant difference could be found between the OC(D) positive group and the negative group either at 6 weeks and at 6 months of age. The foals had a fair amount of imbalance when they were born and at 6 months of age the foals still were not as balanced as an adult horse.

Introduction

Foals are able to stand very soon after birth and walk around, at first glance their gait looks the same like an adult horse. However foals do not have the same postural control as adult horses. Development of balance requires maturation of the nervous and musculoskeletal systems. Also does the interaction between these two systems needs to mature(Nauwelaerts et al. 2013). In human infants development of the ability to walk takes almost a year. After this year, many more are needed to develop the same postural control as an adult. At firs children rely on fast, but imprecise ballistic control (open-loop control). This way of controlling movement uses movement from which the outcome is not clear until it has occurred. At the age of 4-7 years the children gradually change to a closed-loop control system. This system relies more on sensory feedback, this feedback is processed in the central nervous system and therefore causes a time delay. As a result this time delay causes a slower movement of the body's centre of mass and therefore less imbalance. (Riach, Starkes 1994). A strong suggestion that the development of balance in foals works the same way it does in humans is given by a study which studies the balance of foals during the first 5 months of life. Looking at the static balance of foals it was found that initially the foals had a high amplitude and velocity of the centre of pressure movements (COP). The most movement was found in the cranio-caudal direction. During the first week of life these values decreased enormously and they dropped further until the foals were 2-3 months old. At this age the foals displayed more movement in the lateral direction than in the cranio-caudal direction. The frequency of the COP movements did not changes much during the first 5 months of the foals life. (Nauwelaerts et al. 2013).
Aside from the imbalance shown by foals their behaviour also is different from adult horses. Foals need exercise to get a stable movement pattern(Back et al. 1999). However during exercise foals move in an explosive way and may cause increased mechanical strain on their joints at these moments. Together with the imbalance and ligament instability some horses show(Bohndorf 1998), these factors may lead to osteochondrosis (dissectans); OC(D).

Osteochondrosis is described as a focal failure of enchondral ossification. An area of growing cartilage fails to undergo calcification or vascular ingrowth. This results in a failure of ossification of the cartilage. Failure of enchondral ossification can occur at two sites, the physis where the lesions are caused by abnormal hypertrophic chondrocytes and the epiphysis where necrosis of cartilage is the main problem(Ytrehus et al. 2007). In foals the main problem is located in the epiphysis. The pathogenesis of lesions at both places isn't entirely known. Necrosis is thought to be one of the reasons in the pathogenesis of OC. However two different theories are formed on account of the necrosis in cartilage. One states that a focal interruption of canal blood supply cause chondrocytes closest to the metaphysis to die and this creates a barrier for vascularisation of normal matrix. This causes a thickened barrier to develop which consists of a mass of hypertrophic chondrocytes. The second hypothesis states that micro trauma in the vessels of the metaphysis interrupts the blood supply at the ossification front, because of this the terminal differentiation of hypertrophic chondrocytes cannot happen and a thickened cartilage plate persists(Ytrehus et al. 2007). Another reason for the development of OC is a malfunction of the production of type 2 collagen fibres in the cartilage. Hypertrophy of the cartilage leads to the production of type x collagen instead of type 2 this may lead to weakness and micro- or macro trauma of the blood vessels(Laverty, Girard 2013). Besides the decrease in collage fibres there is also evidence that the production of collage type 2 is upregulated in young animals suffering from osteochondrosis, this also may destroy the normal structure of the cartilage and also make it more susceptible to trauma, especially considering the movement pattern of foals (Laverty, Girard 2013).

The ethology of osteochondrosis is multifactorial, factors which play a role in the disease of epiphyseal cartilage are rapid growth, heredity, anatomic characteristics, trauma and dietary factors (Ytrehus et al. 2007).

In horses osteochondrosis is most commonly found in the hock and knee(Sloet van Oldruitenborgh-Oosterbaan et al. 2007). There are predilection sites inside de hock and knee like the proximal articular surface of the femur, the lateral trochlear ridge of the femur, the medial condyle of the femur, the intermediate ridge of the distal tibia, the lateral trochlear ridge of talus and the dorsal aspect of the distal metacarpus and metatarsus (Adams 2002).These localisations are areas were high biomechanical stress occurs during movement. This biomechanical stress may be a factor in the development of osteochondrosis (Ytrehus et al. 2007). The increased stress on these specific areas may cause microtrauma and in time increase the prevalence of macroscopic osteochondral leasions (Ytrehus et al. 2007).

During this study a pressure plate was used to measure the gait of the foals. This study is the first to apply the pressure plate to foals, however it was previously used to study the gait in a number of different animals. (Meijer et al. 2014a)for example used the pressure mat to study the longitudinal development in growing pigs and found that the weight of the pigs was distributed unevenly in the cranio-caudal direction. Around 60% of their body weight is situated on their front legs. This weight distribution between the front and hind limbs is found to be the same in horses and ponies (Oosterlinck et al. 2011). In another study medio-lateral and toe-heel hoof balance was tested and it was found that horses have a significant left-right asymmetry in medio-lateral hoof balance. This knowledge may help in making decisions in shoeing a horse(Oosterlinck et al. 2010). A fourth study shows that the pressure plate can be used to study toe-heel and medio-lateral balance on a hard and soft surface. A peripheral load distribution was found on a hard surface and a more centrally located load distribution was found. Furthermore a significantly higher toe loading was found at mid stance on the soft surface compared to the hard surface at a walk and a trot(Oosterlinck et al. 2014). These studies show that the pressure plate is a valuable tool to analyse gait patterns and therefore a pressure plate was used in this study.

The aim of this study was to investigate the development of gait and balance in growing foals and the relationship with the occurrence of OC(D) . Horses of this age group have not been studied before. In order to study the gait patterns the nPVF (peak vertical force corrected for weight) was calculated to obtain measurements which could be used to examine the weight distribution of the foals. Also asymmetry indexes (ASIs) were calculated to examine the balance of the foals. The ASIs can be used to examine the weight distribution of the foals in cranio-caudal direction, medio-lateral and the diagonal direction at a trot. The results of these values were used to determine whether foals which had a positive OC(D) score had a different balance and peak vertical force compared with the foals which had a negative score. During this study the hypothesis states that foals which have a higher nPVF, more imbalance and need more time to develop balance will have a higher OCD score.

Materials and methods

Horses

11 healthy Dutch warmblood foals (5 mares, 6 stallions) all born between May and August 2014 and housed on the same stud farm where used for this study.

Methods of measurement and data collection

The runway consisted of the pressure mat with wooden plates next to it to broaden the surface. On top of the pressure plate a 5mm thick and 10m long rubber mat was laid(Nauwelaerts et al. 2013, Oosterlinck et al. 2011).

The pressure mat recordings were performed using Footscan® 3D Gait Scientific 2 m system (RSscan International, Olen, Belgium) with an active sensor surface 1.95 m × 0.32 m containing 16384 sensors (2.6 sensors per cm^2), with a sensitivity of 0.27-127 n/cm^2 and a measuring frequency of 126 Hz. The pressure mat was connected to a laptop with dedicated software (FootsScientific Gait 7 gait ^{2nd} generation, RSscan International). Calibration was performed with an 85kg person walking across the plate, following the manufacturer's instructions.

Before the foals where led across the pressure plate, measurements were taken to predict their weight using the method used by Staniar et al.(Staniar et al. 2004) since they could not be weighed at the location. Also photos were made of each foal to be able to look at the posture of their feet later.

The foals were led first at a walk and later at a trot across the pressure mat by a handler walking on the left side of the foal, depending if the foal was weaned or not the mother was led next to the foal. A run was considered valid if a foal was walking straight across the plate at its own normal velocity, with a minimal amount of manipulation by the handler and at least one limb fully contacted the pressure plate. The foal was led across the plate until 5 valid measurements were collected of each limb at walk and at trot.

Videos were made of each run to be able to determine which feet were measured in each run.

Measurements were taken every week starting the week the foal was born during the first 3 weeks, once every two weeks for the next 10 weeks and once a month until the foals were 6 months old. During the first two weeks measurements were only taken at a walk.

When the foals were around 6 weeks and 6 months of age radiographs were made to determine the OCD score. These radiographs were assessed according to previous used scores(Dik et al. 1999, Sloet van Oldruitenborgh-Oosterbaan et al. 2007), by a radiologist. To be able to obtain the radiographs safely, the foals were sedated with domosedan® (detomidine, Orion pharma) before making the radiographs.

Data processing

Using RSscan software, limb loading values (peak vertical force (nPVF in newtons), peak vertical pressure (PVP in newtons per square centimetre per kilogram),vertical impuls (VI in newton seconds per kilogram), load rate (LR in newtons per second per kilogram) were calculated for each run of each foot. Also the speed was obtained. PVF, PVP and VI were normalized for the body weight of each foal and are further used as nPVF, nPVP and nVI. The formula used to calculate the nPVF was: nPVF= PVF/ body weight . The mean of 5 runs was calculated per value for each week and each foal and these values were used for further statistical analysis.

An asymmetrical index (ASI) as has been introduced by(Nauwelaerts et al. 2013, Oomen et al. 2012) and has also been used previously in other studies(Meijer et al. 2014a, Meijer et al. 2014b, Oosterlinck et al. 2014, Oosterlinck et al. 2013) was calculated, this shows the balance of the foals between different limbs. All the directions and formulas are used before by (Meijer et al. 2014b)and are show in figure 1.

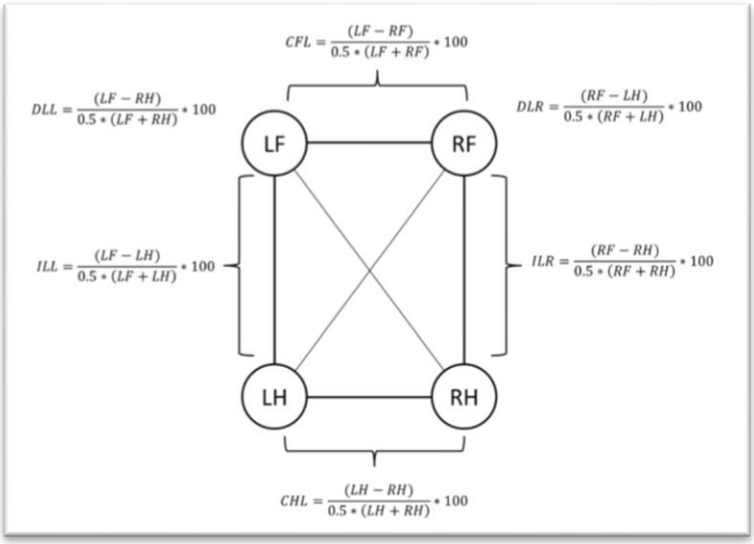


Figure 1 Formulas used for the calculation of the various ASIs (Meijer et al. 2014b). CFL: contralateral forelimbs, CHL: contralateral hind limbs, Ill: Ipsilateral left limbs, IRL: ipsilateral right limbs. DLL: Diagonal left fore and right hind limbs, DRL: Diagonal right fore and left hind limbs. LF: left fore, RF: right fore, LH: left hind, RH: right hind.

Three different types of ASI (the CHL, DLL and DRL) were used to calculate the difference between two following measuring moments, for example the difference between week 2-4, 4-6 and 6-8 for the first eight weeks. This was done to determine the variation in balance for each of the foals between the measuring moments. Two groups were made, the mean variation until eight weeks was divided using the OCD scores from the first set of radiographs. The mean of the variation from 8 to 24 weeks was divided using the OCD score of the last set of radiographs.

Statistical analysis

To determine if the data was normally divided, a Shapiro-Wilk test was performed. Also an independent sample t-test was used to determine if there was a significant difference between the OCD positive and the OCD negative group at 6 weeks and at 6 months. The significance was set on $p<0,05$.

Results

OCD scores

Radiographs of the knee and the tarsus were made. At the first set of radiographs at 4-8 weeks OCD scoring of the knee was not possible because of the physiological irregular contour and granular subchondral bone opacity of the femoral trochlear ridges. This may persists in the foals until the age of 3-5 months. In the second set OCD scoring of the knee was possible, however all the foals scored an A on this joint according to the scoring system used by(Dik et al. 1999). For this reason only the OCD scores of the Tarsus were used in this study.

The OCD scores of the foals at 6 weeks and 6 months are shown in figure 2 The scores were simplified into a binary score according to which grade of OCD is still accepted by insurance regulations(Sloet van Oldruitenborgh-Oosterbaan et al. 2007). Foals who scored an A and a B got a 0 and foals which scored a C, D or E got an 1. For the OC(D) scores for each specific location, see the table in appendix 1.

Of the 6 foals which scored OCD positive at 6 weeks, only 2 were found positive at 6 months.

	Location	Right hind Binary code	Left Hind Binary code
Foal 6 weeks	1	1	1
	2	1	0
	3	0	0
	4	0	1
	5	1	1
	6	0	0
	7	1	0
	8	0	0
	9	1	1
	10	0	0
	11	0	0

	Location	Right hind Binary code	Left Hind Binary code
Foal 6 months	1	0	0
	2	0	0
	3	0	0
	4	0	0
	5	1	1
	6	0	0
	7	0	0
	8	0	0
	9	1	0
	10	0	0
	11	0	0

Figure 2 OCD scores of the tarsus of the 11 foals at 6 weeks and 6 months. The binary code represents the positive and negative animals. A 0 represents a negative animal and a 1 represents a positive animal.

Velocity

The foals were led across the pressure plate at their own normal velocity. The velocity increased between the measuring moments, however it did not change much over the course of time. The mean velocity in week 2 was 2,23±0,57, in week 6 2,74±0,27 and in week 24 3,11±0,30. Figure 3 shows the mean velocity of all the foals for each week, it also show that there is little variation in the speed between the foals.

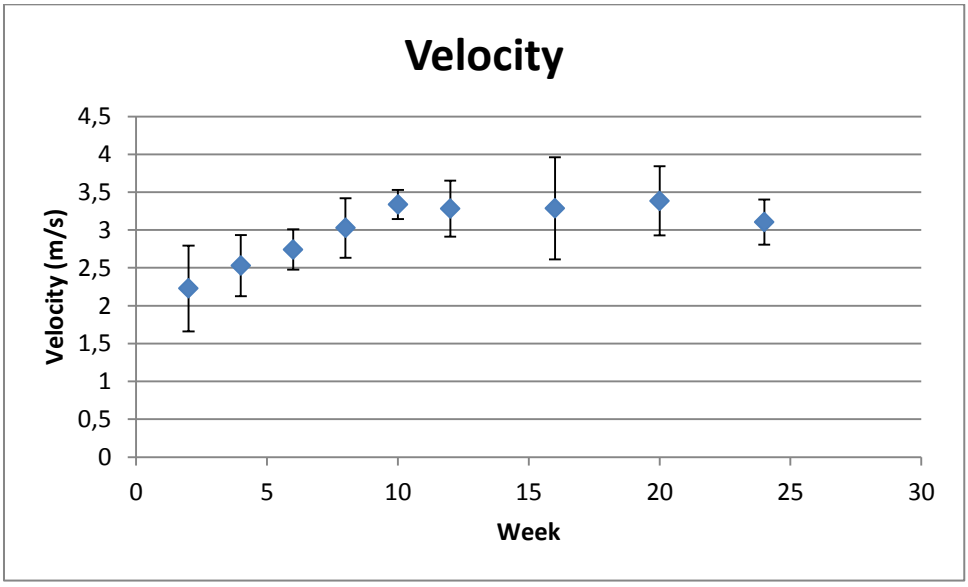


Figure 3 The mean velocity at a trot, for all the measuring moments.

Peak vertical force

The nPVF did not increase much over time, which is in accordance with the slight increase in the velocity. The mean nPVF for the left hind and the right hind limb are shown in figure 4.
In contrast to what is suggested by figure 4 the mean nPVF of the left and right hind legs of the foals show a lot of variance and the values are not as close together as initially thought, when we look at the foals individually in figure 5. Foal 10 and 11 show an higher nPVF in some of the weeks and foal 4 shows a high force at the last measuring moment.

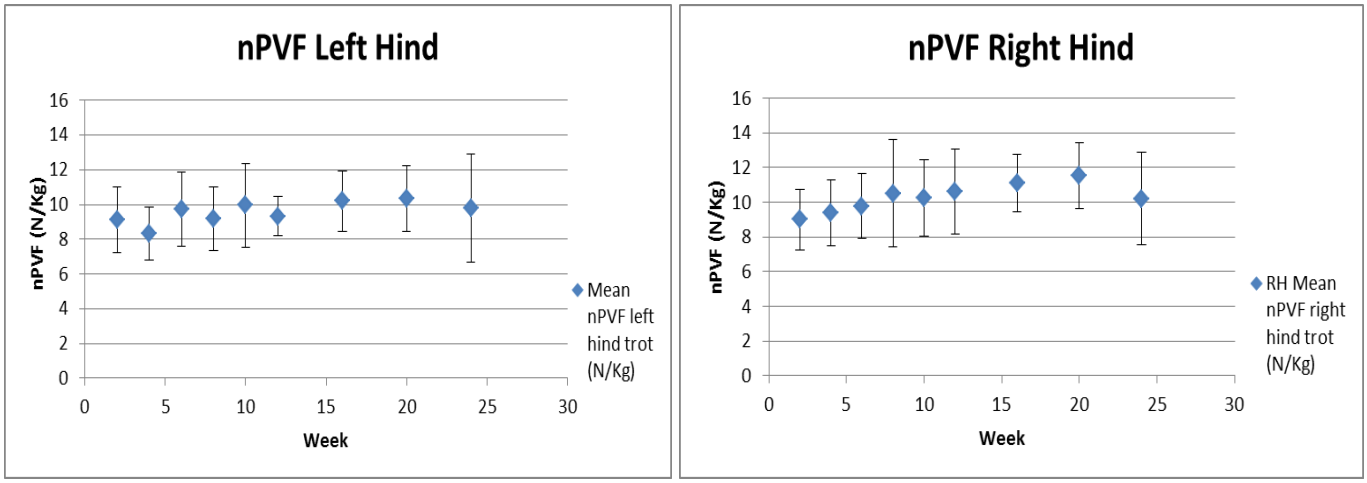


Figure 4 The mean nPVF and the standard deviation of the entire group of foals. Given for the left hind limb and the right hind limb.

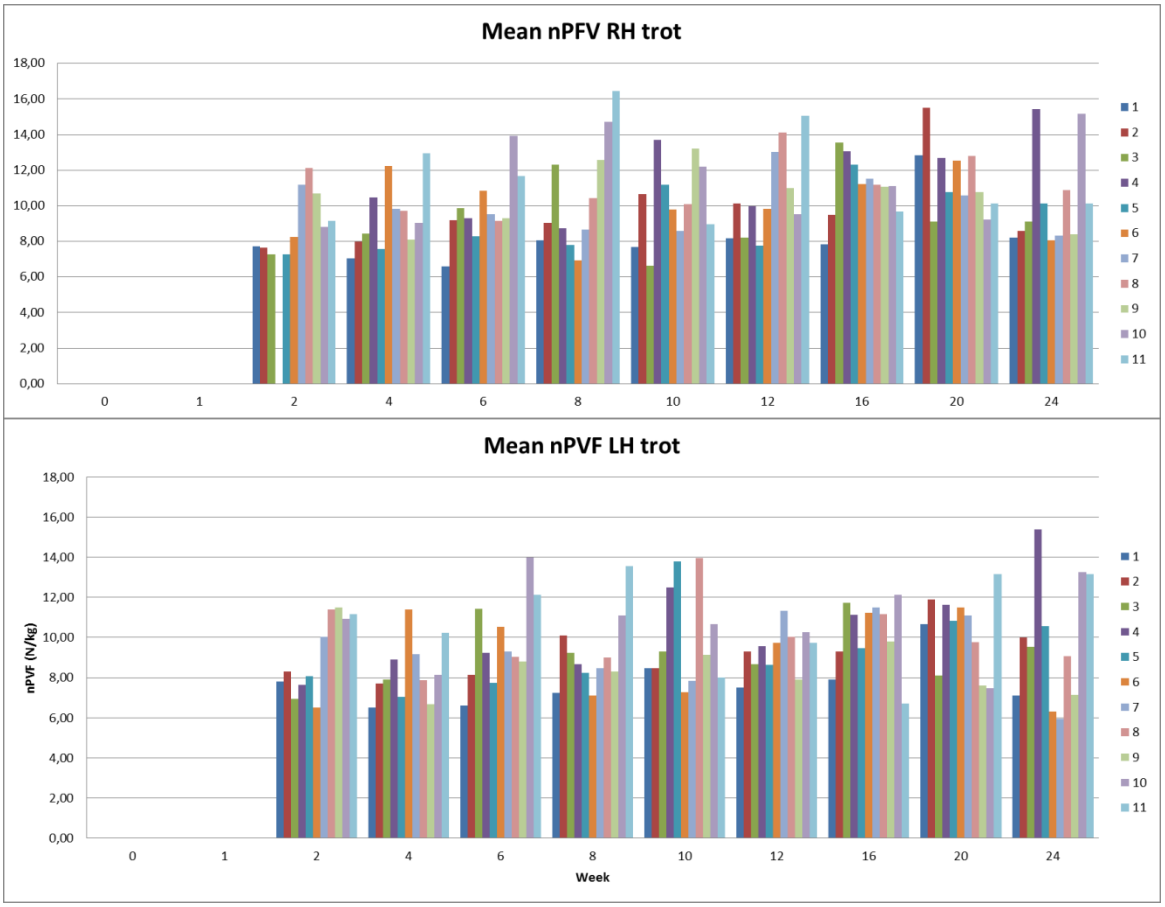


Figure 5 nPVF of the 11 foals individually given for the left hind leg (LH) and the right hind leg (RH).

When comparing the nPVF of the OCD positive and OCD negative groups for the hind legs, it is noticeable that the positive group shows a lower mean force than the negative group at 6 weeks. At 6 months only a small difference between the two groups was found. Although the positive group still showed a lower peak vertical force. On the right hind leg the mean force of the negative group was 10,74±1,20 and the positive group showed a mean force 10,58±0,83. The left hind leg showed the same trend the nPVF of the negative group was 9,91±1,06 and the nPVF of the positive group was 9,29±1,37.

The nPVF data was statistically tested and was found to be normally divided. Also a significant difference was found between the nPVF of the OCD positive group and the negative group at 6 weeks. At 6 months no significant difference was found between the two groups.
In figure 6 an overview is given of the mean and standard deviations of each limb, also the significance is indicated.

		6 weeks				6 months			
		OCD Positive		OCD Negative		OCD Positive		OCD Negative	
		Mean	Stdv	Mean	Stdv	Mean	Stdv	Mean	Stdv
Limb	LH	8,28*	0,92	9,97	1,06	9,29	1,37	9,91	1,06
	RH	8,60*	1,13	10,78	1,4	10,58	0,83	10,74	1,2

Figure 6 The mean and standard deviation of the left hind (LH) and right hind (LH) limbs, for the positive and negative group at 6 weeks and 6 months. The * shows which means are significantly lower than the other group of foals of the same age p<0,05.

ASI

The mean of the ASI of the collateral front legs and the collateral hind legs is -5,20±13,99 for the CFl and -7,02±14,94 for the CHL. These values show that the foals put more weight on their right hand side. The figures in appendix 4, which show the ASI balance between the left and right side of the foals (CFL and CHL), also make clear that the foals tend to lean towards their right side. The figures also show that not only there is a lot of difference between the ASIs of the foals, but also a lot of inter foal variability exists. Although not every foal changes the same amount.
When we look at the balance between the front and hind legs of the foals, the mean of the ILL ASI is 19,82±12,21 and the mean of the IRL is 18,42±13,69. This makes clear that the foals put more weight on their front legs, which is in accordance with some other studies done with horses and other animals(Kim 2008). The figures which show the ILL and IRL ASI of the foals can be found in appendix 4. These figures make clear that all the foals put the most weight on their front end, only foal 4 and 8 regularly change their balance in a way that puts more weight on their hind legs.

The ASI data was statistically tested and was found to be normally divided.
When we compared the difference in ASIs (CHL,DLL and DRL) between the OCD positive group and the OCD negative group statistically, it became clear that no difference between the two groups could be found. Both of the two groups show a lot of variation between each of the weeks.
The mean and the standard deviation of the variation of each of the different ASIs is shown in figure 7.

		6 weeks				6 months			
		OCD Positive		OCD Negative		OCD Positive		OCD Negative	
		Mean	Stdv	Mean	Stdv	Mean	Stdv	Mean	Stdv
Variation	CHL	11,83479499	7,347727223	20,31186003	8,490613607	16,13836014	3,401911423	19,593611	8,40552992
	DLL	17,99124893	5,02594418	11,57018615	7,099441648	15,16916581	3,692243689	19,360917	9,33287131
	DRL	17,00367267	11,37133888	18,20576892	7,84139712	19,01622587	4,758386868	16,25395	7,35114369

Figure 7 The Mean and standard deviation of the variation calculated for the contralateral hind limbs (CHL), diagonal left fore and right hind limbs (DLL) and diagonal right fore and left hind limbs (DRL) ASIs.

The balance of the foals does not become better over the months. The scatter plots in appendix 2 show that the variation between the foals does not become smaller and that each foal had a great variation between each of the measuring moments.

It has become clear in figure 2 that only two foals stay OC(D) positive during the second set of radiographs. When we look at the DRL ASI at 6 months of one of the foals which stays positive in one leg, it is noticeable that this one puts more weight on its front leg compared to the other foals. The ASI values are shown in figure 8.

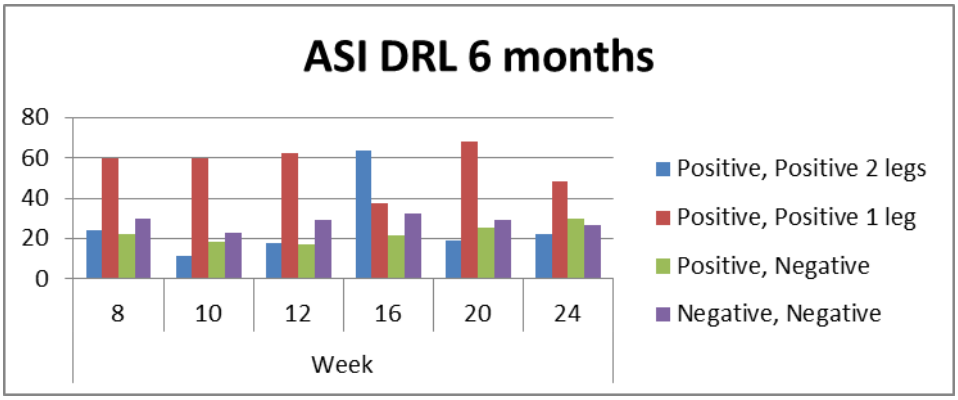


Figure 8 The DRL ASI of the foals at 6 months, the foals are divided in four groups specified on their OCD scores during the first and second set of radiographs. One of the foals stays positive in one leg after the second set of radiographs and shows that it puts more weight on its front limb, compared to the other foals.

Discussion

Measurements

During this study a low nPVF was found for the OCD positive foals during the first 6 weeks. A reason for this finding could be that osteochondrosis causes pain on the afflicted limb. This would cause the foal to lean more towards the collateral limb or towards the diagonal front limb when at a trot.
The differences in peak vertical force between the left and right hind limb mentioned in the results, may be explained by the difference in handling the foals. This is not very likely however, because the foals which show the highest nPVF values were not the foals which were the most difficult to handle. The most difficult foals to handle were foals 6, and 7. Foal 11 also turned out to be difficult at the last measuring moment, however this foals shows high force for a number of weeks. Foal 11 did show a dressage horse like trot, which may be the cause of the high force values.

The speed between the foals varies. Also the foals become faster as they grow older, the mean velocity in week 2 was 2,23±0,57 and in week 24 3,11±0,30. The developments of the speed of the foals at the walk and at a trot is shown in appendix 3. Although the speed of each foal varies slightly, the results of the foals still can be compared. The ASIs are percentages calculated using two feet of the same foal and therefore these percentages nullify the velocity of the foals.

Balance

The ILL and IRL ASIs given in appendix 4 show that most foals put the major part of their body weight on their front legs. However in contrast with the other foals foal 4 and 8 regularly change their balance between their front and their hind limbs. An explanation for this change of balance may be that the foals had problems with their front limbs. OC(D) occurs mostly in the hind limbs, however it can occur in the front limbs, also other problems could have existed in the front limbs of these foals. It is also possible that the foals just had a different weight distribution compared to the other foals, however since the weight distribution changed during every measuring moment, this is not the most likely explanation.
When we look closely at the ASIs of the CFL and CHL in appendix 4 the data shows that the horses all put a greater amount of body weight on their right hand side. This finding was surprising considering the fact that all the foals were clinically judged sound before each day of testing. There are multiple explanations which may be the cause of the foals favouring their right side. First the handler always walked on the left hand side of the foals. Since the foals sometimes were resisting being led by a handler it may be possible that the foals were pulling away from the handler and therefor landed more heavily on their right hand side. However the data collected shows that all the foals consistently favour their right side and not always were resisting being led this is not very likely.

Secondly the asymmetry may be caused by being led from the left side and while they may not resist this all of the time. Leading foals from one side permanently may cause the horses being trained to walk on their right side. This is also suggested by studies done on the development of laterality in horses consistently handled from their left side(McGreevy, Thomson 2006). However in another study it was show that only a small amount of the horses had a significant limb preference(Oosterlinck et al. 2013). Our foals were led from their left side for 6 months so they certainly were trained this way. However the favouritism of the right side shows from the first week of testing. Therefor training cannot be a reason of right handedness in these animals, since the foals did not have any training during the first week.
Thirdly the asymmetry can be a result of a functional difference between the collateral limbs. Research has identified extra-saggital movements which may indicate functional asymmetry(Heaps et al. 2011). This extra-saggital movement indicates a biomechanical difference between the force distribution on the left and right front limb even in sound horses(Oosterlinck et al. 2013). It may be possible that sound horses are not entirely symmetrical and this may be the cause of the right handedness in the foals used in this study.

During this study we were looking for variations in gait patterns, however during the experiment several methods may have caused a decrease in these variations. During the study 5 individual runs for each foot were used to calculate the mean values for each limb at a certain measuring moment. However criteria for selecting these five runs can be reason for discussion. Normally the 5 first runs were used for each limb, to calculate the mean. However when a value was extremely high or low, this run for this limb was excluded. It may be the case that by doing this, the variation between the limbs was made less than it originally would have been. When looking at other studies it does not become clear which criteria's have been used to select valid runs(Meijer et al. 2014b, Oosterlinck et al. 2013, Oosterlinck et al. 2014).
All horses have a certain amount of asymmetry, because of contralateral limb variations (Weller et al. 2006). However another way the extreme imbalance values may have been excluded is through the usage of sound foals. Asymmetry can be visually recognized when there is a difference in amplitude of 25% or more between two limbs. Therefore because of the exclusion of visually lame foals the variations between the limbs of the foals will be lower than 25% (Parkes et al. 2009). Since most of the ASIs are lower than 25% this is likely to have happened.
It may have been possible that a foal did not walk sound, because of the osteochondrosis, however osteochondrosis does not always causes lameness Also the foals which were excluded from a measuring moment because of lameness, did have signs for other reasons of lameness. For example thickening of the limb and some blood on the joint.

Ideally the ASI values would have been calculated using measurements of the two compared feet found in a single run. However it was difficult to walk the foals across the pressure plate in a way that would obtain measurements of all four feet. As the foals grew older the foals did not fit entirely on the pressure plate, which made it impossible to obtain measurements of all four feet in a single run. Because of this reason most of the compared feet come from independent measured limbs. It would have been better to obtain measurements of all the limbs in a single trial to minimise inter-trial variability like done by (Oosterlinck et al. 2010). However studies like (Barr et al. 1995) collected data from left and right front limbs independently, and therefore it is suggested that collecting data from two independent front limbs would give a reliable result. Especially since the mean of 5 runs has been used. Furthermore to obtain enough measurements with two compared feet on the plate in the same run, numerous more trials would have been necessary. This would have not been possible, because the foals got tired after a number of runs. It would not have been friendly to the foals to continue any more trials than around 12 at a walk and the same amount at a trot.
It is necessary to develop a pressure plate with a larger measuring area for large animals. This way measurements of all the limbs can be made in each trial.

Radiographs

During this study radiographs were made at two moments. At the first moment the foals were around 6 weeks old and during the second moment the foals were around 6 months old. Ideally radiographs would have been made during every measuring session. Making only two radiographs for each foal results in not knowing when the foals change from OCD positive in the first set of radiographs to negative in the second set of radiographs. When more radiographs had been made it would have been possible to determine in which group each foals should have been categorized for each measuring moment.

It was not possible to make more radiographs, because it would have been too expensive. Also would it not have been animal friendly for the foals, since it was necessary to sedate the foals to make it possible to make the radiographs.

It was chosen to make radiographs at these specific moments, because of the development of osteochondrosis. Osteochondrosis can be detected in foals as early as 3 days, and all OC can be detected within 3 months(Dik et al. 1999). Because of the possibility of early detection the first set of radiographs was made at 6 weeks. Osteochondrosis lesions are permanent after 5 months (Dik et al. 1999) in the hock and therefore it was chosen to make the second set of radiographs when the foals were around 6 months old.

After the first set of radiographs was assessed, it was found that 5 foals were positive for OC and one foal even had OCD. However only 2 foals remained OC positive during the last set of radiographs. Because of the low number of positive foals, no reliable conclusions can be made about the significance of the results in the second half of the study.

Ideally more foals would have been used for this study, however due to financial reasons and availability this was not possible. The foals which are used in this study are sport bred foals, which all have an owner. To obtain a large number of foals these should have been purchased and this was financially not possible. Also larger numbers of foals would take longer to measure during each week, and because of the availability of manpower during this study it was not possible to measure more days a week aside from what was already done.

To localize the lesions ideally diagnostic analgesia of the affected limb would have been used to localize the exact location of the lesions, however it was not possible to perform this procedure at the location.

Pressure plate vs. Force plate

To take measurements of the foals a pressure plate was used in this study, however a force plate is accepted as the 'gold standard' for the evaluation of lameness in different studies(Ishihara et al. 2009, Oosterlinck et al. 2010). The most important parameters in the gait of horses , the peak vertical force and vertical impulse can be measured more precise with the force plate. The problem with using a force plate is that it can only be used in experimental settings because of the way it has to be built into the floor. Also taking the welfare of the foals in mind and the money concerned with transporting the foals, it was not possible to transport the foals to an experimental setting to use a force plate and a pressure plate simultaneously. Another problem with the usage of a force plate in this study, is that it is impossible to differentiate between the force of different limbs hitting the plate simultaneously. Therefor a small force plate is needed and consecutive strides cannot be measured. Gathering data of all four feet would require an enormous amount of trials.

A pressure plate can be used to measure consecutive strides because of the high density of sensors, also it gives more detailed information about the loading of different areas of the foot during the entire stance period(Back et al. 2007, Adams 2002, Heel et al. 2004). Previously a pressure plate has been used to quantify lameness in dogs using a stand-alone foot pressure measuring system. Also has the pressure plate successfully been used to study the gait pattern of horses(Oosterlinck et al. 2010, Heel et al. 2004). A pressure plate was used in this study because of the ability of a pressure plate to distinguish consecutive feet during one trial and because of the option to carry the plate to the measuring location. Also its usage in the studies mentioned above, proves it to be a reliable instrument for measuring asymmetries.

Conclusion

This study provides data on the peak vertical force and the balance and the development of balance in Dutch warmblood foals followed during the first 6 months of their lives. The aim of this study was to determine the correlation between the peak vertical force and OC(D). Also a relation between OC(D) and balance and the development of balance was searched.
A significant difference was found between the nPVF of the OC(D) positive group and the OC(D) negative group. The positive group has a lower nPVF than the negative group. This was the case for the left hind limb and the right hind limb and also for the mean nPVF of the two limbs at 6 weeks. At 6 months no significant difference could be found between the two groups. An explanation for the lower nPVF value could be that the limb which has been affected with OC(D) hurts the foals. If one of the limbs causes pain for the foal, it would be logical to lean towards the sound limb.
The ASI values show that the foals have a preference for walking on their right hand side. Furthermore they put the major part of their body weight on their front limbs.
When looking at the variation between the CHL, DLL and DRL ASIs it became clear that there is a lot of variation between each of the measuring moments when we look at the foals individually and as a group. The foals clearly do not have the same balance as an adult horse, even at 6 months of age. Also no significant difference in variation could be found between the positive and negative group. Because of the small number of foals this study can be seen as an pilot study and further research is necessary to determine the correlation between OCD, nPVF and the balance of the foals. A larger group of foals is necessary, especially more foals which remain OC(D) positive until 6 months are needed.

References

ADAMS, O., 2002. Diseases of joints, tendons, ligamens, and related structures. In: *Adams' Lameness in Horses*5th ed.Lippincott Williams & Wilkins, pp. 459-644.

BACK, W., MACALLISTER, C., VAN HEEL, M.C., POLLMEIER, M. and HANSON, P., 2007. Vertical frontlimb ground reaction forces of sound and lame Warmbloods differ from those in Quarter Horses. *Journal of Equine Veterinary Science*, vol. 27, no. 3, pp. 123-129.

BACK, W., SMIT, L., SCHAMHARDT, H. and BARNEVELD, A., 1999. The influence of different exercise regimens on the development of locomotion in the foal. *Equine Veterinary Journal*, vol. 31, no. S31, pp. 106-111.

BARR, A.R., DOW, S.M. and GOODSHIP, A.E., 1995. Parameters of forelimb ground reaction force in 48 normal ponies. *The Veterinary Record*, Mar 25, vol. 136, no. 12, pp. 283-286 ISSN 0042-4900; 0042-4900.

BOHNDORF, K., 1998. Osteochondritis (osteochondrosis) dissecans: a review and new MRI classification. *European Radiology*, vol. 8, no. 1, pp. 103-112.

DIK, K., ENZERINK, E. and WEEREN, P., 1999. Radiographic development of osteochondral abnormalities, in the hock and stifle of Dutch Warmblood foals, from age 1 to 11 months. *Equine Veterinary Journal*, vol. 31, no. S31, pp. 9-15.

HEAPS, L., FRANKLIN, S. and COLBORNE, G., 2011. Horizontal moment around the hoof centre of pressure during walking on right and left circles. *Equine Veterinary Journal*, vol. 43, no. 2, pp. 190-195.

HEEL, M.v., BARNEVELD, A., WEEREN, P.v. and BACK, W., 2004. Dynamic pressure measurements for the detailed study of hoof balance: the effect of trimming. *Equine Veterinary Journal*, vol. 36, no. 8, pp. 778-782.

ISHIHARA, A., REED, S.M., RAJALA-SCHULTZ, P.J., ROBERTSON, J.T. and BERTONE, A.L., 2009. Use of kinetic gait analysis for detection, quantification, and differentiation of hind limb lameness and spinal ataxia in horses. *Journal of the American Veterinary Medical Association*, vol. 234, no. 5, pp. 644-651.

KIM, J., 2008. Temporospatial and kinetic characteristics of sheep walking on a pressure sensing walkway. *Canadian Journal of Veterinary Research*, vol. 72, no. 1, pp. 50-55 ISSN 0830-9000.

LAVERTY, S. and GIRARD, C., 2013. Pathogenesis of epiphyseal osteochondrosis. *The Veterinary Journal*, vol. 197, no. 1, pp. 3-12.

MCGREEVY, P.D. and THOMSON, P.C., 2006. Differences in motor laterality between breeds of performance horse. *Applied Animal Behaviour Science*, vol. 99, no. 1, pp. 183-190.

MEIJER, E., BERTHOLLE, C.P., OOSTERLINCK, M., van der Staay, Franz Josef, BACK, W. and VAN NES, A., 2014a. Pressure mat analysis of the longitudinal development of pig locomotion in growing pigs after weaning. *BMC Veterinary Research*, vol. 10, no. 1, pp. 37.

MEIJER, E., OOSTERLINCK, M., VAN NES, A., BACK, W. and van der Staay, Franz J, 2014b. Pressure mat analysis of naturally occurring lameness in young pigs after weaning. *BMC Veterinary Research*, vol. 10, no. 1, pp. 193.

NAUWELAERTS, S., MALONE, S.R. and CLAYTON, H.M., 2013. Development of postural balance in foals. *The Veterinary Journal*, vol. 198, pp. e70-e74.

OOMEN, A., OOSTERLINCK, M., PILLE, F., SONNEVELD, D., GASTHUYS, F. and BACK, W., 2012. Use of a pressure plate to analyse the toe–heel load redistribution underneath a normal shoe and a shoe with a wide toe in sound warmblood horses at the walk and trot. *Research in Veterinary Science*, vol. 93, no. 2, pp. 1026-1031.

OOSTERLINCK, M., PILLE, F., BACK, W., DEWULF, J. and GASTHUYS, F., 2011. A pressure plate study on fore and hindlimb loading and the association with hoof contact area in sound ponies at the walk and trot. *The Veterinary Journal*, vol. 190, no. 1, pp. 71-6 ISSN 1090-0233. DOI 10.1016/j.tvjl.2010.08.016.

OOSTERLINCK, M., HARDEMAN, L., VAN DER MEIJ, B., VERAA, S., VAN DER KOLK, J., WIJNBERG, I., PILLE, F. and BACK, W., 2013. Pressure plate analysis of toe–heel and medio-lateral hoof balance at the walk and trot in sound sport horses. *The Veterinary Journal*, vol. 198, pp. e9-e13.

OOSTERLINCK, M., PILLE, F., BACK, W., DEWULF, J. and GASTHUYS, F., 2010. Use of a stand-alone pressure plate for the objective evaluation of forelimb symmetry in sound ponies at walk and trot. *The Veterinary Journal*, vol. 183, no. 3, pp. 305-309.

OOSTERLINCK, M., ROYAUX, E. and PILLE, F., 2014. Pressure Plate Evaluation of Forelimb Toe-Heel and Medio-Lateral Hoof Balance on a Hard Versus a Soft Surface in Sound Ponies at the Walk and Trot. *Equine Veterinary Journal*, vol. 46, no. S46, pp. 45-45.

PARKES, R., WELLER, R., GROTH, A., MAY, S. and PFAU, T., 2009. Evidence of the development of 'domain-restricted'expertise in the recognition of asymmetric motion characteristics of hindlimb lameness in the horse. *Equine Veterinary Journal*, vol. 41, no. 2, pp. 112-117.

RIACH, C. and STARKES, J., 1994. Velocity of centre of pressure excursions as an indicator of postural control systems in children. *Gait & Posture*, vol. 2, no. 3, pp. 167-172.

SLOET VAN OLDRUITENBORGH-OOSTERBAAN, M., BARNEVELD, A. and VAN DEN BELT, A.J., 2007. De Veterinaire keuring van het paard. In: 3rd ed. Leeuwarden: BV Libre, pp. 103.

STANIAR, W., KRONFELD, D., HOFFMAN, R., WILSON, J. and HARRIS, P., 2004. Weight prediction from linear measures of growing Thoroughbreds. *Equine Veterinary Journal*, vol. 36, no. 2, pp. 149-154.

WELLER, R., PFAU, T., MAY, S. and WILSON, A., 2006. Variation in conformation in a cohort of National Hunt racehorses. *Equine Veterinary Journal*, vol. 38, no. 7, pp. 616-621.

YTREHUS, B., CARLSON, C. and EKMAN, S., 2007. Etiology and pathogenesis of osteochondrosis. *Veterinary Pathology Online*, vol. 44, no. 4, pp. 429-448.

Appendix 1

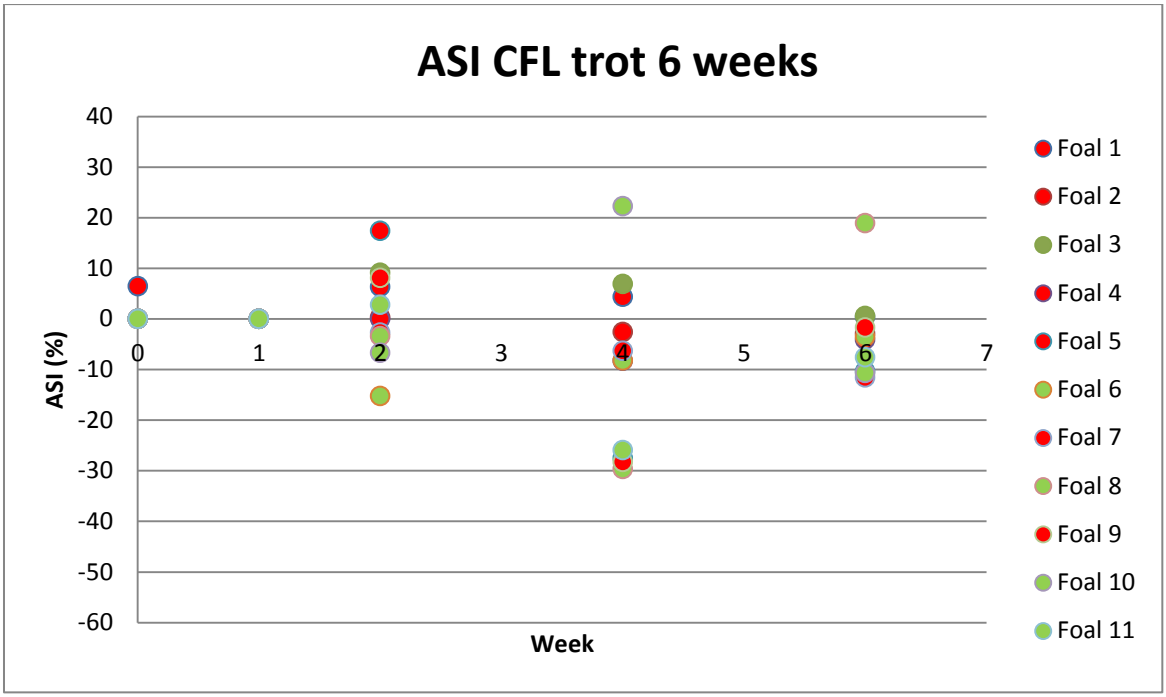
		Right Hind						Left Hind					
	Location	*1*	*2*	*3*	*4*	*5*	Binairy code	*1*	*2*	*3*	*4*	*5*	Binairy code
Foal 6 weeks	**1**	B	B	C	A	A	1	B	C	A	A	A	1
	2	A	C	A	A	A	1	B	A	A	A	A	0
	3	A	A	A	A	A	0	A	A	A	A	A	0
	4	B	B	A	A	A	0	C	B	A	A	A	1
	5	C	C	A	A	A	1	A	B	E	A	A	1
	6	A	B	A	A	A	0	A	A	A	A	x	0
	7	C	A	A	A	x	1	A	A	A	A	x	0
	8	A	A	A	A	A	0	A	A	A	A	B	0
	9	C	A	A	A	x	1	C	A	A	A	A	1
	10	A	A	A	A	x	0	A	A	A	A	A	0
	11	A	B	A	A	A	0	B	B	A	A	A	0

The OC(D) scores of the tarsus of the 11 foals at 6 weeks. The locations represent: 1 intermediate ridge of the tibia, 2 lateral trochlear ridge, 3 medial trochlear ridge, 4 lateral malleolus, 5 medial malleolus. The x represents times where the location could not be assessed properly.

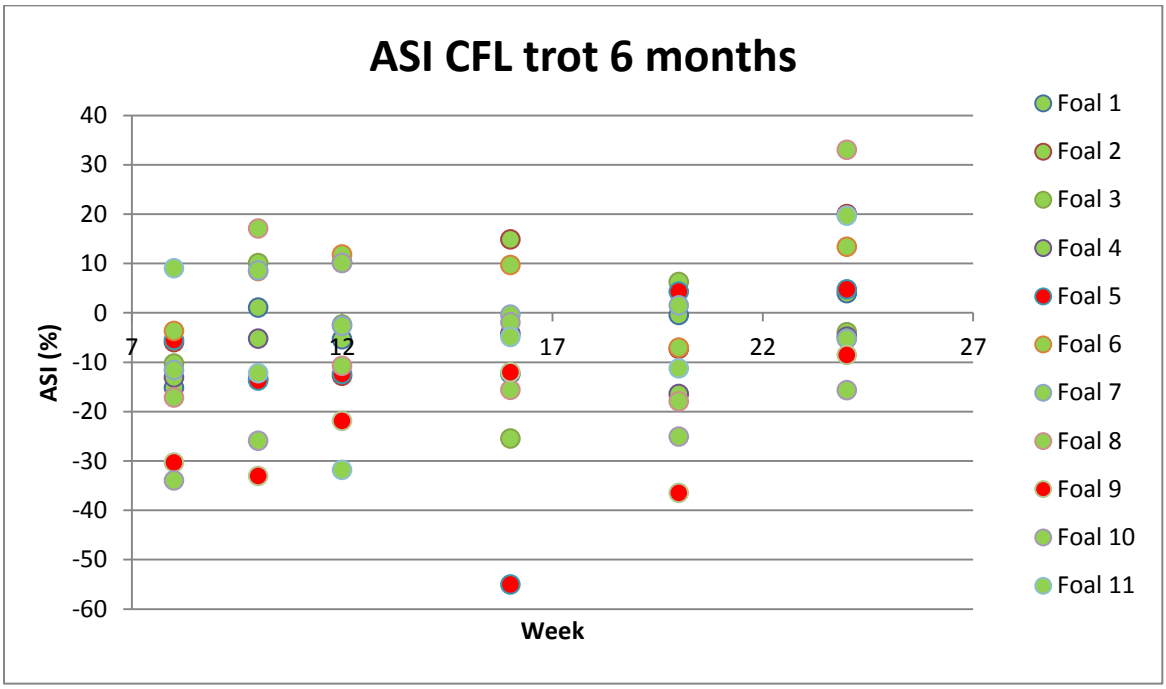
		Right Hind						Left Hind					
	Location	*1*	*2*	*3*	*4*	*5*	Binairy code	*1*	*2*	*3*	*4*	*5*	Binairy code
Foal 6 months	**1**	A	A	A	A	x	0	A	A	A	A	A	0
	2	A	A	A	A	A	0	A	B	A	A	A	0
	3	A	A	A	A	A	0	A	A	A	A	A	0
	4	A	A	A	A	A	0	A	A	A	A	A	0
	5	A	B/D	A	A	B	1	A	B/D	C	A	A	1
	6	A	A	A	A	A	0	A	A	A	A	A	0
	7	A	A	A	A	A	0	A	A	A	A	A	0
	8	A	A	A	A	A	0	A	A	A	A	A	0
	9	A	A	A	E	A	1	A	A	A	A	A	0
	10	A	A	A	A	A	0	A	A	A	A	A	0
	11	A	A	A	A	A	0	A	A	A	A	A	0

The OC(D) scores of the tarsus of the 11 foals at 6 months. The locations represent: 1 intermediate ridge of the tibia, 2 lateral trochlear ridge, 3 medial trochlear ridge, 4 lateral malleolus, 5 medial malleolus. Foal number 5 received two different scores for location number 2, the radiologist could not determine with certainty which score should have been given to the location.

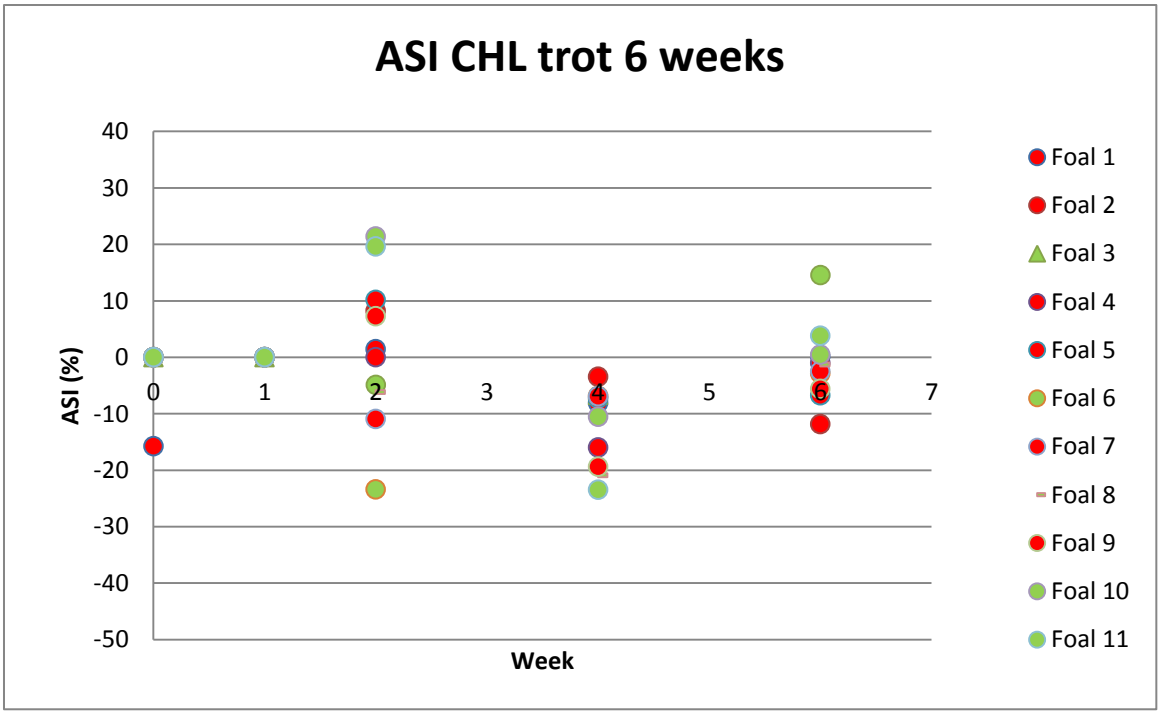
Apendix 2



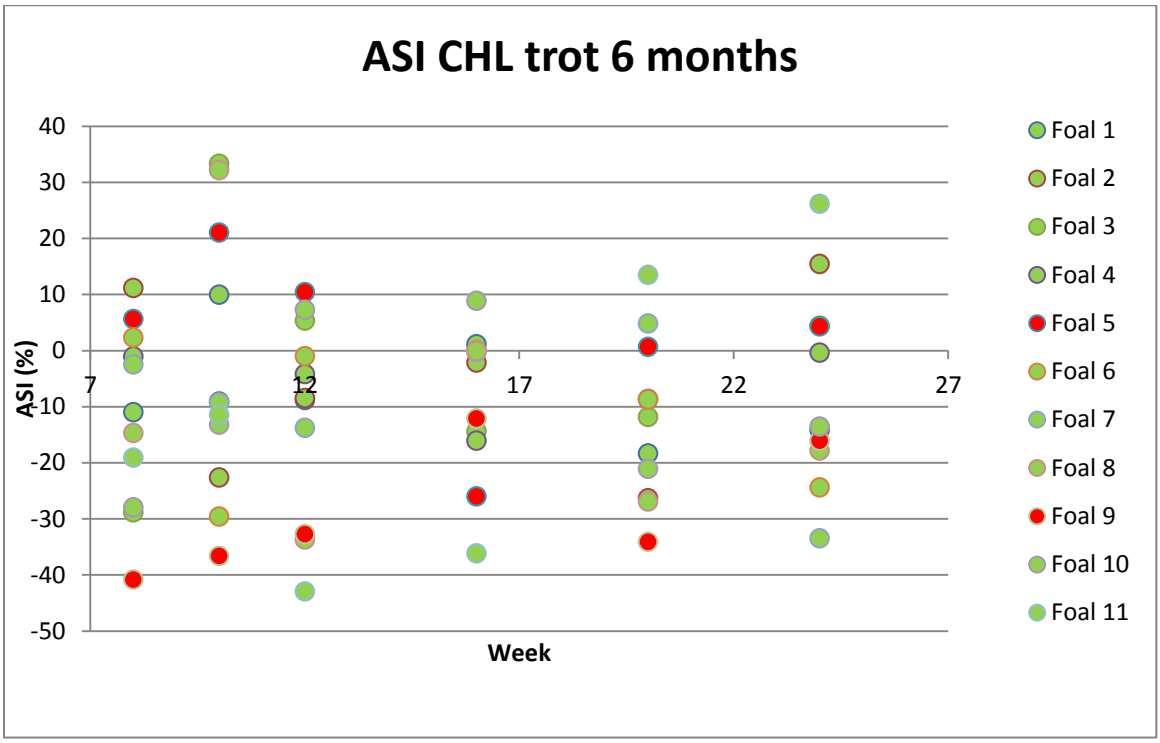
The ASI of the contralateral front limbs at the trot at 6 weeks. The red dots represent the OC positive foals and the green dots represent the OC negative foals.



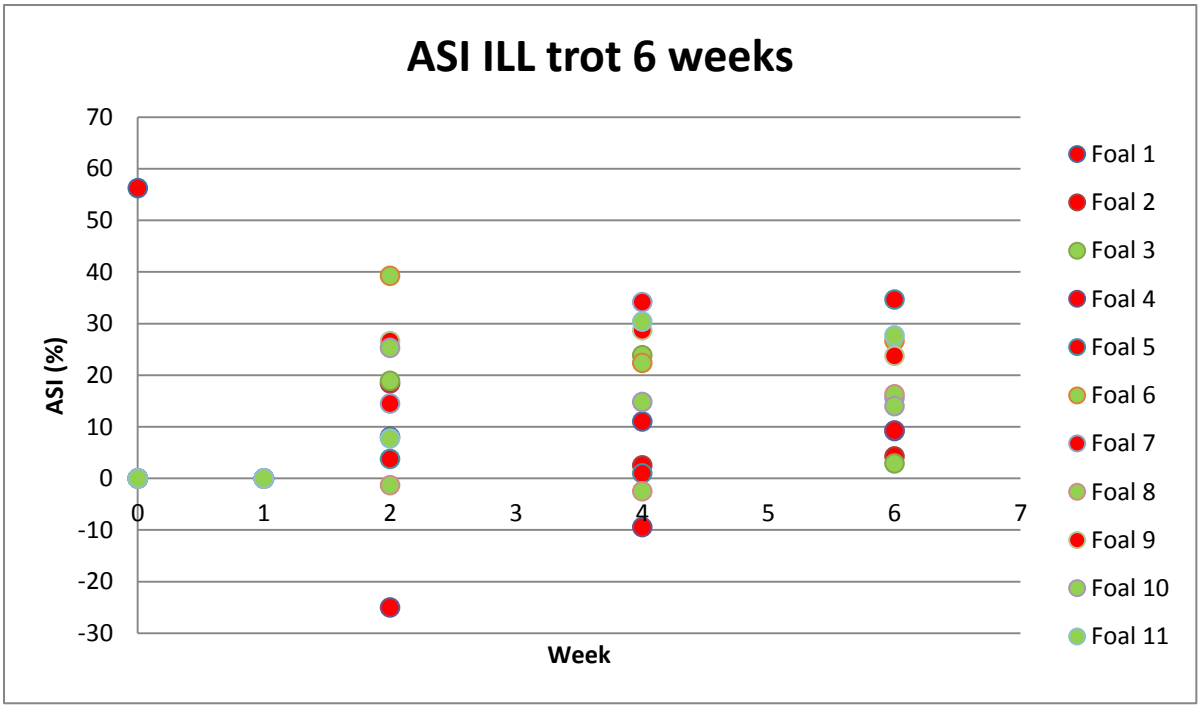
The ASI of the contralateral front limbs at the trot at 6 months. The red dots represent the OC positive foals and the green dots represent the OC negative foals.



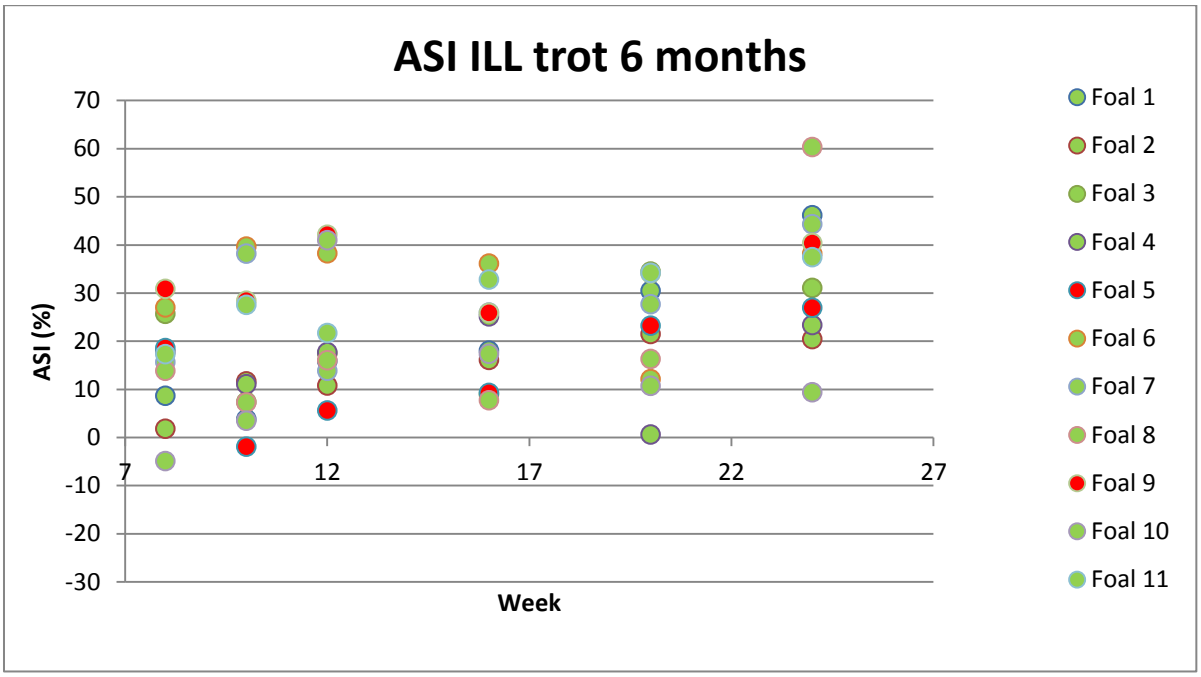
The ASI of the contralateral hind limbs at the trot at 6 weeks. The red dots represent the OC positive foals and the green dots represent the OC negative foals.



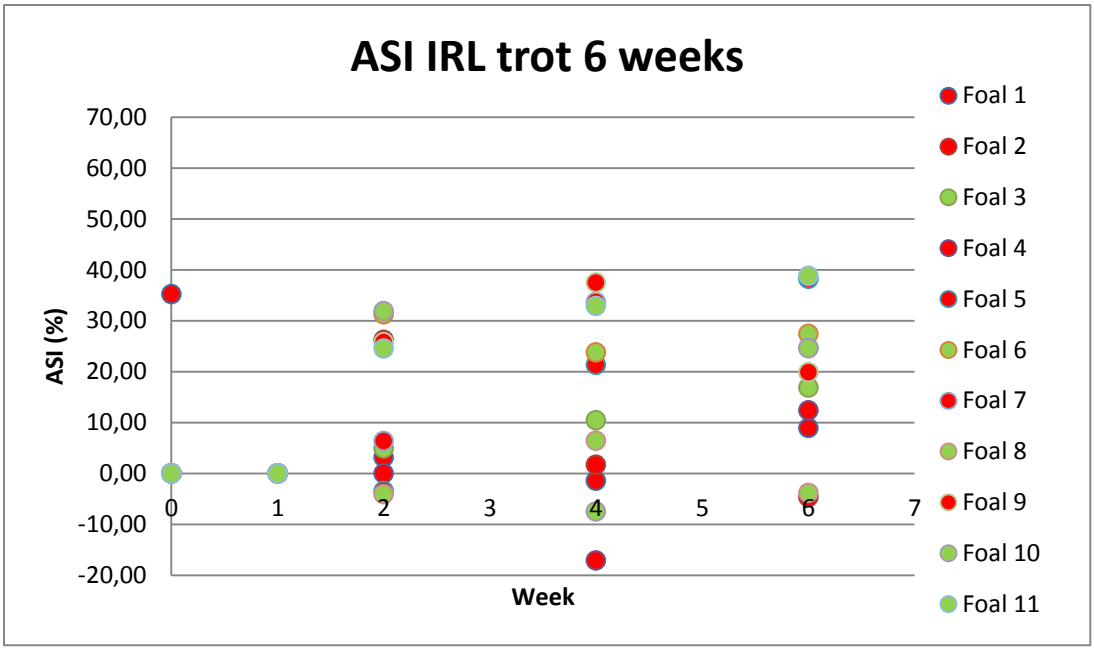
The ASI of the contralateral hind limbs at the trot at 6 months. The red dots represent the OC positive foals and the green dots represent the OC negative foals.



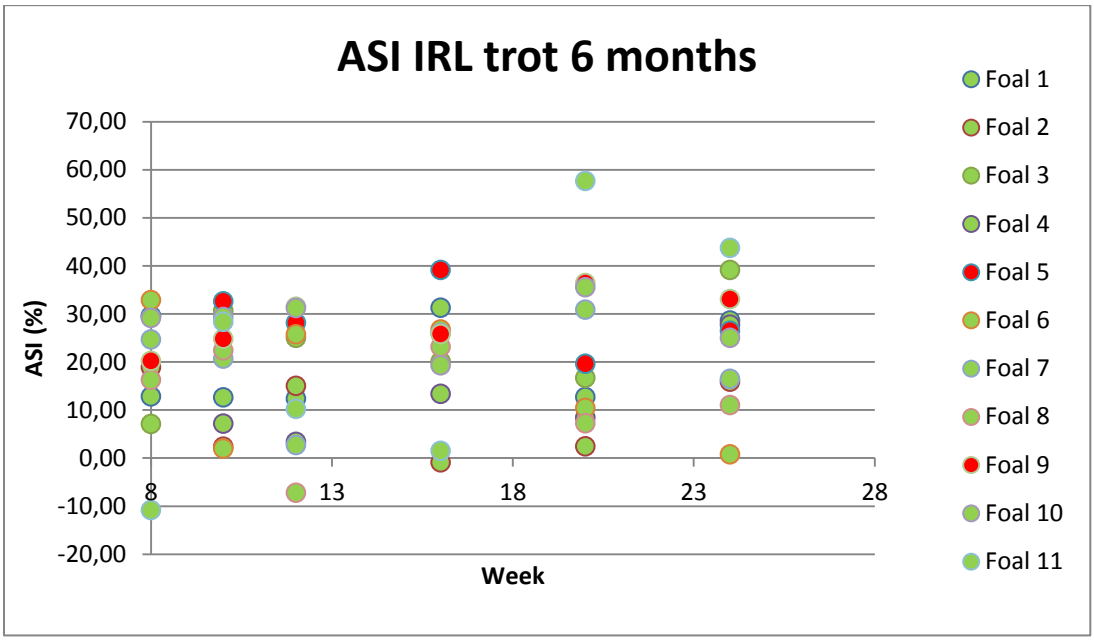
The ASI of the ipsilateral left limbs at the trot at 6 weeks. The red dots represent the OC positive foals and the green dots represent the OC negative foals.



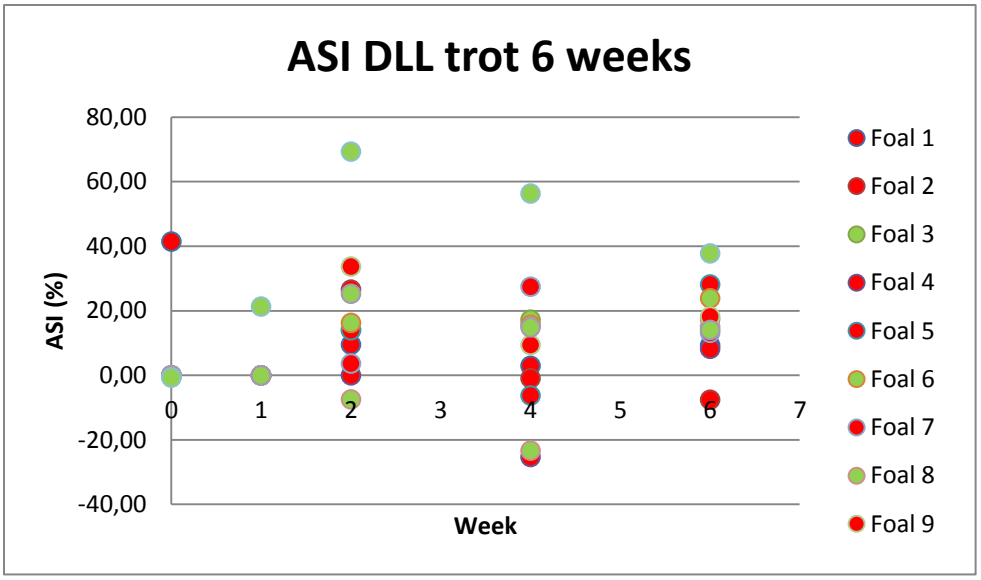
The ASI of the ipsilateral left limbs at the trot at 6 months. The red dots represent the OC positive foals and the green dots represent the OC negative foals.



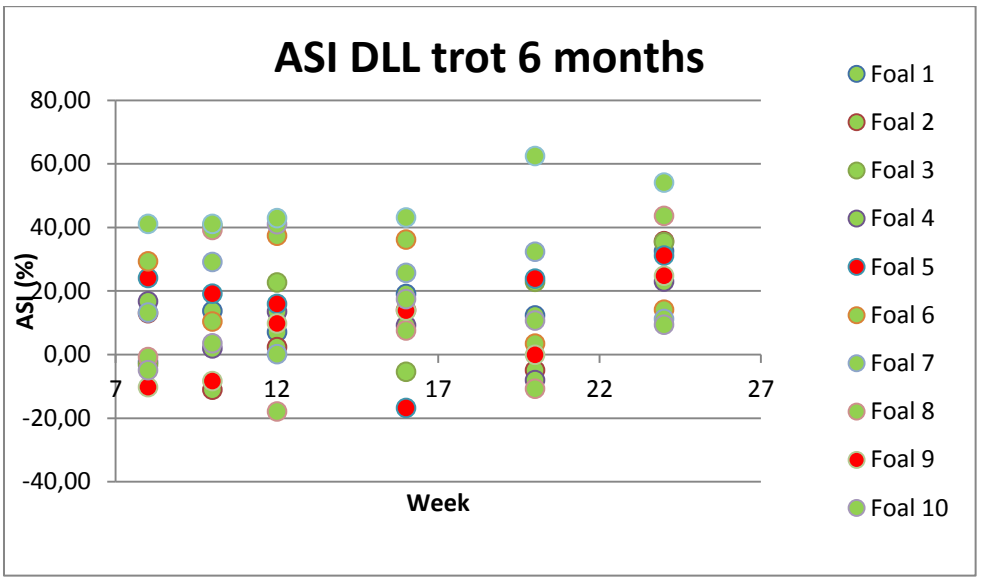
The ASI of the ipsilateral right limbs at the trot at 6 weeks. The red dots represent the OC positive foals and the green dots represent the OC negative foals.



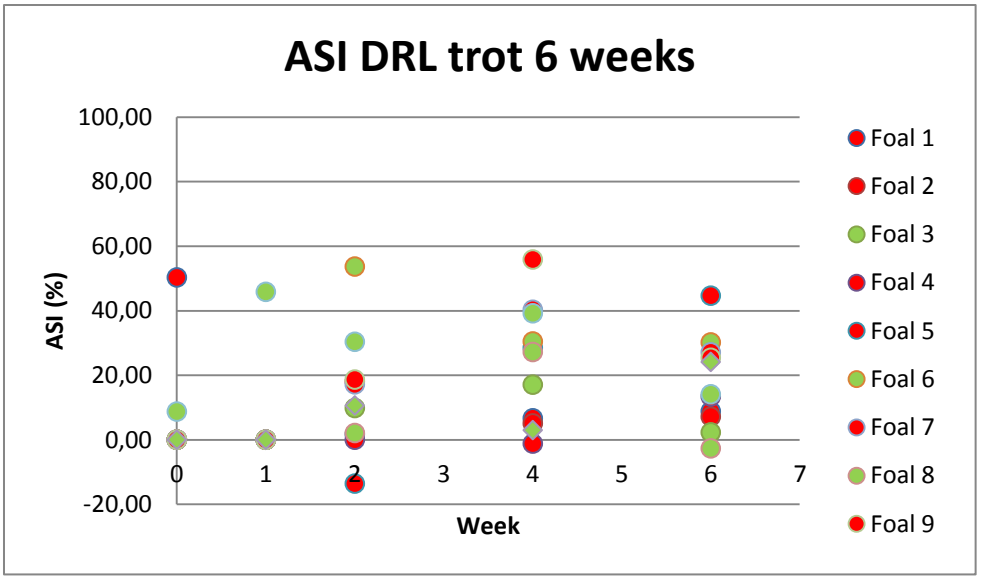
The ASI of the ipsilateral right limbs at the trot at 6 months. The red dots represent the OC positive foals and the green dots represent the OC negative foals.



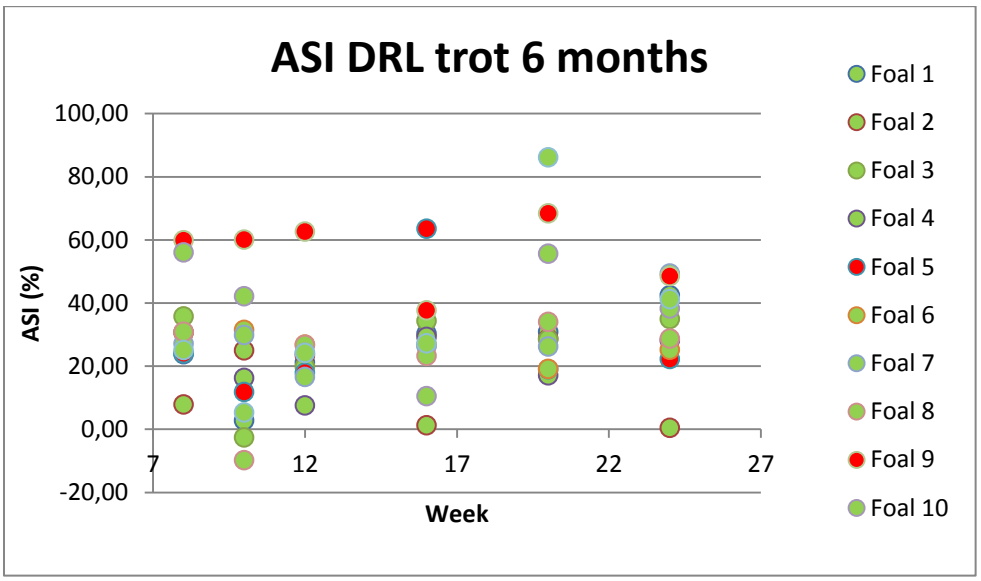
The ASI of the diagonal left limbs at the trot at 6 weeks. The red dots represent the OC positive foals and the green dots represent the OC negative foals.



The ASI of the diagonal left limbs at the trot at 6 months. The red dots represent the OC positive foals and the green dots represent the OC negative foals.

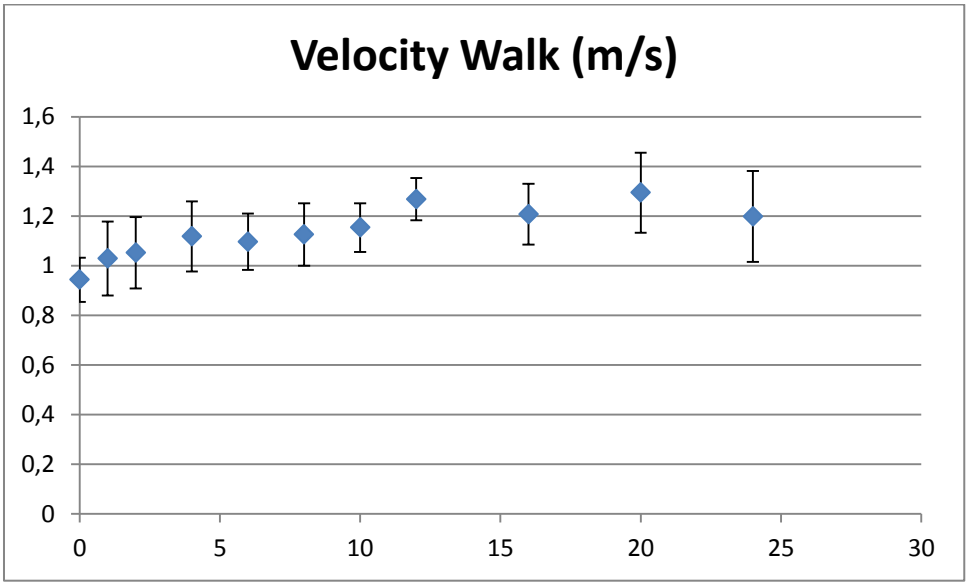


The ASI of the diagonal right limbs at the trot at 6 weeks. The red dots represent the OC positive foals and the green dots represent the OC negative foals.

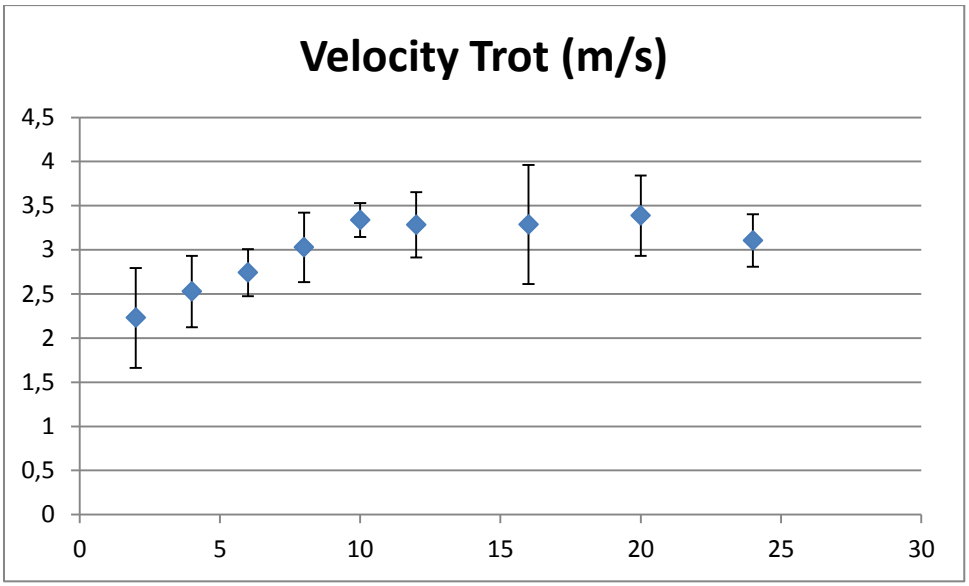


The ASI of the diagonal right limbs at the trot at 6 months. The red dots represent the OC positive foals and the green dots represent the OC negative foals.

Appendix 3

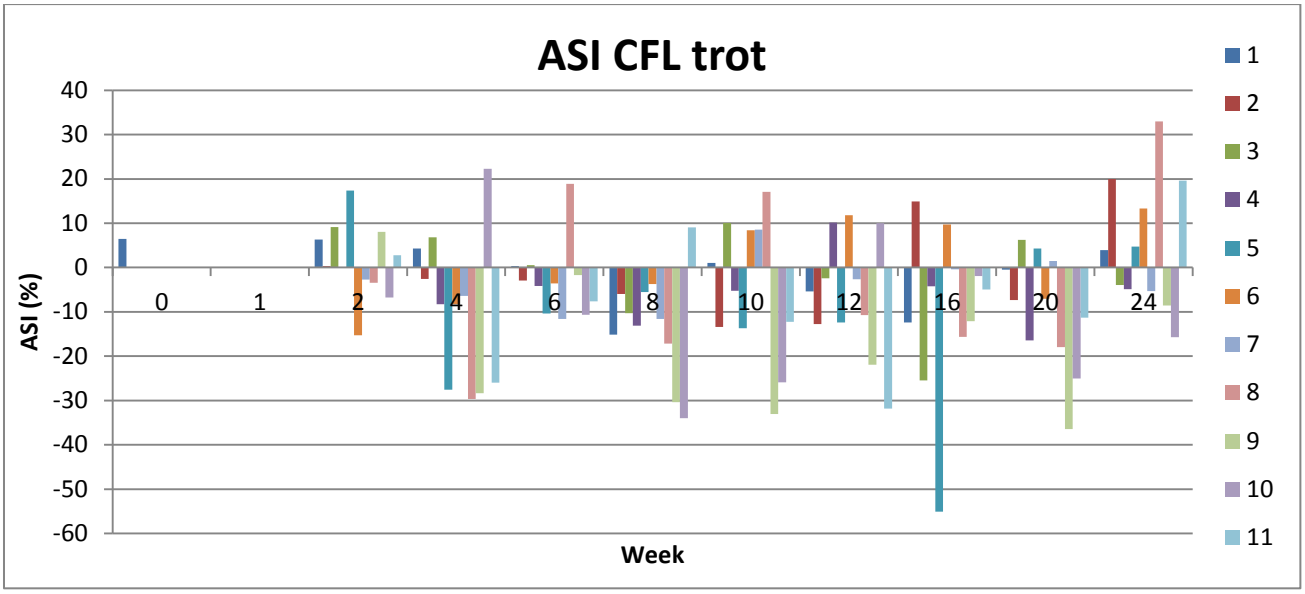


The velocity at a walk. Mean and standard deviation for every measuring moment.

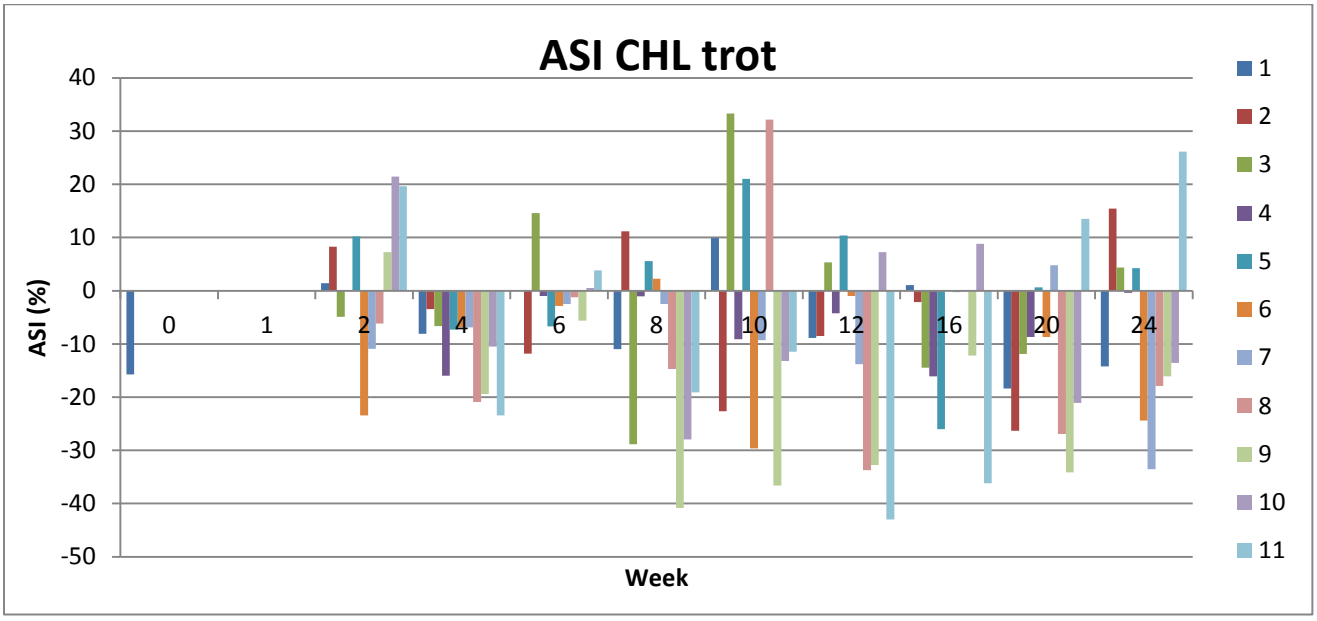


The velocity at a trot. Mean and standard deviation for every measuring moment.

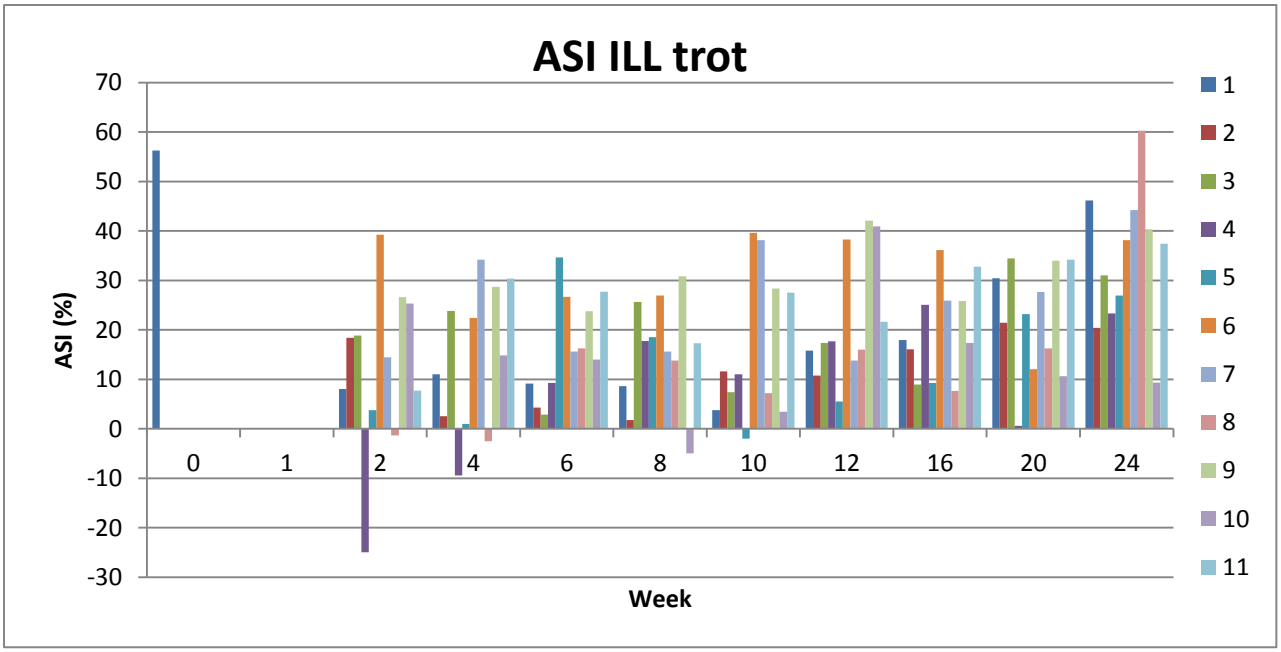
Appendix 4



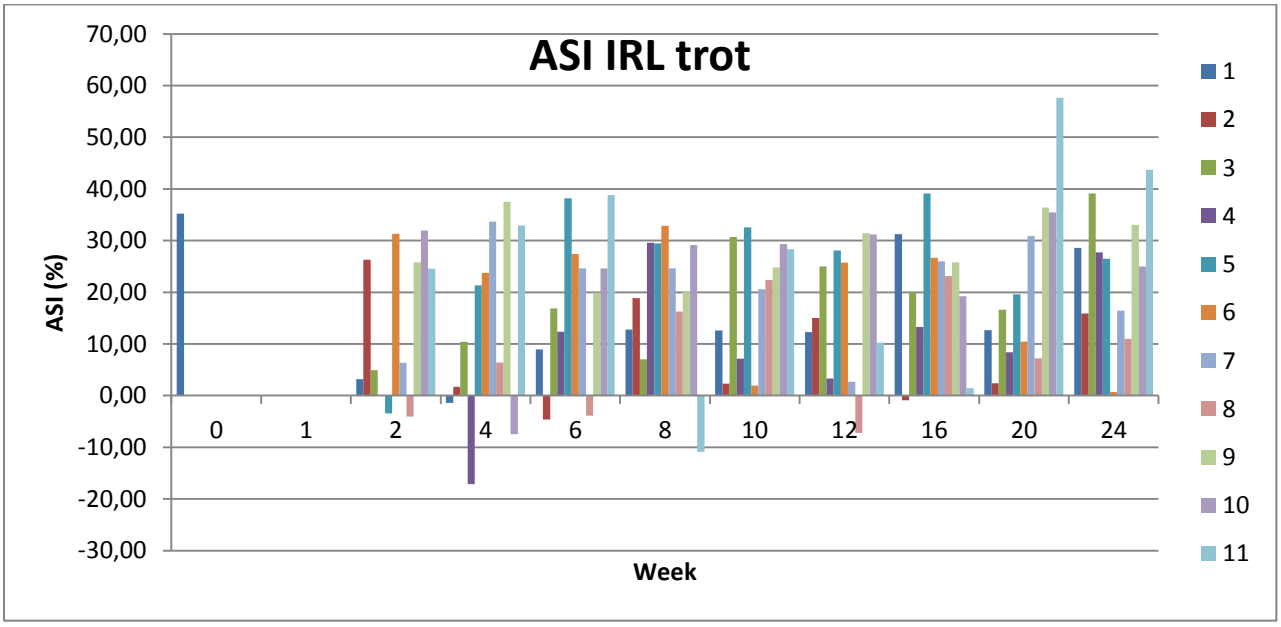
The ASIs of the contralateral front limbs at a trot, given for each of the measuring moments. Each of the 11 individual foals has its own colour.



The ASIs of the contralateral hind limbs at a trot, given for each of the measuring moments. Each of the 11 individual foals has its own colour.



The ASIs of the ipsilateral left limbs at a trot, given for each of the measuring moments. Each of the 11 individual foals has its own colour.



The ASIs of the ipsilateral right limbs at a trot, given for each of the measuring moments. Each of the 11 individual foals has its own colour.