The effect of training and showing on the locomotor symmetry of young warmblood horses at the trot

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Abstract

Introduction: lameness in horses is an important, ~~wide spread~~common problem, both for the horse and for the owner and it can have multiple causes. Clinical visual lameness examination has long been the most important way for veterinarians to diagnose lameness, but this method is not always reliable, especially when the asymmetry is small or the veterinarian unexperienced. Gait analysis~~recording~~ systems can be used to objectively measure the symmetry of a horse's locomotion and also to evaluate the change in symmetry over time. That symmetry development is mostly important in young horses, and important to prevent injuries from becoming chronic at a young age. Therefore, the objective of this study was to measure the effect of training and showing on the symmetry in young warmblood horses.

Materials and methods: measurements were done before and after training and during showing using the QHorse system. Data collected included Range of Motion (ROM), including Range Down Difference (RDD) and Range Up Difference (RUD), MaxDiff and MinDiff, velocity, stride length and stride frequency and~~,~~ hip and shoulder ~~swing and stance symmetry~~hike during swing and stance. Subjective assessment was carried out by the professional horse trainer in charge and retrospectively from the videos recorded during the measurements, including length of stride, elasticity, impulsion, balance and symmetry.

Results: a linear mixed effect model was used for the analysis of the data. ~~a lot of~~Obvious variation was seen in symmetry parameters between measurements within individual horses and between individuals, but no significant differences were found. There were significant correlations between the measurements for range up of head and withers, range down and MinDiff of pelvis, MaxDiff of withers, shoulder hike during swing and hip hike during stance (P<0.05). Velocity, stride length and stride frequency decreased significantly after training and then increased when the horses were showed (P<0.05).

Discussion: a previous study has shown some effect of training on the symmetry of a horse's locomotion. However, that reported training did not include exercises specifically for dressage, ~~whereas~~ and the asymmetry caused by training might be reversible: the horses in the study, who became asymmetric in the front limbs during training, became symmetric again over time, ~~showed complete reversibility of asymmetry in the front limbs~~ but less reversibility was seen in the hind limbs. Thus, there still is a lot of room for future research including standardizing training schedules. The decrease in stride length and stride frequency ~~in velocity~~ can be explained by the decrease in velocity~~in stride length and stride frequency~~. Decrease in stride length as a result of training is seen in other studies as well, as is a decrease in stride frequency. Stride frequency however, can also increase as a result of training. This effect might be breed-dependent, since both Dutch Warmblood horses and Anglo-Arabian horses showed a decrease in stride frequency, whereas Andalusian horses, which have a larger vertical component in their locomotion pattern, showed an increase in stride frequency. Growth is not likely to have an effect on these parameters in this study. Showing changes the symmetry of the horse's locomotion patterns, which can be explained by the stimulating effect of the handler, up to and including the arousal from the participating groom.

Conclusions: training and showing change the symmetry of a young horse's locomotion, but this effect is not necessarily an improvement. Velocity, stride length and stride frequency decrease during training and increase when the horses are showed. Future research should include a longer follow up period and standardized training schedules and housing conditions.

Lameness in horses is an important problem with regard to animal welfare, but also to the horse's riding career, it's saleability and thus the usefulness of the horse for the owner (Jönsson et al., 2013; Rhodin et al., 2017). In one study, 520 Dutch sport horses from 4 different disciplines (dressage, jumping, eventing and endurance) were followed from 2004 till 2009 (SLOET van OLDRUITENBORGH-OOSTERBAAN et al., 2010). Of these horses, 64.2% ended their career during the study period. 23% of these career endings was caused by veterinary problems in horses competing at low levels and 24.6% in horses competing at higher levels. Orthopaedic problems were the cause behind 63.7% of these career endings. A large amount of the horses (74%) included in the study also underwent one or more breaks in their career. 21.8% of these breaks was caused by veterinary problems, 53.6% of which was caused by orthopaedic problems. It was concluded in this study that pathologies in the musculoskeletal system are the most important veterinary causes of career endings in sport horses. In working military horses in the UK, 25.3% of the total population had to stop working because of lameness in one year time (Putnam et al., 2014). For 88% of these horses this was a break in the career and the other cases were either still in rehabilitation by the end of the study period or had ended their career. When evaluating a group of n=8281 young (4-5 year old) horses assessed by the Swedish Warmblood studbook over several years, 74% had remarks on palpatory orthopaedic health, 24% of which moderate-severe, and 21% of the horses were positive for the flexion tests, 5% of which moderate-severe (Jönsson et al., 2013). This shows that orthopaedic pathologies are a widespread and important problem in different riding horse populations and can occur already at young age of 4-5 years. Orthopaedic problems can have many different causes.

Several risk factors were found to significantly increase the likelihood of lameness in dressage horses. The level on which horses were trained and competed was shown to be one of these factors ~~(P=0.018)~~, just as the amount of time the horse has been competing ~~(P=0.002)~~ and shoeing of the hind limbs only ~~(P=0.006)~~ (Murray et al., 2010). Other factors include digestive illness ~~(P<0.001)~~, a high amount of training sessions ~~(P=0.034)~~, little training on specific exercises required for different competition levels ~~(P=0.005)~~, deep, patchy or uneven training surfaces ~~(P= 0.018, 0.002, 0.011, respectively)~~ and horses that stumble or lose balance easily ~~(P=0.030, 0.052, respectively).~~. When considering horse related factors specifically, older age ~~(P<0.001)~~, greater height ~~(P=0.001)~~ and a history of back problems ~~(P<0.001)~~ are significant risk factors for lameness. More extensive use of a horse walker is also associated with a greater prevalence of lameness ~~(P=0.003)~~, however use of a horse walker can also be increased because of lameness of a horse, for example in rehabilitation, rather than being the cause of this lameness. Type of usage of a horse is another factor associated with lameness, with horses used for instruction, recreation or breeding showing a higher prevalence of lameness than horses used for competitions ~~(P<0.001)~~ (Visser et al., 2014). As with the use of a horse walker, type of usage of a horse might be a cause but also a consequence of lameness of a horse.

Clinical visual lameness examination, with head nod and hip hike as most frequently used lameness parameters, has long been the most important way for veterinarians to diagnose lameness in horses (Pfau et al., 2016). This clinical lameness examination however, does have a few drawbacks. One of these drawbacks is that the human eye can only reliably detect a movement asymmetry above a limit of 20% or 25%~~, and usually operates at a sampling frequency of only 20 Hz~~ (Pfau et al., 2016; Rhodin et al., 2017). Furthermore, different veterinarians do not always give the same lameness score to one horse. In fact, when 131 horses underwent a full lameness evaluation using the AAEP score by 2-5

Met opmerkingen [FB1]: Where is it cyted the 20 Hz of the human eye /?

veterinarians each, these veterinarians agreed on which limb was lame or not 72.9% of the time (Keegan et al., 2010). This agreement was 93.1% when the AAEP score was above 1,5 and 61.9% when the AAEP score was ≤ 1,5, showing that clinical visual lameness examination is less reliable when the asymmetry in the horse's locomotion is small. When the veterinarians were asked which limb was most lame, they agreed only 51.6% of the time. Because of these limitations the asymmetry caused by mild orthopaedic diseases can be too small to be detected by a standard clinical visual lameness examination and thus these may be overlooked (Rhodin et al., 2017). These mild, undetected pathologies may progress into more severe pathologies causing a more obvious lameness over time. This has consequences for the treatment possibilities and prognosis. Because of this, it is important to detect the start of a lameness as early as possible. As mentioned before, abnormalities in palpatory orthopaedic health and flexion tests can already be found in horses aged 4-5 years, thus, it would be useful to evaluate the symmetry of horses already at this young age.

The clinical visual lameness examination is based on the asymmetry in the horse's locomotion caused by the lameness. However, many horses move asymmetrically, without being notably lame. Of 222 horses that were said to move soundly by the owners, 161 showed some degree of asymmetry (Rhodin et al., 2017). This asymmetry was measured with a gait analysis system based on inertial measure units. Such gait ~~recording~~ analysis systems have been an important research focus for the past decades and have a higher sensitivity when it comes to detecting mild lameness and deciding on which limb is lame (McCracken et al., 2012; Rhodin et al., 2017). They become more and more accepted as aids for veterinarians to measure locomotor asymmetry and lameness in horses, thus enabling the veterinarian to objectively and earlier detect more subtle asymmetries in the movements of the horse (Pfau et al., 2016; Rhodin et al., 2017). An example of such systems is the QHorse system installed at Utrecht University's Equine Clinic. When a horse is measured with this system at different time points, an increasing asymmetry can be measured which is an important warning sign because this progressing asymmetry can eventually lead to lameness. The progress from asymmetry to lameness can be influenced by usage and training of the horse.

Met opmerkingen [FB2]: Analisys?

The aim of this study was to measure the effect of training and showing on the symmetry in young warmblood horses. For this, twelve young warmblood horses were measured with the QHorse system before and after a three month training period. After the training period, the horses were measured during showing as well. By comparing the data collected from these measurements, the effect of training and showing on the symmetry of the horse could be assessed. The hypotheses were that (1) an objective and subjective change in locomotor symmetry of a young sport horse between two measuring time points can be caused by the training effect of a trainer and (2) an objective and subjective change in locomotor symmetry of a young sport horse between two measuring time points can be caused by the showing effect of a handler.

Materials and methods

For this research, 11 Dutch warmblood horses aged 4-6 years were used and one German warmblood horse aged 4 years old was used. 3 Mares, 6 geldings and 3 stallions were included and horses had various weights and heights (detailed information see appendix A).

Lost to follow up

After the training period, one horse failed to show up for the follow up measurements. This was not due to any locomotion problem of the horse. The horse has not been included in the analysis of the data, since only the measurement of before the training period was available. This concerns a 5 year old Dutch warmblood mare.

All horses were supervised by a professional KNHS/KWPN horse trainer. The horses were divided in 3 groups of 4 and measurements were done before (March 6, 13 and 27 2017) and after (June 19 and 26 and July 3 2017) a three month training period. During the training period, 4 horses were lunged and the remaining 8 horses were ridden under the saddle. Training was dressage-oriented but no horse was trained on a high level. More precise information about the training can be found in appendix B. The effect of showing was measured after the training period. During this measurement, the professional handler supported the horse in its movements like he would do on an auction or inspection and a second handler held a whip behind the horse. The way in which the handler supported the horse differed between individual horses and depended on the locomotion of the horses.

Objective assessment

All measurements were done using the QHorse system installed at Utrecht University's equine clinic. The QHorse system uses infrared light ~~signals~~ and reflective markers placed in clusters of three on the head, withers and pelvis of the horse, by which the movement of the horse can be objectively measured. Before the actual measurements took place, the horses were walked and trotted on a straight line on hard surface and lunged on soft surface in walk, trot and gallop and on hard surface in walk and trot on left and right reins. After this, the measurements were done in trot on a straight line on hard surface. During the whole procedure, the same professional handler was used for every horse. The following parameters were taken from the measurements:

- Velocity, stride length and stride frequency
- ~~Symmetry of the s~~Shoulder and hip hike during swing and stance phases.
- Maximal and minimal values of head, withers and pelvis and difference between left and right (figure 1)
- Range up and range down of head, withers and pelvis ~~-~~and difference between left and right (figure 1)

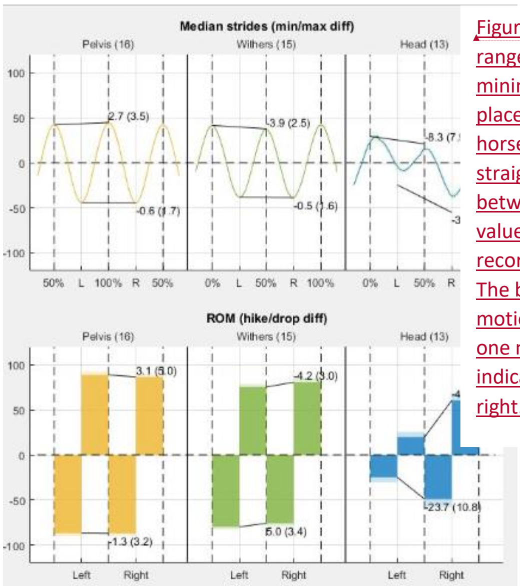

Figure 1: maximal and minimal values and range up and range down. The maximal and minimal values measured by the markers placed on the pelvis, withers and head of the horse are shown in the top graphs with the straight black lines indicating the differences between left and right. These are median values of the highest and lowest points recorded during one measurement. The bottom graphs show entire the range of motion of the pelvis, withers and head during one measurement with the black lines indicating the difference between left and right.

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- ~~Symmetry of the shoulder and hip during swing and stance phases.~~

Subjective assessment

Beside the measurements carried out by the QHorse system, videos were made during the measurements using a single home-video camera placed in the top left corner behind the horse. These videos have been used to evaluate the quality of movement for each horse, which was done by the professional KNHS/KWPN horse trainer who also supervised the horses. Also the possible influence of the handler on the symmetry of the horse's movements was assessed this way. This subjective evaluation was compared with the objective measurements from QHorse. The following scoring criteria were used for the subjective evaluation of the videos:

- Length of stride (long-short)
- Elasticity (elastic-stiff)
- Impulsion (powerful-weak)
- Balance (carrying-pushing)
- Symmetry (symmetric-asymmetric toward left/right)

Like with the QHorse measurements, the above mentioned criteria were evaluated on a straight line in trot on a hard surface before and after training and a third time to evaluate the effect of showing.

Data analysis

The data collected by QHorse were analysed using a linear mixed effect model with horse as a random effect and time of measurement (before/after training, during showing) and location of measurement (head/withers/pelvis) as fixed effects. ~~Calculations were~~This was done using the Chi-square test in RStudio. A significance level of P <0,05 was chosen.

Met opmerkingen [FB3]: What calculations ?

Objective assessment

Difference between left and right of range down (RDD) and range up (RUD) of head, withers and pelvis
The difference between left and right for the ranges down and up were measured. For both range down and range up these differences showed no significant change between the different measurements (p= 0,3083 and 0,3638 respectively). Neither was there a significant difference between head, withers and pelvis (p= 0,7262 for range down and p= 0,4309 for range up). There was no interaction between time (before or after training or during showing) and place (head, withers or pelvis) of measurement.
The standard deviations of the differences between left and right of both the range down and the range up showed no significant change between the different measurements, but did differ significantly between head, withers and pelvis (p< 0.001~~2e-16~~ for both). Neither showed a significant interaction between time and place of measurement.
When comparing the data from before and after the training period, seven out of eleven horses became more symmetrical (had a smaller difference between left and right) in the range down of the head, five horses became more symmetrical in the range down of the withers and four horses became more symmetrical in the range down of the pelvis (see appendix D). For the range up, 6, 5 and 4 horses became more symmetrical during the training period in the movement of the head, withers and pelvis respectively. When evaluating the effect of showing, for the range down 4, 6 and 3 horses and for the range up 7, 3 and 4 horses became more symmetrical in the movement of head, withers and pelvis respectively. A lot of variation was found between horses when comparing the symmetry measured before and after training and again when the effect of showing was measured (see appendix D). The same counts for the standard deviations.

Range down and range up of head, withers and pelvis (RD, RU)
The range down towards the left and range up toward the right did not change significantly between the three measurements, but it did differ significantly between head, withers and pelvis (p< 0.001)~~2e-16)~~. For the range down toward the right, an interaction was found between time and place of measurement (p= 0,0447). This interaction was also found when analysing the range up towards the left (p= 0,0151).

Difference between left and right of maximal and minimal values of head, withers and pelvis (MaxDiff, MinDiff)
Like with the range up and down, the difference between left and right was measured for the maximal and minimal values, giving the MaxDiff and MinDiff. No significant changes were found between the three measurements for both the MaxDiff (p=0,1373) and the MinDiff (p=0,6229). Neither did the MaxDiff and MinDiff differ significantly between head, withers and pelvis. The standard deviations did not differ significantly between the three measurements (p=0,8951 and 0,7814 respectively), but they did differ between head, withers and pelvis (p< 0.001 ~~2e-16~~ for the standard deviation of MaxDiff and ~~and p= 7,865e-12~~ for standard deviation of MinDiff). Neither showed an interaction between time and measurement. Like with the range up and range down, there was a lot of variation between the horses. Some showed improvement of symmetry after the training period whereas others became more asymmetrical instead. The same variation between horses was seen when measuring the effect of showing.

Maximal and minimal values of head, withers and pelvis

The maximal values towards the left and minimal values toward the right did not change significantly between the three measurements but did differ significantly between the places of measurement (p< 2e-16). An interaction was found between time and place of measurement for the maximal values toward the right (p= 0,0097) and for the minimal values towards the left (p= 0,0326).

Velocity

For velocity, a p-value of 0,0117 was found, which means that velocity has changed significantly between the three measurements. As can be seen in figure 2~~1~~, the velocity decreased during the 3 month training period and subsequently increased when the horses were showed. The same effect is seen with regard to the standard deviation, which significantly decreased during the training period and then increased when the horses were showed (p=0,0104).

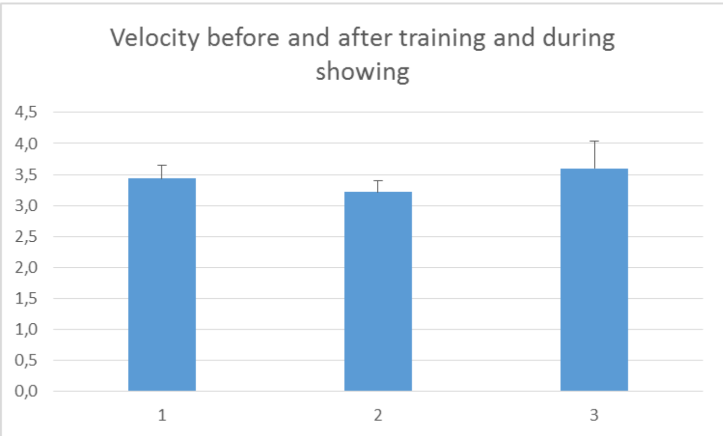


Figure 2~~1~~: velocity before and after training and during showing (1= before training, 2= after training, 3= during showing)

Stride length

As shown in figure 3~~2~~, stride length decreased during the training period and then increased when the horses were showed. These changes were significant (p=0,0025). For the standard deviation, a significant difference between the three measurements was found as well (p=0,0272).

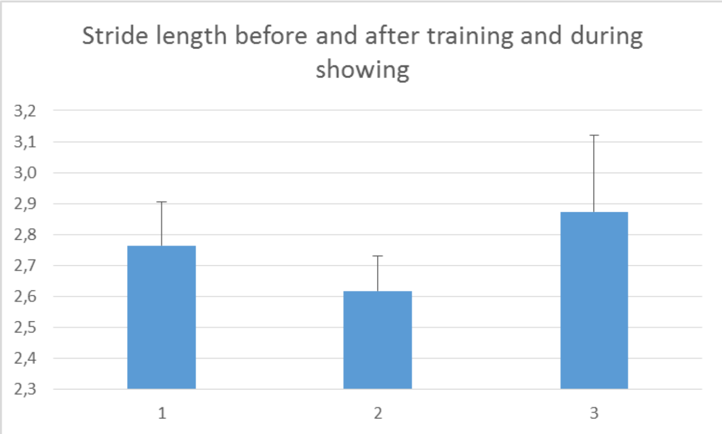


Figure 3~~2~~: stride length before and after training and during showing (1= before training, 2= after training, 3= during showing)

Stride frequency

Stride frequency showed slight, though significant changes between the measurements (p=0,0031). The stride frequency decreased during the training period and increased when the horses were showed. The standard deviation however, did not change significantly (p=0,7766).

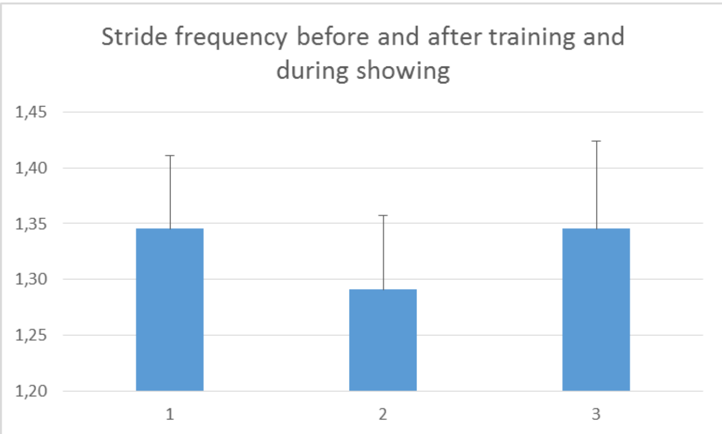


Figure 4~~3~~: stride frequency before and after training and during showing (1= before training, 2= after training, 3= during showing). Note the extra decimal on the y-axis indicating that these are smaller differences than those measured for the previous values.

S~~ymmetry of the s~~houlder hike during swing and stance

~~Both the shoulder~~The shoulder hike during both swing and stance did not change significantly between the three measurements (p=0,0884 and 0,3014 respectively). Before and after training and during showing, a wide variety of symmetry was measured between the horses.

~~Symmetry of the h~~Hip hike during swing and stance

~~Both the hip~~The hip hike during both swing and stance did not change significantly between the different measurements (p=0,7176 and 0,6739 respectively). Like with the shoulder ~~swing and stance~~hike, a large variety of hip ~~swing and stance~~hike ~~symmetry~~values between horses was measured.

Correlation between symmetry parameters

Correlations were found between the three measurements for the RUD of the head and of the withers, the RDD of the pelvis, the MaxDiff of the withers, the MinDiff of the pelvis, the shoulder swing and the hip stance.

Relation between velocity, stride length and horse height

Since the horses used in this study have different heights, velocity and stride length are not one on one comparable between horses. To reliably compare the changes in velocity and stride length, these must be scaled to the height of the horses. This is possible by calculating the Froude number, the dimensionless number for speed. This can be calculated using the following formula:

$$Froude\ number = v/\sqrt{height \times 9{,}81}$$

When evaluating the Froude number values, a p-value of 0,0112 was found. This does not differ much from the p-value found for velocity (0,0117) and shows a slightly more significant difference between the three measurements. However, the differences between velocities of the horses are much larger, ranging from 3,10-3,70 before training, than the differences in Froude number, ranging from 0,78-0,92 before training. The same counts for after training (velocity 3,00-3,60 and Froude number 0,73-0,83) and for showing (velocity 2,80-4,20, Froude number 0,69-1,02).

The same evaluation can be done for stride length, using the following formula:

$$Dimensionless\ stride\ length = 2{,}3 \times Froude\ number^{0{,}6}$$

When evaluating the values of dimensionless stride length, a p-value of 0,0111 was found. This p-value does differ obviously from the one found for stride length (0,002477). The differences between the values of stride length and dimensionless stride length however, are smaller than those seen between velocity and Froude number.

There also is a relationship between velocity and stride length and between velocity and stride frequency. When velocity is divided by stride length or stride frequency, the following tables can be made.

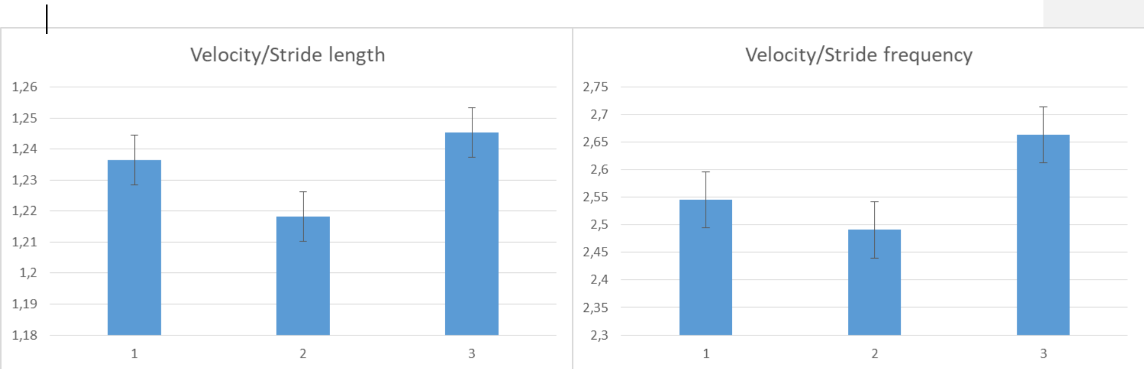


Figure 4: velocity divided by stride length and stride frequency (1= before training, 2= after training, 3= during showing)

These tables show a similar effect of training and showing as the ones shown in figures 2 and 3, implicating that the effect of training and showing on velocity, stride length and stride frequency is as shown in those figures.

For the results of the subjective assessment, see Appendix C.

Discussion

The hypotheses were that (1) an objective and subjective change in locomotor symmetry of a young sport horse between two measuring time points can be caused by the training effect of a trainer and (2) an objective and subjective change in locomotor symmetry of a young sport horse between two measuring time points can be caused by the showing effect of a handler.

A lot of variation can be observed in locomotor symmetry between young warmblood horses. When these horses are challenged with a three month training period, the range of motion of these horses changes, becoming either smaller or larger. These changes overall as a group, however, are not significant. The MaxDiff and MinDiff also showed no significant change after the training period, despite, or because of, a large amount of variation between the horses. RUD of the head and of the withers, RDD of the pelvis, MaxDiff of the withers, MinDiff of the pelvis, shoulder hike during swing and hip hike during stance showed a correlation between the three measurements. Velocity, stride length and stride frequency decreased significantly during the three month training period. The Froude number also decreased significantly after the training period, as did the dimensionless stride length. S~~ymmetry of the s~~houlder hike during swing and stance and ~~of the~~ hip hike during swing and stance did not change significantly during the training period. The standard deviations of the range of motion, of the MaxDiff and MinDiff and the maximal values toward the left and minimal values toward the right did not change significantly between the measurements before and after training, but they did differ between head, withers and pelvis. There was a correlation between time and place of measurement for the range down toward the right, the range up toward the left, the minimal values toward the left and the maximal values toward the right, meaning that, for these parameters, the motion pattern of the horses stayed the same between the different measurements.

A lot of variation in locomotor symmetry was also found ~~when~~ within the~~the~~ horses when they were measured before and during showing, but no significant differences were found in range of motion, MaxDiff, MinDiff or maximal or minimal values. Also shoulder hike during swing and stance and hip hike during swing and stance did not differ significantly when the horses were showed. Velocity, stride length and stride frequency however, increased significantly when the horses were showed. Also Froude number and dimensionless stride length increased significantly.

Of the eleven horses used in this study, five showed more or less ~~severe~~ obvious asymmetry before or after training or during both measurements. All horses were used for dressage. Dressage horses tend to have a longer lumbar back region and move less symmetrical than jumping horses (Johnston et al., 2010). This was found in horses with different ages and from different competition levels. The suppleness required from dressage horses can account for a wider range of motion and thus a more asymmetrical motion pattern, explaining the wide variety of asymmetry found in our study population. Although training did not have a significant effect on range of motion, MaxDiff, MinDiff, Hip Hike during ~~S~~swing and s~~S~~tance and Shoulder Hike during swing and stance ~~Symmetry and Shoulder Swing and Stance Symmetry~~ when statistically analysed, a lot of variation was found for individual horses between the measurements done before and after training. Every horse showed some change in these symmetry parameters, either for better or worse. Training has shown to have an effect on the symmetry of a horse's locomotion in 2 and 3 year old Standardbreds trained for trot racing (Ringmark et al., 2016). Higher occurrence of front limb asymmetry was seen when the horses were submitted to speed training, whereas uphill training coincided with more asymmetry in the hind limbs. The asymmetry in the front limbs decreased when the horses had been submitted to speed training for a longer period of time. This suggests that during the training period, the horse's tissues have adapted to the loading caused by the training and at least some of the asymmetry caused by the training can be reversible. To evaluate the precise effect of different training exercises used for dressage and the reversibility of asymmetry caused by training, future research should include standardised training schedules and a longer follow up period. For now, it can be concluded that training of young dressage horses at least has some effect on the symmetry of the horse's locomotion and that the locomotion of the horse can become either more symmetrical or more asymmetrical.

Velocity decreased significantly during the three month training period, as did stride length and stride frequency~~. This can be explained by the shorter stride length and decreased stride frequency~~. The decrease in stride length corresponds with a study done on young warmblood horses undergoing a 70 day training period (Back et al., 2010). Here, the trained horses showed a shorter stride length in the forelimbs, whereas the pastured horses showed an increase in stride length. Training of these horses included both dressage and jumping and growth did not differ between the trained and pastured groups. The measurements were all done at a speed of 4 m/s. Shorter stride length was also found in Andalusian horses submitted to a three month training period, but the stride frequency of the horses included in this study increased (MuñOz et al., 1999). The stride frequency of the Andalusian horses increased with about the same magnitude as it decreased in the warmblood horses used in this study. This might be breed-dependent since Andalusian horses have a larger vertical component in their locomotion pattern; also Anglo-Arabian horses, which do not have this vertical component, used in the same study as the Andalusian horses showed a decrease in stride frequency. Thus, training of young horses can be expected to cause a shorter stride length, mainly caused by a decrease in stride length of the forelimbs, but stride frequency can either increase or decrease, which is possibly breed-dependent. It should be taken into account, that housing in a stable might affect the stride length. No information is known about the housing conditions of the horses used in this study and no literature is yet available on this subject. Thus, future research should be done to evaluate the effect of housing conditions on stride length and stride frequency in horses.

The maximal values toward the left and minimal values toward the right differed significantly between head, withers and pelvis, as did the standard deviations of the range of motion, the MaxDiff and the MinDiff. This is not surprising because the different places on the equine body have a different range of motion. For example, the head has a much wider range of motion than the shoulder or the pelvis, including the possibility of making large movements toward the left or right while the shoulder and pelvis continue moving in a forward direction.

Several symmetry parameters showed a correlation between the three measurements. This implicates that for one horse, these symmetry parameters (range up of head and withers, range down and MinDiff of pelvis, MaxDiff of withers, shoulder hike during swing and hip hike during stance) ~~showed a similar motion pattern before training, after training and during showing~~are highly correlated, independent of the stage of training of the horse or whether the horse is showed. In other words, training and showing have an effect on the magnitude of asymmetry, but do not necessarily change the direction of this asymmetry.

Impulsion did not increase visibly in the horses that were used in this study (see appendix C). In another study however, impulsion did improve after a 70 day training period in Dutch warmbloods (Back et al., 2010). In our study, as mentioned in the M&M section, the impulsion was evaluated using videos shot by one camera placed in the top left corner behind the horse. This is not an ideal location for evaluating the horse's locomotion and thus future research should include either videos shot from right behind, in front and on the side of the horse or on the site evaluation by a trainer or veterinarian to provide conclusive proof of whether or not the impulsion improves during a training period.

Four of the horses included in this study were lunged only as training whereas the other seven horses were mainly ridden. Of the four horses that were lunged only, one became more symmetrical during the three month training period, one become a lot more asymmetrical and the other two did not improve or worsen obviously over the training period. When the data of these four horses was statistically analysed separately from the other horses, no significant changes in symmetry between the before and after training measurements were found. It is not known if or how often the seven horses that were ridden, were lunged during the three month training period. Lunging was found to have an effect on the prevalence of lameness in horses (Murray et al., 2010). Among horses that were regularly lunged beside their other exercises, the prevalence of lameness was smaller than among horses that were not regularly lunged. This effect was measured in horses that were also trained in other ways and the effect was thought to be due to the combination of different exercises or a higher effectiveness of warming up or cooling down (Murray et al., 2010). The four horses that were lunged only could not have had the advantage of different types of exercise, which could explain why the positive effect of lunging was not reflected in the symmetry measured in these horses.

Considering the age range (4-6 years of age), ~~G~~growth of the horses should be taken into account as a factor possibly affecting the data found in this study. However, in another study, the locomotion of 3 year old and adult (around 12 year old) Andalusian horses was compared and no significant differences were found between the two groups for velocity, stride length and stride duration, among other values (Cano et al., 1999). Horses from neither group were submitted to training and all horses received the same amount and type of exercise, thus any possible influence of training was excluded. Since the range of ages used in this study includes the age-range used in our study, ~~(4-6 years of age),~~ no horses were trained and no significant changes were found in velocity, stride length and stride duration, it can be concluded that any growth the horses underwent during the three month training period, did not affect the data found on these parameters.

Showing of the horses had no significant effect on the symmetry parameters, but did cause a significant increase in velocity, stride length and stride frequency. Like with the training, a lot of variation was found between horses in their response to being showed. Some became more symmetrical whereas others became more asymmetrical. During showing, the horse is supported in its locomotion and often forced to move more upward and with more impulsion. For most horses, the head and neck were moved into a higher position but for those with problems in the hindquarters, the head and neck were lowered by the handler. The different head neck positions in which the horses were forced and the extensive influence of the handler, can account for the changes in symmetry seen when the horses were showed. A second handler ran along behind the horse with a whip. This explains the higher velocity. The increase in stride length and frequency can also be explained by the increase in velocity and by the whip, which causes excitement and the urge to move faster.

Conclusions

~~The hypotheses were that (1) an objective and subjective change in locomotor symmetry of a young sport horse between two measuring time points can be caused by the training effect of a trainer and (2) an objective and subjective change in locomotor symmetry of a young sport horse between two measuring time points can be caused by the showing effect of a handler.~~

The study group comprised of only eleven horses which all underwent different types and amounts of training. This can account for the variation between horses on the symmetry parameters, which in turn can account for the lack of significant results. Future research should include a larger study group with standardised training schedules and a longer follow up period. Subjective assessment should be done on site or by videos shot in front, behind and on the side of the horse. Ideally, the horses should all be held under the same housing conditions.

Met opmerkingen [FB4]: Move this tot he beguining of the dicussion section.

Back, W., Hartman, W., Schamhardt, H.C., Bruin, G., Barneveld, A., 2010. Kinematic response to a 70 day training period in trotting Dutch Warmbloods. Equine Vet. J. 27, 127–131. https://doi.org/10.1111/j.2042-3306.1995.tb04904.x
Cano, M.R., Miro, F., Vivo, J., Galisteo, A.M., 1999. Comparative Biokinematic Study of Young and Adult Andalusian Horses at the Trot. J. Vet. Med. Ser. A 46, 91–102. https://doi.org/10.1046/j.1439-0442.1999.00196.x
Johnston, C., Holm, K.R., Erichsen, C., Eksell, P., Drevemo, S., 2010. Kinematic evaluation of the back in fully functioning riding horses. Equine Vet. J. 36, 495–498. https://doi.org/10.2746/0425164044877431
Jönsson, L., Roepstorff, L., Egenvall, A., Näsholm, A., Dalin, G., Philipsson, J., 2013. Prevalence of clinical findings at examinations of young Swedish warmblood riding horses. Acta Vet. Scand. 55, 34. https://doi.org/10.1186/1751-0147-55-34
Keegan, K.G., Dent, E.V., Wilson, D.A., Janicek, J., Kramer, J., Lacarrubba, A., Walsh, D.M., Cassells, M.W., Esther, T.M., Schiltz, P., Frees, K.E., Wilhite, C.L., Clark, J.M., Pollitt, C.C., Shaw, R., Norris, T., 2010. Repeatability of subjective evaluation of lameness in horses: Repeatability of subjective evaluation of lameness in horses. Equine Vet. J. 42, 92–97. https://doi.org/10.2746/042516409X479568
McCracken, M.J., Kramer, J., Keegan, K.G., Lopes, M., Wilson, D.A., Reed, S.K., LaCarrubba, A., Rasch, M., 2012. Comparison of an inertial sensor system of lameness quantification with subjective lameness evaluation: Comparison of inertial system with subjective lameness evaluation. Equine Vet. J. 44, 652–656. https://doi.org/10.1111/j.2042-3306.2012.00571.x
MuñOz, A., Santisteban, R., Rubio, M.D., AgüEra, E.I., Escribano, B.M., CastejóN, F.M., 1999. Locomotor, cardiocirculatory and metabolic adaptations to training in Andalusian and Anglo-Arabian horses. Res. Vet. Sci. 66, 25–31. https://doi.org/10.1053/rvsc.1998.0235
Murray, R.C., Walters, J.M., Snart, H., Dyson, S.J., Parkin, T.D.H., 2010. Identification of risk factors for lameness in dressage horses. Vet. J. 184, 27–36. https://doi.org/10.1016/j.tvjl.2009.03.020
Pfau, T., Fiske-Jackson, A., Rhodin, M., 2016. Quantitative assessment of gait parameters in horses: Useful for aiding clinical decision making? Equine Vet. Educ. 28, 209–215. https://doi.org/10.1111/eve.12372
Putnam, J.R.C., Holmes, L.M., Green, M.J., Freeman, S.L., 2014. Incidence, causes and outcomes of lameness cases in a working military horse population: A field study: Incidence and causes of lameness in a working horse population. Equine Vet. J. 46, 194–197. https://doi.org/10.1111/evj.12084
Rhodin, M., Egenvall, A., Haubro Andersen, P., Pfau, T., 2017. Head and pelvic movement asymmetries at trot in riding horses in training and perceived as free from lameness by the owner. PLOS ONE 12, e0176253. https://doi.org/10.1371/journal.pone.0176253
Ringmark, S., Jansson, A., Lindholm, A., Hedenström, U., Roepstorff, L., 2016. A 2.5 year study on health and locomotion symmetry in young Standardbred horses subjected to two levels of high intensity training distance. Vet. J. 207, 99–104. https://doi.org/10.1016/j.tvjl.2015.10.052
SLOET van OLDRUITENBORGH-OOSTERBAAN, M.M., Genzel, W., Van WEEREN, P.R., 2010. A pilot study on factors influencing the career of Dutch sport horses: Career of sport horses. Equine Vet. J. 42, 28–32. https://doi.org/10.1111/j.2042-3306.2010.00251.x
Visser, E.K., Neijenhuis, F., de Graaf-Roelfsema, E., Wesselink, H.G.M., de Boer, J., van Wijhe-Kiezebrink, M.C., Engel, B., van Reenen, C.G., 2014. Risk factors associated with health disorders in sport and leisure horses in the Netherlands. J. Anim. Sci. 92, 844–855. https://doi.org/10.2527/jas.2013-6692

Appendix A: general horse information

Name & ID	Breed	Weight (kg)	Age (years)	Gender	Height (m)
Horse 1~~Good Boy~~					
1702275	Dutch warmblood	568	6	Gelding	1.72
Horse 10~~Gucci~~					
1703060	Dutch warmblood	551	6	Mare	1.66
Horse 12~~.~~*					
1703066	Dutch warmblood	516	5	Mare	NA
H~~arvey vh Vossenhol~~orse 3					
1702273	Dutch warmblood	518	5	Stallion	1.68
Horse 11~~eerde~~					
1703064	Dutch warmblood	611	5	Gelding	1.65
Horse 2~~ighlander~~					
1702272	Dutch warmblood	568	5	Stallion	1.72
H~~urry on V.D.T.~~orse 4					
1702274	Dutch warmblood	514	5	Stallion	1.66
Ho~~cus Pocus K~~rse 8					
1702564	Dutch warmblood	514	5	Gelding	1.65
~~I am Sam RDP~~Horse 7					
1702562	Dutch warmblood	544	4	Gelding	1.75
~~Ibrahim~~Horse 6					
1702553	Dutch warmblood	602	4	Gelding	1.75
~~Iniesta~~Horse 5					
1702554	Dutch warmblood	543	4	Gelding	1.70
Horse 9~~Ilsa~~					
1703059	German warmblood	533	4	Mare	1.69

*This horse was lost to follow up

Appendix B: details about training of the horses

Name and ID	Form of training	Details

Horse 1~~Good Boy~~
1702275 Lunged only

Horse 10~~Gucci~~
1703060 Ridden Very powerful and thus hard to ride, seeks support on the right and on the front.

Horse 12~~.~~
1703066 Ridden NA

H~~arvey vh Vossenhol~~orse 3
1702273 Lunged only

~~Heerde~~Horse 11
1703064 Ridden Powerful and stiff in its back movements.

~~Highlander~~Horse 2
1702272 Lunged only

H~~urry on V.D.T.~~orse 4
1702274 Lunged only

~~Hocus Pocus K~~Horse 8
1702564 Ridden Mostly gallop training to make the horse carry itself better and be more collected in its movements. Started very asymmetrical under the saddle but improved during the training period.

~~I am Sam RDP~~Horse 7
1702562 Ridden Mostly gallop training and training in the forest, aimed at strengthening the horse. Has good balance under the saddle and is easy to ride.

~~Ibrahim~~Horse 6
1702553 Ridden Refused to be ridden on the right hand at first, difficult on the right circle, straighter in its movements after the training period.

~~Iniesta~~Horse 5
1702554 Ridden Basic dressage training by amateur rider.

Horse 9~~Ilsa~~
1703059 Ridden Hard to ride, very stiff.

Appendix C: subjective assessment

Length of stride

Most horses showed a clear decrease in the stride length after the training period. During showing no obvious difference was seen compared to the after training measurement for most horses. One horse did increase in stride length during showing and two horses decreased in stride length during showing.

Elasticity
No major changes were noted with regard to elasticity when the three measurements were compared. Improvement of elasticity was seen in three horses when these horses were showed. The other horses did not show a noteworthy change in elasticity when showed.

Impulsion
One horse was more powerful after the training period than before. One horse became weaker in the hind limbs. The other nine horses did not improve in impulsion during the training period. When the horses were showed, three horses clearly had more powerful movements and one horse improved slightly in impulsion. The other seven horses did not show improvement in impulsion when showed.

Balance
Three horses showed a clear improvement in balance after the training period and one horse showed a slight improvement in balance. The other horses did not show any notable change in balance after the training period. When the effect of showing was evaluated, one horse showed a clear improvement in balance and the other ten did not show any obvious change.

Symmetry
After the training period, two horses showed a clear improvement in symmetry whereas two other horses became more asymmetric toward the left hind limb. The other horses did not show any noteworthy change in symmetry after the training period. Showing of the horses did not have a clear visible effect on symmetry.

Influence of the handler
With one horse, the handler had an effect on the symmetry of the head during the measurement that was done after training. During all the other measurements that were done before and after training, the handler did not have any notable effect on the locomotion of the horses.
During showing of the horses, the handler supported the horses in such a way that their locomotion would improve. This was done by bringing the head and neck in a specific position, which differed between horses. For most horses, the handler moved the head upwards, but for those who had problems in the hind limbs, the handler moved the head downwards. Those horses who were more asymmetrical toward the left or right, were corrected by the handler so that they would move more symmetrically. Also some horses were held back on the front so that they would move with more impulsion and balance.

Appendix D: ROM, MaxDiff and MinDiff

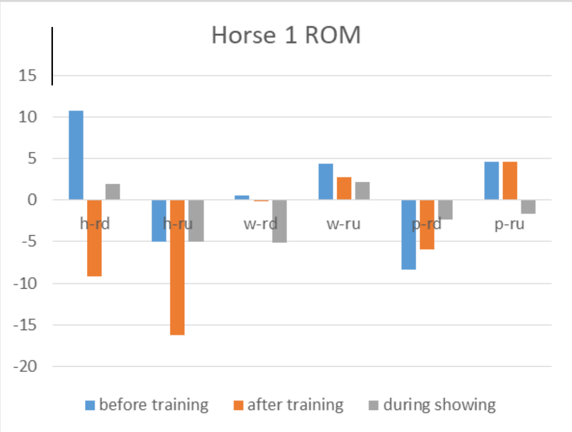
Horse	Measurement	H-rd	H-ru	W-rd	W-ru	P-rd	P-ru
1~~Good Boy~~	1	10,7	-5,0	0,6	4,4	-8,4	4,6
~~Good Boy~~1	2	-9,2	-16,3	-0,2	2,8	-5,9	4,6
~~Good Boy~~1	3	1,9	-5,0	-5,1	2,2	-2,3	-1,7
~~Highlander~~2	1	-8,7	-3,3	2,1	-4,0	9,1	3,4
~~Highlander~~2	2	3,9	0,9	4,4	-1,3	13,3	0,6
~~Highlander~~2	3	-1,0	15,9	-5,7	-5,1	11,8	5,1
~~Harvey vh Vossenhol~~3	1	8,3	5,6	1,6	-5,0	2,2	-4,4
~~Harvey vh Vossenhol~~3	2	10,4	-8,5	0,1	-5,5	1,7	2,9
~~Harvey vh Vossenhol~~3	3	6,0	7,1	-0,1	-6,2	0,6	8,9
~~Hurry On V.D.T.~~4	1	-9,8	22,7	-6,7	12,8	-12,5	-6,7
~~Hurry On V.D.T.~~4	2	-29,0	2,5	1,1	26,9	-17,6	-31,5
~~Hurry On V.D.T.~~4	3	-6,4	7,8	1,3	18,1	15,8	-23,1
~~Iniesta~~5	1	7,2	4,4	-0,9	-8,5	9,0	3,4
~~Iniesta~~5	2	-1,3	-1,8	-7,2	-16,1	14,5	3,9
~~Iniesta~~5	3	-2,4	12,6	0,7	-5,8	10,4	-0,5
~~Ibrahim~~6	1	25,2	5,4	2,5	8,9	-1,8	-7,3
~~Ibrahim~~6	2	1,1	-3,9	-1,9	7,0	-4,3	-2,2
~~Ibrahim~~6	3	-25,9	14,7	-2,5	1,1	-5,6	2,8
~~I am Sam~~7	1	9,9	1,9	-5,7	3,1	-4,7	-0,7
~~I am Sam~~7	2	3,3	5,1	-5,9	5,1	-3,8	-2,9
~~I am Sam~~7	3	-0,2	4,4	-8,4	6,4	-3,6	0,2
~~Hocus Pocus K~~8	1	-9,4	-9,0	-0,6	1,1	-6,6	4,1
~~Hocus Pocus K~~8	2	5,8	-10,2	4,7	7,4	-14,1	-3,3
~~Hocus Pocus K~~8	3	-8,6	-22,8	3,2	-0,7	-18,6	5,8
~~Isa~~9	1	11,3	5,7	3,4	3,3	6,6	-1,3
~~Isa~~9	2	28,1	-7,2	3,2	-13,0	6,9	-1,5
~~Isa~~9	3	-7,7	11,7	1,8	-10,4	2,5	0,6
~~Gucci~~10	1	-23,7	-41,3	5,0	-4,2	-1,3	3,1
~~Gucci~~10	2	-7,4	-21,2	5,7	-3,3	-4,4	-6,2
~~Gucci~~10	3	-7,5	-23,1	4,1	-0,9	-2,7	-4,9
~~Heerde~~11	1	9,0	16,3	1,0	9,6	4,7	-4,1
~~Heerde~~11	2	9,5	9,0	-1,7	9,1	3,0	-5,4
~~Heerde~~11	3	18,0	11,5	1,6	6,9	-2,4	-2,8

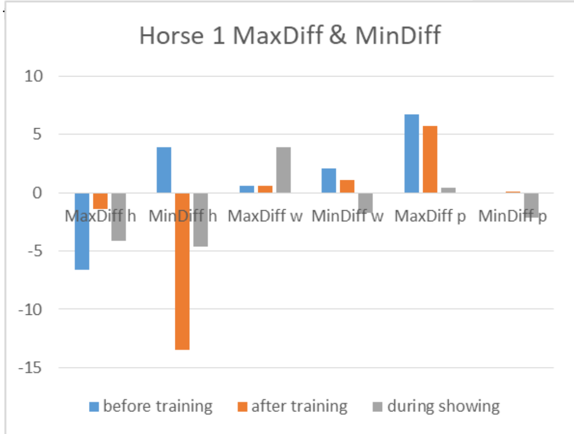
Table 1: Range of motion, 1= before training, 2= after training, 3= during showing. H= head, W= withers, P= pelvis. Rd= range down, ru= range up

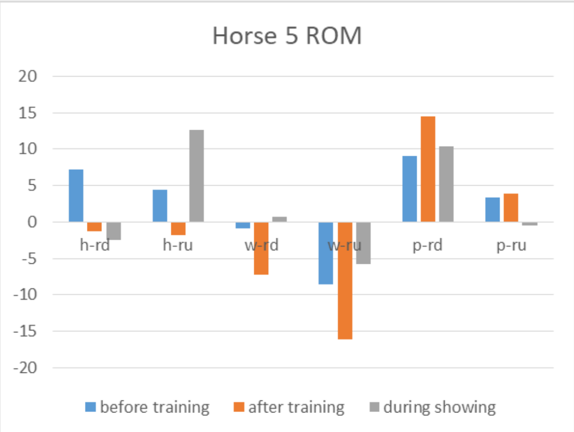
Horse	Measurement	H-MaxDiff	H-MinDiff	W-MaxDiff	W-MinDiff	P-MaxDiff	P-MinDiff
~~Good Boy~~1	1	-6,8	3,9	0,6	2,1	6,7	0,0
~~Good Boy~~1	2	-1,4	-13,5	0,6	1,1	5,7	0,1
~~Good Boy~~1	3	-4,1	-4,6	3,9	-1,7	-0,4	-2,1
~~Highlander~~2	1	0,7	-5,0	-4,3	-0,4	-3,3	4,5
~~Highlander~~2	2	-3,0	3,6	-2,9	1,4	-10,5	4,6
~~Highlander~~2	3	9,6	5,9	0,3	-5,8	-3,7	11,0
~~Harvey vh Vossenhol~~3	1	-4,0	4,4	-2,1	-1,1	-1,7	-1,3
~~Harvey vh Vossenhol~~3	2	-11,1	1,3	-2,9	-3,2	0,2	2,3
~~Harvey vh Vossenhol~~3	3	-0,5	5,0	-3,6	-3,2	3,2	4,6
~~Hurry On V.D.T.~~4	1	15,6	6,5	11,1	3,4	3,5	-10,0
~~Hurry On V.D.T.~~4	2	17,3	-12,7	14,0	14,6	-7,0	-24,3
~~Hurry On V.D.T.~~4	3	10,5	0,7	8,9	10,7	-4,4	-19,8
~~Iniesta~~5	1	-3,6	3,1	-4,1	-5,0	-2,9	6,7
~~Iniesta~~5	2	0,5	0,5	-3,4	-12,9	-4,5	9,2
~~Iniesta~~5	3	7,1	5,5	-2,8	-3,3	-5,1	5,6
~~Ibrahim~~6	1	-4,9	13,2	3,3	5,2	-3,3	-6,2
~~Ibrahim~~6	2	0,6	-0,8	3,7	2,3	0,9	-3,5
~~Ibrahim~~6	3	20,5	-2,7	1,2	-1,8	2,9	-1,6
~~I am Sam~~7	1	-4,9	6,0	4,2	-0,4	1,6	-2,0
~~I am Sam~~7	2	4,0	11,5	3,8	-1,0	0,3	-4,2
~~I am Sam~~7	3	0,5	1,1	8,5	-0,8	1,9	-2,3
~~Hocus Pocus K~~8	1	3,4	-9,0	0,6	0,1	5,3	-1,6
~~Hocus Pocus K~~8	2	-8,5	-3,4	1,6	5,7	4,3	-9,5
~~Hocus Pocus K~~8	3	-5,4	-17,2	-0,5	0,6	10,7	-8,2
~~Isa~~9	1	-0,4	11,7	-1,3	3,2	-4,7	2,0
~~Isa~~9	2	-16,3	8,4	-8,0	-4,9	-4,3	1,5
~~Isa~~9	3	6,9	-4,6	-4,9	-3,6	-0,8	1,2
~~Gucci~~10	1	-8,3	-30,5	-3,9	-0,5	2,7	-0,6
~~Gucci~~10	2	-7,8	-15,6	-4,9	1,4	-1,2	-5,3
~~Gucci~~10	3	-10,6	-15,8	-2,0	1,9	-0,9	-4,1
~~Heerde~~11	1	4,9	9,9	4,3	4,2	-3,9	-1,0
~~Heerde~~11	2	0,3	8,2	5,2	2,3	-4,6	-1,2
~~Heerde~~11	3	2,0	15,0	2,9	3,7	0,7	2,5

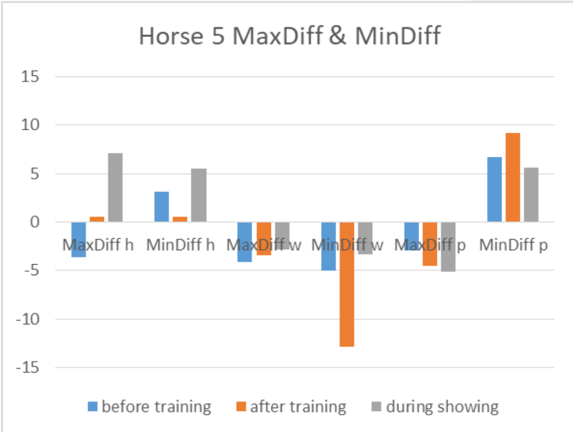
Table 2: MaxDiff and MinDiff. 1= before training, 2= after training, 3= during showing. H= head, W= withers, P= pelvis.

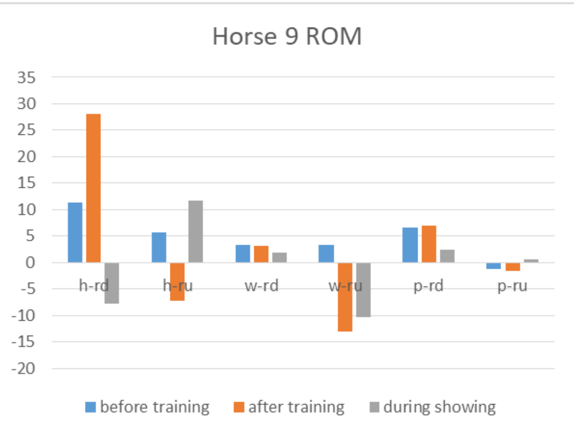
To demonstrate the changes in symmetry and the variation in this, these tables show the symmetry

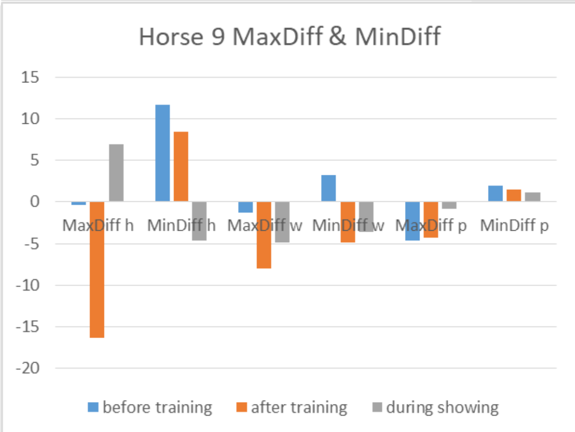


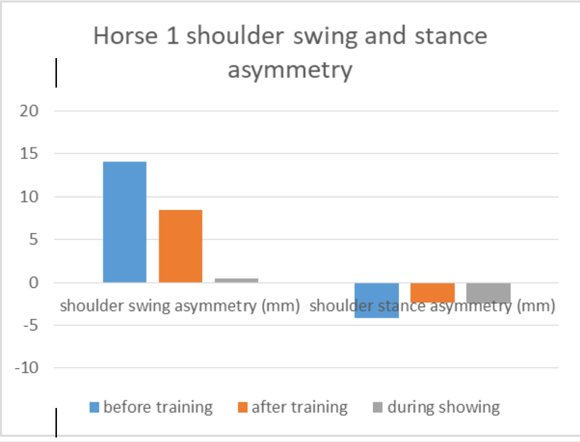


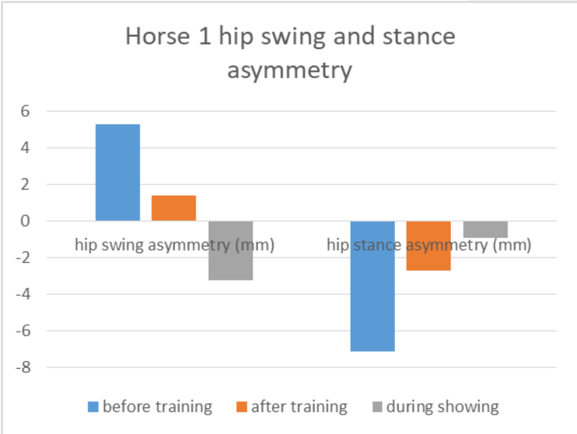


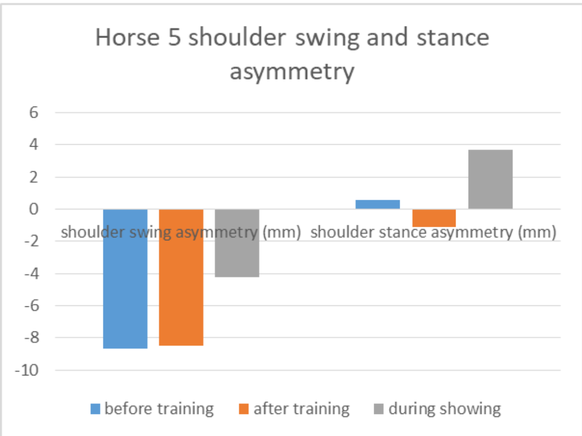


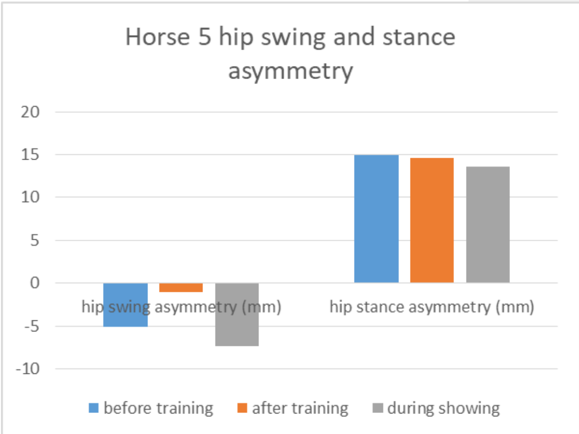


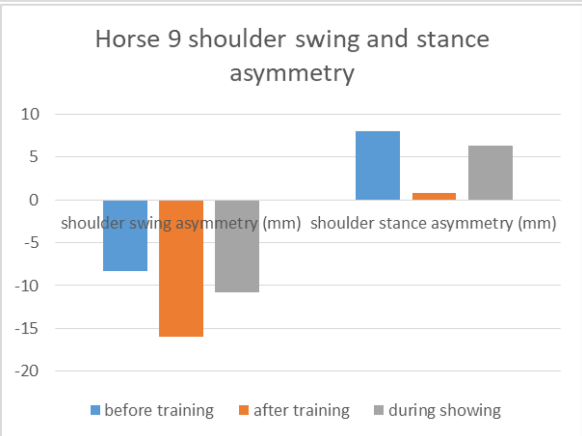


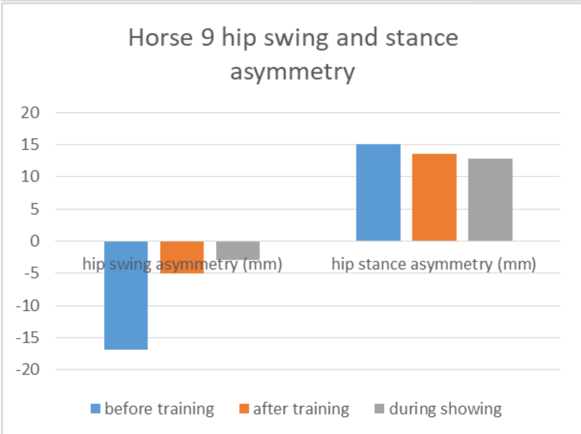

Horse 1 shoulder swing and stance asymmetry
20
15
10
5
0
-5
-10
shoulder swing asymmetry (mm)
shoulder stance asymmetry (mm)
before training
after training
during showing


Horse 1 hip swing and stance asymmetry
6
4
2
0
-2
-4
-6
-8
hip swing asymmetry (mm)
hip stance asymmetry (mm)
before training
after training
during showing


Horse 5 shoulder swing and stance asymmetry
6
4
2
0
-2
-4
-6
-8
-10
shoulder swing asymmetry (mm)
shoulder stance asymmetry (mm)
before training
after training
during showing


Horse 5 hip swing and stance asymmetry
20
15
10
5
0
-5
-10
hip swing asymmetry (mm)
hip stance asymmetry (mm)
before training
after training
during showing


Horse 9 shoulder swing and stance asymmetry
10
5
0
-5
-10
-15
-20
shoulder swing asymmetry (mm)
shoulder stance asymmetry (mm)
before training
after training
during showing


Horse 9 hip swing and stance asymmetry
20
15
10
5
0
-5
-10
-15
-20
hip swing asymmetry (mm)
hip stance asymmetry (mm)
before training
after training
during showing