Upper-body asymmetry of 19 elite dressage horses: trot in hand on the straight versus collected- and extended trot during a standardized dressage test

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Abstract

Asymmetry in motion of the dressage horse is frequently debated among clinicians, riders, trainers and judges. The aim of the current study was to objectively describe the vertical upper-body movement asymmetry of owner-sound elite dressage horses in trot in hand on the straight and collected- and extended trot during a standardized dressage test. Differences in protraction and retraction of the fore- and hindlimb pairs were also analysed. Linear mixed models were performed for all variables with horse ID as random effect and trot condition as fixed effects. There was a significant increase in ROM of the head ($p<0.01$), withers ($p<0.01$) and pelvis ($p<0.01$) for both extended trot and collected trot compared with trot in hand. For collected trot vs. trot in hand, an increase was seen in HDmin ($p<0.01$), HDmax ($p<0.01$), WDmax ($p<0.01$) and PDmin ($p=0.04$). For extended trot vs. trot in hand, there was an increase in HDmin ($p<0.01$), HDmax ($p<0.01$) and WDmax ($p=0.04$). No significant differences were found for any upper-body parameter in collected trot vs. extended trot. DiffProtraction of the front limbs increased in both extended trot vs. trot in hand ($p<0.01$) and collected trot vs. trot in hand ($p<0.01$). An increase in DiffRetraction of the front limbs was seen for extended trot vs. trot in hand ($p=0.02$) and extended trot vs. collected trot ($p=0.02$). Factors that could have affected movement asymmetry under saddle include the increased ROM, the rider's aids, the rider's weight, the rider's static or dynamic postural asymmetry, the horse's head-neck position and the horse's laterality pattern. Regarding trot in hand measurements, horses showed asymmetry values greater than the currently recommended symmetry thresholds. This raises the highly important question: should all of our dressage horses, based on their degree of upper-body asymmetry, be classified as lame? Or should the current symmetry thresholds be re-evaluated, at least for highly trained sports horses? These asymmetries namely might also be the result of laterality, conformation, shoeing or training. The main conclusion of this study was that no elite dressage horse will trot perfectly symmetrical, neither in a natural moving trot in hand on the straight nor in collected- and extended trot under saddle. It should be investigated to what degree detectable movement asymmetries in dressage horses can be directly attributed to orthopaedic pain or natural asymmetry in the horse's locomotor pattern. Furthermore, studies investigating the long-term effect of asymmetrical motion on the development of musculoskeletal injuries would be appropriate as part of prevention and early recognition of orthopaedic disease in the dressage horse.

Keywords

Horse, asymmetry, upper-body, trot, quantitative analysis, laterality, lameness, range of motion

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Introduction

Asymmetry in motion of the dressage horse is frequently debated among clinicians, riders, trainers and judges. Movement symmetry is highly desirable in dressage horses, as symmetry and regularity are important criteria for overall quality of exercises, gait variations and gait transitions in dressage tests (Fédération Equestre Internationale, 2020). Moreover, asymmetrical motion could indicate the presence of a (sub)clinical injury of the musculoskeletal system, which may develop into chronic orthopaedic disease and this could early terminate the dressage horse’s career (Murray et al., 2010).

The most inherently symmetrical gait is the trot, which makes it suitable for detection of movement asymmetries (Byström et al., 20 18). However, it is suggested that the presence of about 20% relative asymmetry in movement is needed for consistent visual detection (Parkes et al., 2009) and there is low inter-rater agreement, expectation bias and inaccuracy among clinicians regarding visual assessment of asymmetry, especially for subtle- and hind limb asymmetries (Hammarberg et al., 2016; Keegan et al., 2010). Nowadays, it is possible to measure very subtle asymmetries due to the development of validated equipment for quantitative analysis of the equine locomotion (Bragança et al., 2018; Keegan et al., 2011). Quantitative gait analysis is based on parameters describing asymmetry of upper-body movement, which can be calculated at the head, withers, sternum and pelvis (Bosch et al., 2018). These asymmetry parameters are currently used to evaluate lameness: hind limb lameness is associated with vertical asymmetrical movement of the pelvis, whereas front limb lameness is associated with vertical asymmetrical movement of the withers and the head (Buchner et al., 1996; Kramer et al. 2004; Kelmer et al, 2005; Vertz et al., 2018).

Early detection of subtle asymmetries in the equine dressage athlete is of great importance regarding optimization of dressage performance, early lameness detection and prevention of orthopaedic disease. To our knowledge, previous studies have analysed the biomechanics of dressage specific trot types (Clayton 1994; Deuel & Park, 1990; Walker et al., 2013; Walker et al., 2017) but studies performing objective assessment of upper-body asymmetry of dressage horses under saddle, especially during these different trot types, are scarce. Recently, a study has shown that ridden trot in a dressage frame makes horses more asymmetrical compared to unridden trot but these data were collected during treadmill locomotion instead of over ground locomotion (Byström et al., 2020). The aim of the current study was to objectively describe the vertical upper-body movement asymmetry of elite dressage horses in trot in hand on the straight and collected- and extended trot during a standardized dressage test while being ridden by their usual rider. Differences in protraction and retraction of the fore- and hind limb pairs were also analysed to identify any correlations with upper-body symmetry parameters. The hypothesis was that upper-body movement would be more asymmetrical in collected- and extended trot under saddle, compared to trot in hand. It was also hypothesised that horses would be most asymmetrical in collected trot.

Materials and methods

This study protocol had been approved by the UCLan Ethical Review Panel (UK) and informed consent for data collection was obtained from the riders prior to the study.

Horses

Data collection took place in Wellington, FL, USA. 22 dressage horses based in this area, perceived as sound by their rider, with a mean age of 10.8 years (±3.7) and a mean height of 16.2hh (±0.8) were included in this study. The study group consisted of various genders (mare, n=3; gelding, n=14; and stallion, n=5), breeds (KWPN, n=3; PRE, n=6; Danish Warmblood, n=2; Westfalian, n=3; Hannoveranian, n=3; Oldenburg, n=1; Lusitano, n=1; Andalusian, n=1; American breed, n=1; Morgan, n=1) and levels (Grand Prix, n=9;

Fédération Equestre International (FEI) Intermediate 2, n=1; FEI Intermediate 1, n=2; Prix st. Georges, n=5; 3rd level, n=4).

Data collection protocol

First, horses were identified, and two experienced lameness clinicians performed a clinical examination consisting of inspection and palpation of the musculoskeletal system. After completion of the clinical examination, horses were tacked up with their usual tack and the synchronized wireless inertial measurement units (IMU's) of the EquiMoves system (EquiMoves, the Netherlands). All measurements took place at a familiar site for both rider and horse. Before riding all horses were trotted up on a straight line on a straight hard surface, consisting of walking back and forth once and trotting back and forth twice. Here, horses were also visually judged on soundness by the two experienced equine clinicians. Horses were led by their usual rider, who had as little influence as possible to allow the horse to move in a free and natural trot.

For further data collection, the horse and its usual rider performed a standardized dressage test in a 20x60 metres soft surface indoor or outdoor arena, after a period of using their normal warm up procedure. The test was divided in three parts: 1) collected trot and extended trot; 2) walk, piaffe and passage; 3) canter. Grand prix level horses performed the whole test including passage and piaffe, lower level horses only performed the parts within their capability. Both collected- and extended trot were executed twice, once on the left rein and once on the right rein, over a distance of 50 metres down the long side of the arena. After the test, horses were allowed to have a period of cooling down after which a second trot up was performed, followed by untacking and removal of the sensors. The dressage test was recorded with 3 cameras placed differently around the arena, consisting of 2 GoPro-cameras (GoPro Inc., United States) providing a lateral- and front view and one Sony video camera with zoom function providing an additional front view. From these recorded video's, timeframes of the collected- and extended trot were selected to obtain the data of interest. For this study, only measurements of collected- and extended trot on straight lines were used for data collection.

Equipment for motion analysis

For data collection the EquiMoves system was used, which captured motion of the horse from synchronized wireless IMU's to analyse both upper-body and limb movement (Bosch et al., 2018). The IMU sensors nodes were attached on the poll, withers, lumbosacral region (just behind the saddle), both tuber coxae, pelvis, sternum, each limb and each hoof. The sternum sensor was attached to the lowest point of the girth and wrapped with vetrap. At the head, the sensor was mounted on the bridle with a piece of vetrap or velcro. At the withers, pelvis, lumbosacral region and tuber coxae, sensors were attached to the skin with animal polster and double-sided tape. On each limb, a custom-made lightweight protection boot was used to attach the sensors to the lateral aspect of the cannon bone. Furthermore, sensors were attached on the lateral aspect on each hoof, wrapped with duct tape. An overview of the equipment attached to each horse is shown in Figure 1. Data from the sensors was analysed with the EquiMoves software where the vertical acceleration was converted to vertical displacement (Bosch et al., 2018). For stride segmentation, the angular velocity data from the gyroscope was used (Bragança et al., 2017).

Stride cycle and stride duration

A complete stride cycle of the trotting horse consists of a swing- and stance phase for each diagonal limb pair. The swing phase is the period between the moment the hoof is lifted (hoof-off moment) and the moment the hoof touches the ground again (hoof-on moment) (Bosch et al., 2018; Leach et al., 1984). The IMU sensors detect the hoof-on and hoof-off moments of each limb during a stride cycle, which enables a distinction between the swing- and stance phase for each limb (Bragança et al.,

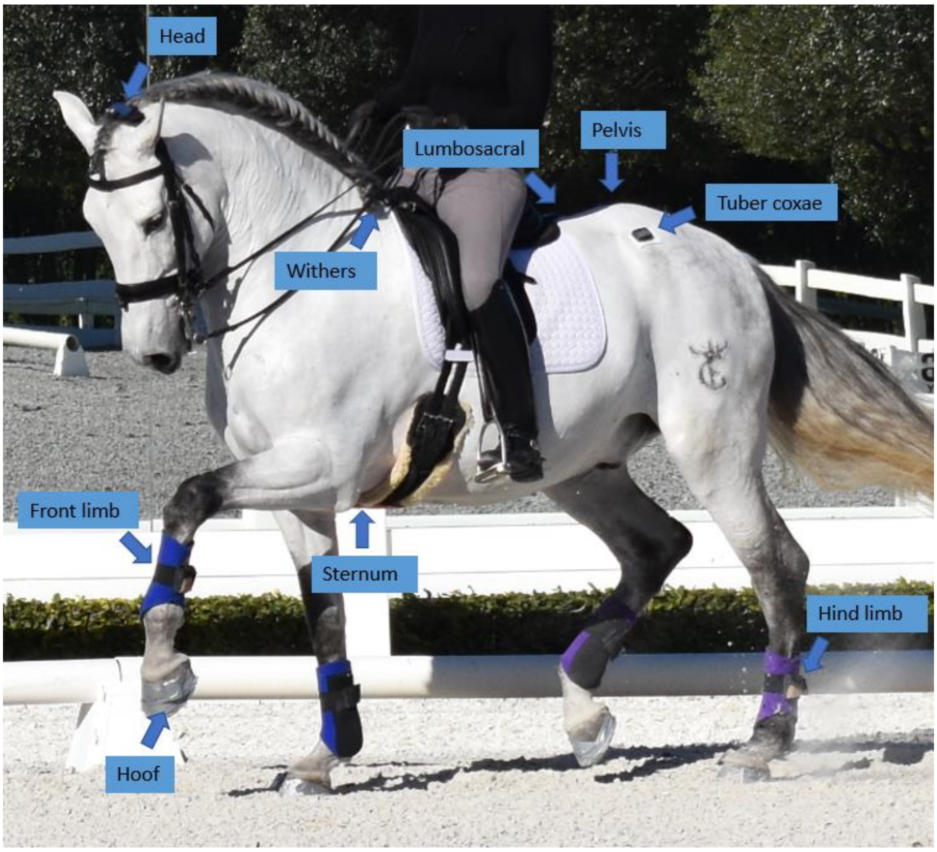


Figure 1. *Overview of the EquiMoves equipment attached to the horse.*

2017). The stride duration is the time that passes between two consecutive hoof-on moments of a single limb.

Upper-body symmetry parameters

In trot on a straight line, the head, withers and pelvis generate a typical sinusoidal pattern by moving upwards and downwards twice during each stride cycle, as shown in Figures 2-4 (Bosch et al., 2018; Bragança et al., 2018). There are two peaks and two troughs at each stride cycle and these extrema are at the same level in perfectly symmetrical moving horses (Bosch et al., 2018). In lame horses, the sinusoidal pattern becomes asymmetrical due to a decrease of vertical displacement during the stance phase of the lame limb and an increase of vertical displacement during the stance phase of the contralateral non-lame limb (Bragança et al., 2018). These changes in vertical displacement result in a difference between minimum positions (MinDiff) of the head (HDmin), withers (WDmin) and pelvis (PDmin) during the stance phase of the lame limb compared to the contralateral non-lame limb (Bosch et al., 2018; Bragança et al., 2018). MinDiff was calculated from the minimum height during right stance minus the minimum height during left limb stance ($min_{1,}$- min_2) (Figures 2-4). In addition, lameness results in a difference between maximum positions (MaxDiff) of the head (HDmax), withers (WDmax) and pelvis (PDmax), with lower maximum positions during the swing phase of the lame limb compared to the contralateral non-lame limb (Bosch et al., 2018; Bragança et al., 2018). MaxDiff was calculated from the maximum height prior to right stance minus the maximum height prior to left limb stance (max_2- max_1) (Figure 2a-2c). Positive MinDiff or MaxDiff values can be interpreted as less downward movement during the stance phase or less upward movement during the swing phase respectively of the right front/hind limb and thus a right-sided lameness/asymmetry, whereas negative values refer to a lameness/asymmetry of the left front/hind limb.

The vertical range of motion (ROM) was calculated as the difference between the maximum and minimum vertical position during a stride cycle. Figures 2a, 2b and 2c show illustrations from the EquiMoves software of vertical head, withers and pelvic

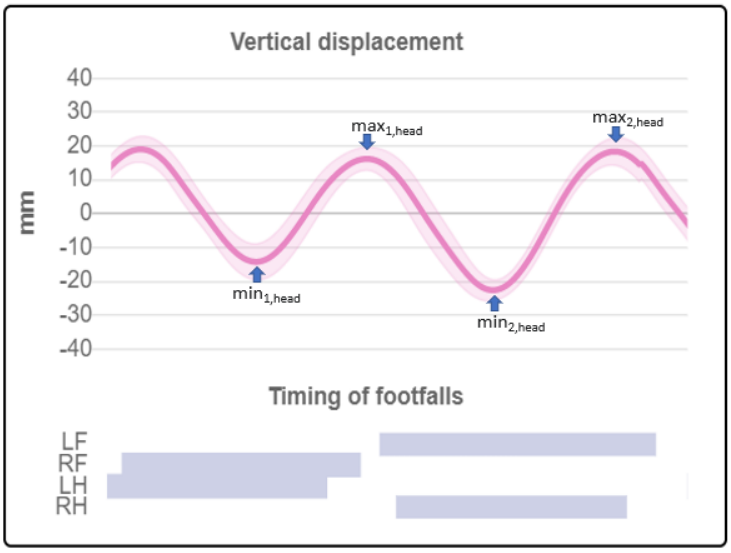


Figure 2a. *An example of right forelimb lameness/asymmetry: there is less downward vertical movement of the head when RF is weight bearing (HDmin). Moreover, there is less upward movement of the head prior to LF stance phase (HDmax). © EquiMoves software*

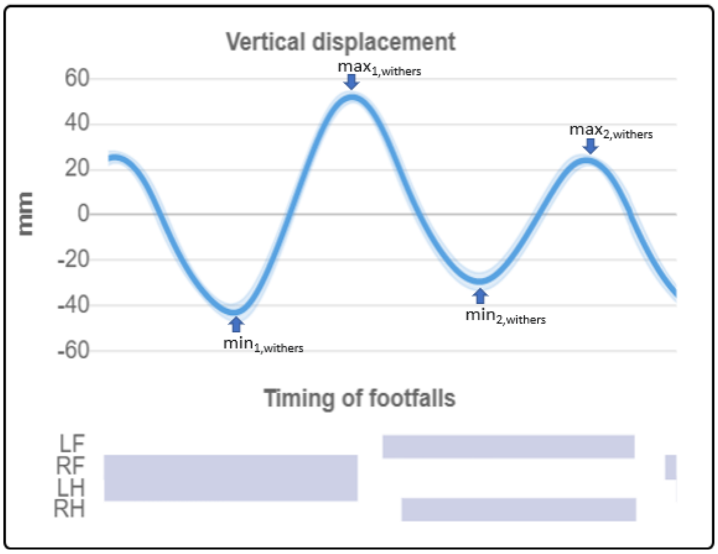


Figure 2b. *An example of a vertical movement asymmetry pattern of the withers: there is less downward vertical movement of the withers when LF is weight bearing (WDmin). Moreover, there is less upward movement during the push off phase of LF (WDmax). © EquiMoves software*

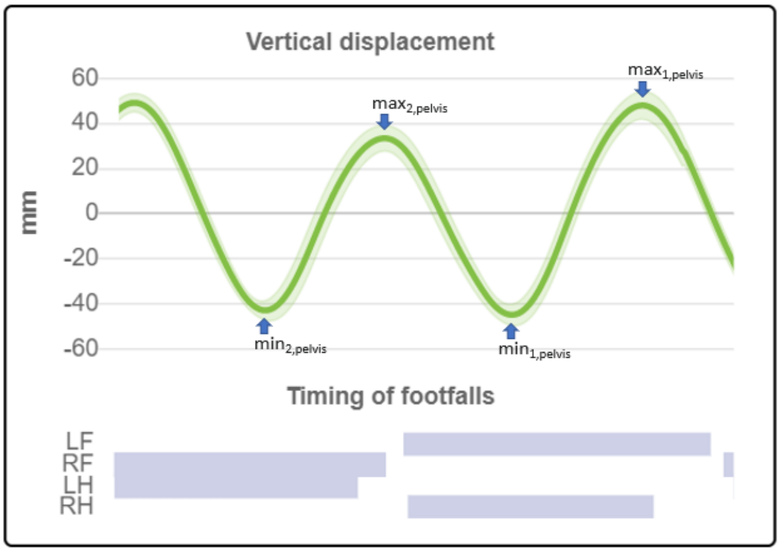


Figure 2c*. An example of right hind limb lameness/asymmetry: there is less upward vertical movement after LH stance phase (PDmax). Moreover, there is slightly less downward movement during LH stance phase (PDmin). © EquiMoves software*

movement during a complete stride cycle. The solid lines represent the mean value of vertical displacement (mm) of all stride cycles during the measurement and the transparent areas represent the distribution of all stride cycle values. The grey bars represent the limb stance phase (LF, RF, LH, RH).

Protraction and retraction

Protraction and retraction angles are defined as the forward/backward swing angles of the cannon bone relative to the vertical and were measured for each limb using the IMU's (Bosch et al., 2018). During a stride cycle, maximum retraction is achieved after push-off (hoof-off) and maximum protraction is achieved prior to stance (hoof-on) (figure 3a-3b). The difference in maximum protraction (DiffProtraction) and the difference in maximum retraction (DiffRetraction) between limb pairs were measured for the front- and hind limbs based on the maximum protraction- and retraction angels of each limb. Figures 3a and 3b show illustrations from the EquiMoves software of front- and hindlimb protraction/retraction during a stride cycle.

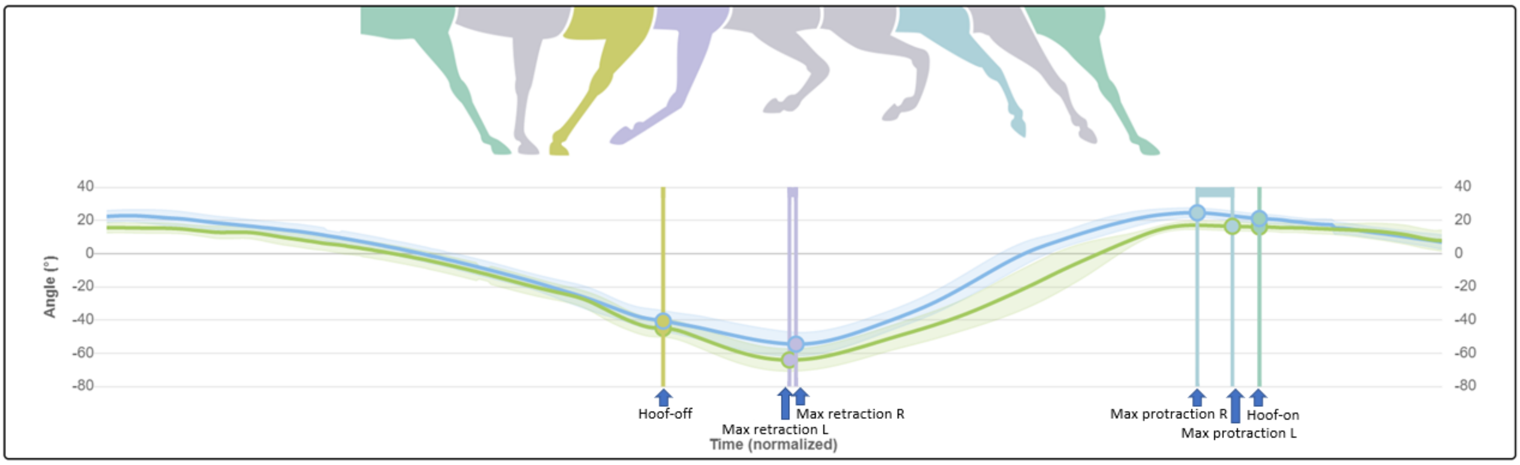


Figure 3a. *An illustration of front limb protraction/retraction asymmetry during a stride cycle. The solid lines represent the mean angle (°) of all stride cycles and the transparent lines represent the distribution of all stride cycle values (green = left front, blue = right front). This horse shows greater maximum protraction but less maximum retraction of the right front limb compared to the left front limb. © EquiMoves software*

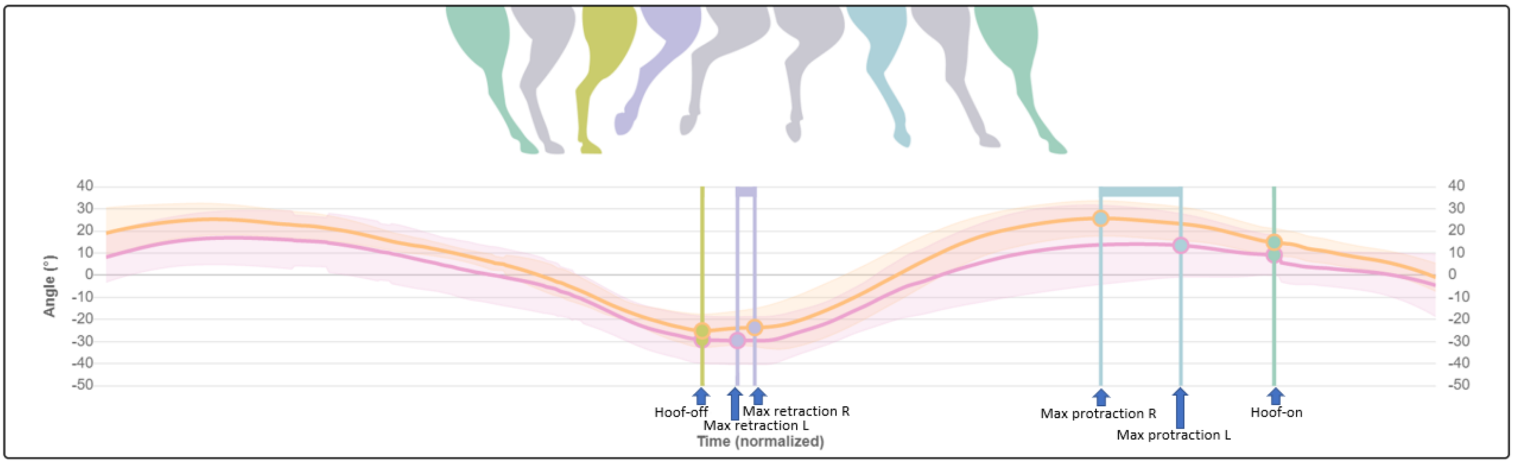


Figure 3b. *An illustration of hind limb protraction/retraction asymmetry during a stride cycle. The solid lines represent the mean angle (°) of all stride cycles and the transparent lines represent the distribution of all stride cycle values (pink = left hind, orange = right hind). This horse shows greater maximum protraction but less maximum retraction of the right hind limb compared to the left hind limb. © EquiMoves software*

Statistical analysis

Descriptive statistics were performed. Box plots were created to demonstrate stride duration, upper-body symmetry parameters, ROM, difference in maximum protraction and retraction for the three different trot conditions (in hand, collected and extended). Positive and negative values of HDmin, HDmax, WDmin, WDmax, PDmin and PDmax were converted to absolute values, as the purpose of this study was to determine the degree of asymmetry in general instead of pointing out a left or right asymmetry. All variables were assessed for normality. Square root transformation of all variables except for stride duration was done to achieve a normal distribution of model residuals. Linear mixed models, using R-studio (version3.6.3 , and package lme4 version 1.1.), were performed for all variables with horse ID as random effect and trot condition (trot in hand, extended trot and collected trot) as fixed effects. For pairwise comparisons, p values of ≤0.05 were chosen to be significant.

Results

Study population

One horse (horse ID 5) was excluded from the study because of a clinically visible left front lameness. The remaining 21 horses were available for all measuring sessions but unfortunately measurements of two horses (horse ID 1 and 21) were lost due to technical issues. Thus, measurement data was analysed for a total of 19 horses.

Stride duration (s)				
	LSmean	Lower C.I.	Upper C.I.	p-value
Trot in hand (Intercept)	0.78	0.75	0.82	-
Extended trot	0.78	0.75	0.82	0.94
Collected trot	0.85	0.81	0.89	<0.01
Extended trot - collected trot	-	-	-	<0.01

Table 1. *Least square mean (LSmean) mean from mixed model analysis with 95% confidence intervals for stride duration in seconds (s) and p-values of pairwise comparisons between trot conditions (trot in hand vs. extended trot, trot in hand vs. collected trot and extended trot vs. collected trot)*

Stride duration

The effect of the 3 different trot conditions on stride duration is shown in figure 4 and linear mixed model output with pairwise comparisons between trot conditions is presented in table 1. Pairwise comparisons showed a significant increase in stride duration in collected trot compared to trot in hand (p<0.01) and extended trot (p<0.01). There was no significant difference in stride duration between trot in hand and extended trot (p=0.94).

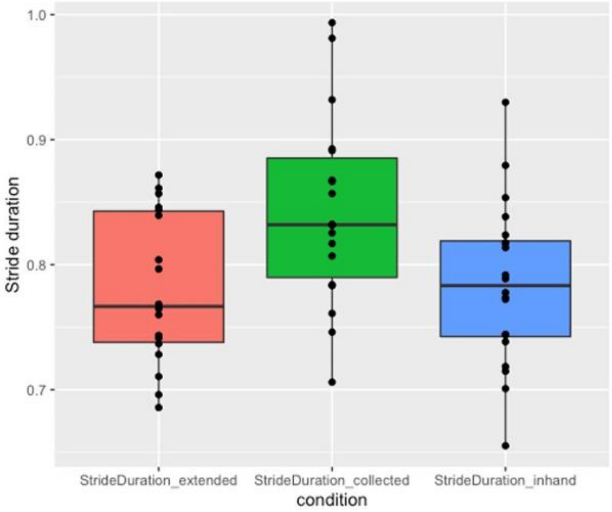
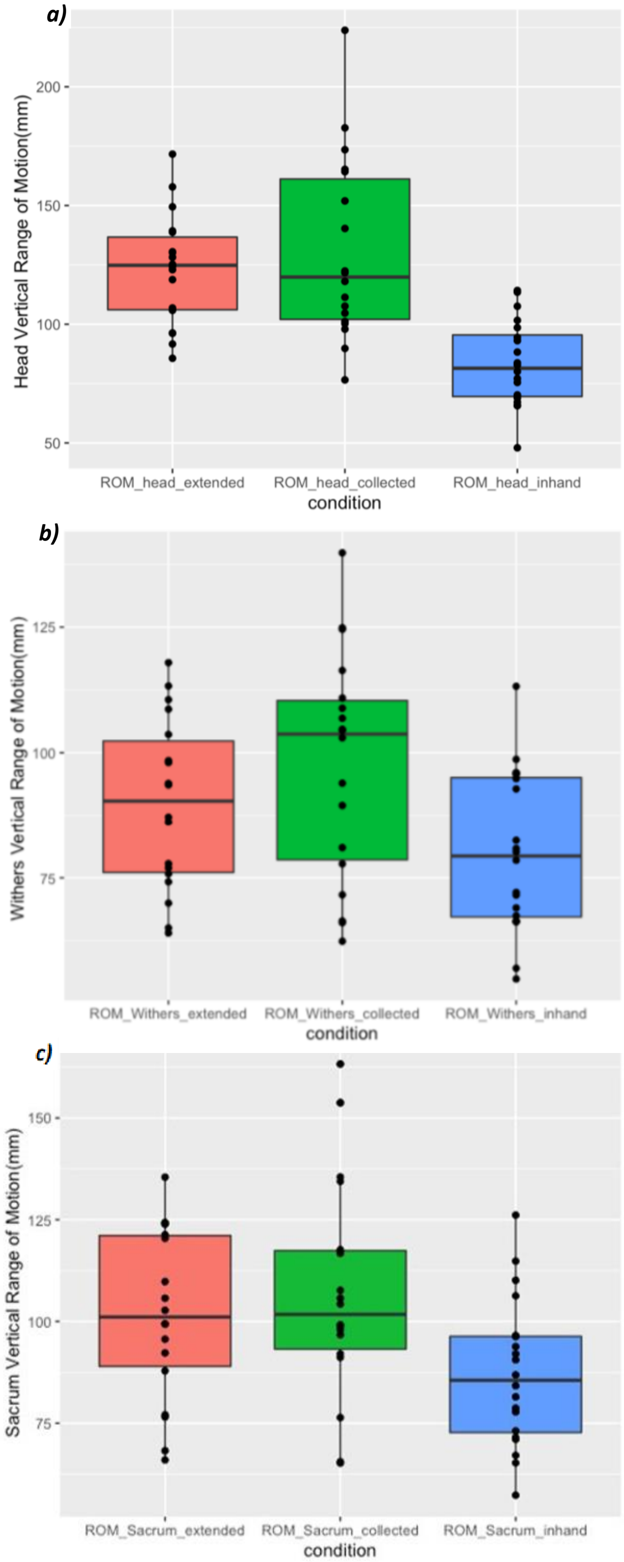


Figure 4. *Boxplots for stride duration (s) of extended trot (red), collected trot (green) and trot in hand (blue).*

Vertical range of motion

Figures 5a-5c show the effect of the 3 different trot conditions on ROM of the head, withers and pelvis respectively. Table 2 presents linear mixed model output with pairwise comparisons between trot conditions. Pairwise comparisons showed a significant increase in ROM of the head (p<0.01), withers (p<0.01) and pelvis (p<0.01) for both extended trot and collected trot compared with trot in hand. No significant differences in ROM of the head, withers and pelvis were seen between



Figures 5a-c. *Boxplots for mean values of ROM of the head (a), withers (b), pelvis (c) (mm) for extended trot (red), collected trot (green) and trot in hand (blue).*

Range of Motion (ROM)					
		LSmean	Lower C.I.	Upper C.I.	p-value
Head	Trot in hand	82.4	70.2	95.5	-
	Extended trot	123.4	107.8	140.1	<0.01
	Collected trot	129.3	113.3	146.4	<0.01
	Extended trot – collected trot	-			0.43
Withers	Trot in hand	79.3	69.6	89.5	-
	Extended trot	90.3	79.7	101.5	<0.01
	Collected trot	97.5	86.5	109.1	<0.01
	Extended trot – collected trot	-	-	-	0.06
Pelvis	Trot in hand	86.2	74.8	98.4	-
	Extended trot	102.3	89.6	115.9	<0.01
	Collected trot	106.9	93.9	120.8	<0.01
	Extended trot – collected trot	-	-	-	0.28

Table 2. *LSmean mean from mixed model analysis with 95% confidence intervals for ROM (mm) and p-values of pairwise comparisons between trot conditions (trot in hand vs. extended trot, trot in hand vs. collected trot and extended trot vs. collected trot)*

extended trot and collected trot (p=0.43, p=0.06 and p=0.28 respectively).

MinDiff and MaxDiff of the head, withers and pelvis

Absolute values of all variables regarding differences in vertical displacement (HDmin, HDmax, WDmin, WDmax, PDmin, PDmax) are presented in table 3 in the appendix. The effect of the 3 different trot conditions on HDmin, HDmax, WDmin, WDmax, PDmin and PDmax is shown in Figure 6a-6f and linear mixed model output with pairwise comparisons between trot conditions is presented in table 4. For the head, pairwise comparisons revealed a significant increase in HDmin (p<0.01) and HDmax (p<0.01) in both collected- and extended trot compared to trot in hand. No significance difference was seen in HDmin (p=0.92) and HDmax (p=0.11) when extended trot was compared to collected trot. Regarding the withers, no significant differences for WDmin were found in pairwise comparisons of trot in hand vs. extended trot (p=0.58), trot in hand vs. collected trot (p=0.31) and extended trot vs. collected trot (p=0.23). WDmax shows a comparable pattern to HDmax, as pairwise comparisons showed a significant increase in WDmax in collected trot (p<0.01) as well as extended trot (p=0.04) compared to trot in hand. There was no significant difference in WDmax between extended trot and collected trot (p=0.38). For the pelvis, pairwise comparisons revealed a significant increase of PDmin in collected trot (p=0.04) compared to trot in hand. However, no significant difference was seen in PDmin between extended trot and trot in hand (p=0.18). Furthermore, there was no significant difference in PDmin between extended and collected trot (p=0.33). Pairwise comparisons showed no significant difference in PDmax for trot in hand vs. extended trot (p=0.96), trot in hand vs. collected trot (p=0.96) and extended trot vs. collected trot (p=0.96).

Protraction and retraction

The effect of different trot conditions on DiffProtraction and DiffRetraction of the front limbs and hind limbs is shown in figures 7a-7d. Table 4 presents linear mixed model output and pairwise comparisons between trot conditions. Pairwise comparisons revealed a significant increase in DiffProtraction of the front limbs for extended trot vs. trot in hand (p<0.01) and collected trot vs. trot in hand (p<0.01). However, no significant correlation between DiffProtraction of the front limbs and HDmin, HDmax or WDmax was found. No significant difference was seen in DiffProtraction of the front limbs between extended trot and collected trot (p=0.28). A significant increase of DiffRetraction of the front limbs was seen for extended trot compared to trot in hand (p=0.02) and collected trot (p=0.02). Again, there was no significant correlation with HDmin, HDmax or

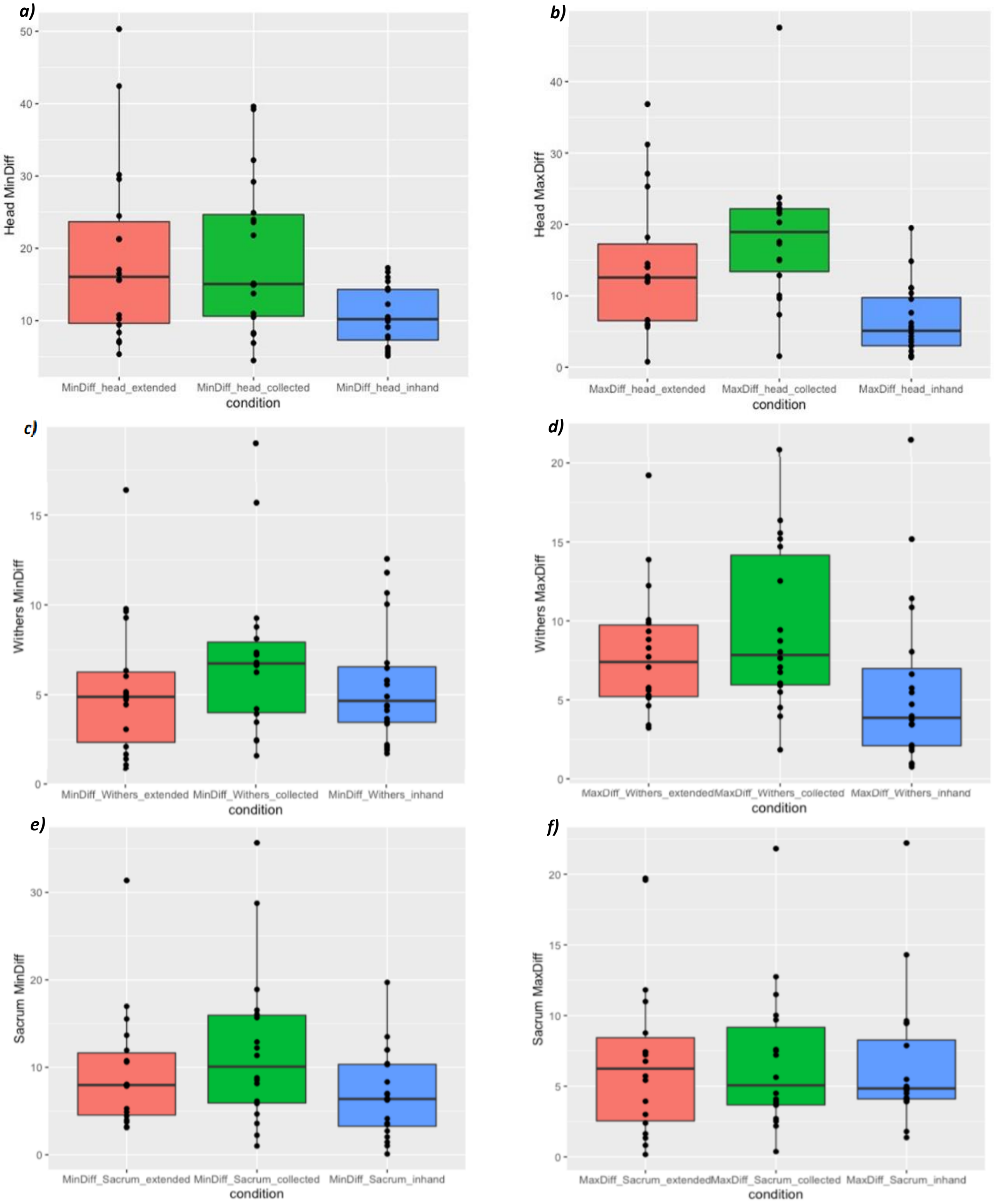
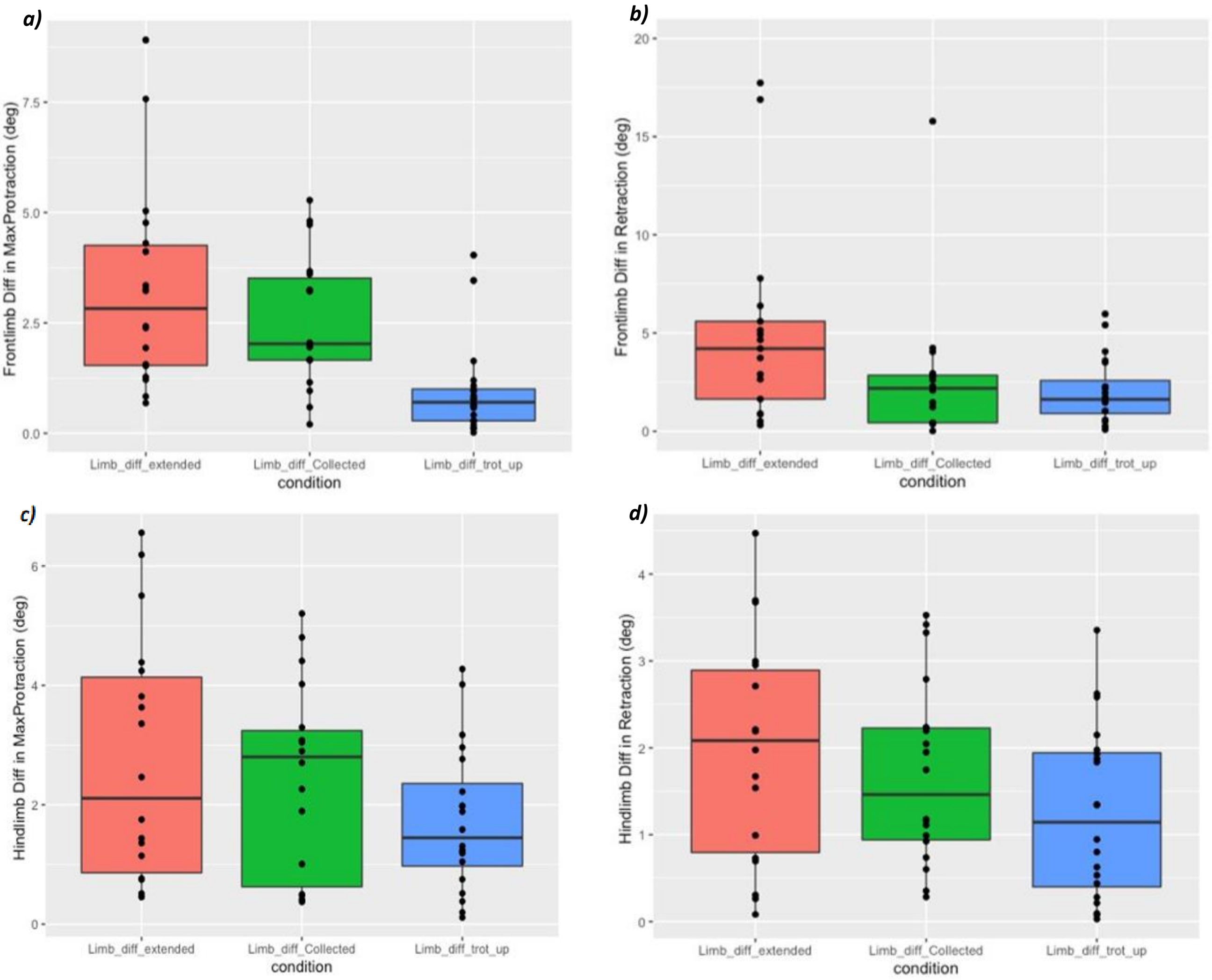


Figure 6a-f. *Boxplots for mean absolute values of HDmin (a), HDmax (b), WDmin (c), WDmax (d), PDmin (e) and PDmax (f) (mm) for extended trot (red), collected trot (green) and trot in hand (blue).*

		MinDiff				MaxDiff			
		LSmean	Lower C.I.	Upper C.I.	p-value	LSmean	Lower C.I.	Upper C.I.	p-value
Head	Trot in hand	10.3	6.7	14.6	-	5.8	3.2	9.1	-
	Extended trot	17.3	12.4	23.1	<0.01	12.8	8.2	17.9	<0.01
	Collected trot	17.5	12.6	23.3	<0.01	16.9	11.9	22.8	<0.01
	Extended trot – collected trot	-	-	-	0.92	-	-	-	0.11
Withers	Trot in hand	5.2	3.4	7.3	-	4.9	3.0	7.2	-
	Extended trot	4.7	2.7	6.8	0.58	7.5	5.0	10.4	0.04
	Collected trot	6.4	4.4	8.8	0.31	8.6	6.0	11.8	<0.01
	Extended trot – collected trot	-	-	-	0.23	-	-	-	0.38
Pelvis	Trot in hand	5.9	3.3	9.2	-	5.9	3.6	8.8	-
	Extended trot	8.5	5.2	12.7	0.18	5.7	3.3	8.6	0.96
	Collected trot	10.5	6.7	15.0	0.04	5.8	3.5	8.8	0.96
	Extended trot – collected trot	-	-	-	0.33	-	-	-	0.96

Table 4. *LSmean from mixed model analysis with 95% confidence intervals for mean absolute values of MinDiff and MaxDiff of the head, withers and pelvis (mm) and p-values of pairwise comparisons between trot conditions (trot in hand vs. extended trot, trot in hand vs. collected trot and extended trot vs. collected trot).*



Figures 7a-d. *Boxplots for DiffProtraction of the front limbs (a), DiffRetraction of the front limbs (b), DiffProtraction of the hind limbs (c) and DiffRetraction of the hind limbs (d) (°) for extended trot (red), collected trot (green) and trot in hand (blue).*

		DiffProtraction				DiffRetraction			
		LSmean	Lower C.I.	Upper C.I.	p-value	LSmean	Lower C.I.	Upper C.I.	p-value
Front	Trot in hand	0.7	0.3	1.3	-	1.7	0.6	3.4	-
	Extended trot	2.9	1.9	4.0	<0.01	5.0	2.8	7.9	0.02
	Collected trot	2.3	1.5	3.3	<0.01	1.9	0.7	3.9	0.81
	Extended trot – collected trot	-	-	-	0.28	-	-	-	0.02
Hind	Trot in hand	1.5	0.8	2.4	-	1.0	0.5	1.6	-
	Extended trot	2.3	1.4	3.4	0.36	1.7	1.0	2.5	0.19
	Collected trot	2.1	1.3	3.2	0.36	1.5	0.9	2.3	0.22
	Extended trot – collected trot	-	-	-	0.73	-	-	-	0.67

Table 5. *LSmean from mixed model analysis with 95% confidence intervals for DiffProtraction (°) and DiffRetraction (°) of the front limbs (Front) and hind limbs (Hind) with pairwise comparisons between trot conditions (trot in hand vs. extended trot, trot in hand vs. collected trot and extended trot vs. collected trot)*

WDmax. No significant difference was found for DiffRetraction of the front limbs for collected trot vs. trot in hand. In addition, no significant differences were seen in DiffProtraction and DiffRetraction of the hind limbs in any pairwise comparison between trot conditions.

Discussion

Upper-body asymmetry and vertical ROM

The aim of this study was to objectively detect vertical upper-body movement asymmetry of elite dressage horses in trot in hand on the straight and collected- and extended trot during a standardized dressage test. It was hypothesised that horses would be more asymmetrical in their upper-body movement collected- and extended trot under saddle, compared to trot in hand. The current study results confirm our hypothesis since horses became significantly more asymmetrical in their upper-body movement in collected- and extended trot under saddle, compared to trot in hand. This is supported by Byström et al. (2020), who measured upper-body movement of high-level dressage horses on a treadmill and concluded that horses were more asymmetrical when ridden in a dressage frame compared with unridden trot. An additional hypothesis was that that horses would be most asymmetrical in collected trot. Although there was a significant difference in stride duration between collected trot and extended trot, suggesting that horses indeed performed different trot types, the study results showed no significant difference for any upper-body parameter between extended- and collected trot. Still, there seems to be a trend of horses being most asymmetric in collected trot, which is supportive but unfortunately not affirmatively for our second hypothesis.

The main significant findings regarding under saddle measurements were the increased vertical ROM (head, withers and pelvis), HDmin, HDmax and WDmax in both trot conditions compared to trot in hand. Additionally, PDmin increased in collected trot but not in extended trot. Regarding vertical ROM, Martin et al. (2017) also showed greater ROM of the vertebral column during ridden trot compared to unridden trot. In contrast, Heim et al. (2016) reported significantly reduced dorsoventral ROM of the vertebral column in ridden trot but their study population, consisting of cold-blooded horses, is not comparable to our study population of highly trained dressage horses. It is likely that training adaptations and/or riding techniques related to create more cadence, which is an important factor for good trot quality in both collection and extension (FEI, 2020), also contribute to the increased vertical ROM under saddle of high-level dressage horses. One might say that the presence of the rider itself affects vertical ROM by adding weight to the horse's back. However, the vertical range of back motion remains the same with or without additional weight but there is a more extended cycle of movement (Clayton & Hobbs, 2017; de Cocq et al., 2004). Another point of discussion is that horses were trotted in hand on a hard surface whereas the under saddle measurements were taken on a soft surface arena which could have caused discrepancy between measurements. Trotting on a soft surface namely reduces impact peak loading and ground reaction forces (Chateau et al., 2010; Oosterlinck et al., 2014) which may result in a higher ROM because the horses possibly feel more comfortable to trot on a soft surface than on a hard surface. This is recently demonstrated by Hardeman et al. (2020), where horses trotting on a straight line had lower objectively measured spinal ROM on a hard surface compared to a soft surface. To exclude this surface effect, our horses should have been trotted in hand on the same soft surface arena where the under saddle measurements were performed.

Of course, the greater ROM of the head, withers and pelvis would logically have caused greater upper-body asymmetry values but we believe that this is not the only contributing factor. For instance, it is well known that a push-off/swinging lameness tends to increase on a soft surface (Baxter, 2020), which might contribute to the fact that greatest increases were seen for HDmax and WDmax. Besides, head asymmetry parameters have been reported to be more greatly affected than wither asymmetry parameters in cases of front limb lameness (Buchner et al., 1996) which could explain the similar but less pronounced pattern of WDmax compared to HDmax. The increased PDmin in collected trot is in accordance with the findings of Licka et al. (2014), where pelvic asymmetry significantly increased in horses ridden by an experienced dressage rider.

Influence of the rider

Other factors that could have affected upper-body movement asymmetry include the rider's aids, the rider's weight, the rider's static or dynamic postural asymmetry and the head-neck position of the horse. For example, unrhythmical tension on the reins or disturbances in connection with the bit may have caused greater head asymmetry values. Furthermore, the rider's additional weight causes increased limb loading of the front and hind limbs (Clayton et al., 1999; Clayton et al., 2017) and possibly reduces the ability of the horse to relocate the centre of mass away from a lame limb (Buchner et al., 2001) which could contribute to greater asymmetry values under saddle. Our riders performed a sitting trot during all trot measurements, shown to be a symmetrical riding style (Licka et al., 2014; Persson-Jodin et al., 2018), but there is some left-right asymmetry in posture of dressage riders (Alexander et al., 2015; Münz et al., 2014; Symes & Ellis, 2009; Walker et al., 2020) which might influence the loading pattern and movement symmetry of the horse. Besides, experienced dressage riders seem to increase pelvic asymmetrical motion (Licka et al., 2014) which is probably related to the rider's demands on the horse to shift more weight onto the hind limbs to obtain the desired collection. Finally, the desired head-neck position for the trot at dressage competitions, where the neck should be raised and arched with the poll as highest point and the bridge of the nose slightly in front of the vertical (FEI, 2020), causes increased peak forces in the front limbs, increased T6 vertical excursion, increased sacral flexion and decreased limb retraction compared to a free, unrestrained trot (Weishaupt et al., 2006; Rhodin et al., 2009).

Degree of upper-body asymmetry during trot in hand

A remarkable finding in this study that should be discussed is the existing degree of upper-body asymmetry during trot in hand. Previous studies on movement symmetry of horses during straight line trot used the reported symmetry thresholds by Keegan et al. (2011) and classified horses as symmetrical when not exceeding 6 mm for HDmin or HDmax and 3 mm for PDmin or PDmax (Rhodin et al., 2016; Rhodin et al., 2017). The currently recommended thresholds would result in a classification of all our horses as asymmetric or ''lame''. Besides, studies evaluating horses with significant lameness reported asymmetry values with equal magnitude to or even lower than our findings (Maliye & Marshall, 2016; Rhodin et al., 2013). In contrast, in the study of Pfau et al. (2018), 163 sound Thouroughbred racehorses also showed asymmetrical upper-body movement during straight line trot. In addition, out of 201 and 222 riding horses perceived as sound by their owner, 53% and 73% respectively, showed head and pelvic movement asymmetries exceeding symmetry thresholds (Rhodin et al., 2016; Rhodin et al., 2017).

The highly important question remains: should all of our dressage horses, based on their degree of upper-body asymmetry, be classified as lame? Or should the current symmetry thresholds be re-evaluated, at least for highly trained sports horses? These asymmetries namely might also be the result of laterality, defined as a side preference of the horse due to cerebral lateralisation (Byström et al., 2018; Hardeman et al., 2019; Weij & Weij, 1980; Williams, 2011), or other factors such as conformation, shoeing or training. For example, Vertz et al. (2018) and Pitts et al. (2020) investigated the effect of induced hindlimb length differences on pelvic movement asymmetry and measured increased push-off of the longer limb and increased weight-bearing of the shorter limb. In addition, Ringmark et al. (2016) revealed that the introduction of a new training program may alter locomotion asymmetry. Furthermore, it is likely that a primary asymmetry originating from any limb indirectly/directly affects symmetry parameters of the ipsilateral and/or contralateral limbs resulting in a more extensive range of asymmetries of individual horses (Pfau et al., 2018; Rhodin et al., 2018).

Persson-Sjodin et al. (2019) determined that anti-inflammatory treatment with meloxicam did not significantly affect movement asymmetry of 66 riding horses in training, suggesting that these asymmetries might not be the result of orthopaedic pain. However, these asymmetries could have been related to pain that was non-responsive to meloxicam and may still be alleviated by other nonsteroidal anti-inflammatory drugs or combination treatments. It should be investigated in future studies to what degree detectable movement asymmetries in dressage horses can be directly attributed to orthopaedic pain or natural asymmetry in the horse’s locomotor pattern. Possible study designs to analyse the presence of pain may include the use of alternative systemic analgesic (combination) treatments, diagnostic analgesia and/or advanced imaging modalities.

Protraction and retraction asymmetry between limb pairs

Measurements of protraction and retraction parameters were included in this study to identify any correlations with upper-body symmetry parameters. Front limb protraction asymmetry increased in collected- extended trot, whereas front limb retraction asymmetry was greater in extended trot compared to trot in hand and collected trot. For the hindlimbs, protraction and retraction seemed to be more asymmetrical in extended- and collected trot but no significant differences were found. These findings are largely in accordance with Byström et al. (2020), who reported increased front limb protraction-, front limb retraction- and hind limb retraction asymmetry in ridden trot compared to unridden trot. It has to be taken into account that ROM of protraction and retraction angles increase in ridden horses (Martin et al., 2017), which logically may cause relative alterations of protraction/retraction differences between limb pairs.

In the current study, there were no significant correlations between protraction/retraction differences and HDmax, WDmax or PDmin despite the comparable pattern of, for example, HDmax and DiffProtraction of the front limbs. Moreover, we were not able to determine whether a certain asymmetric limb indeed protracted/retracted more or less. It is clear that horses become more asymmetrical in their protraction/retraction patterns during trot under saddle, especially for the front limbs, but their correlation with the true asymmetric limb and the type of asymmetry has yet to be determined in further studies.

Long-term effect of asymmetrical motion

The highly repetitive nature of dressage training in combination with a horse moving asymmetrically may lead to repeated uneven loading between limb pairs, resulting in an increased risk of the development of orthopaedic injuries. It is already known that clinical lameness leads to compensatory load redistribution during trot (Maliye et al., 2015). For example, a left front limb lameness results in a slight but significant shift of the body centre of mass towards the side of the sound front limb and creating a higher magnitude of load on the sound limb (Buchner et al., 2001; Maliye et al., 2015). Additionally, studies have reported that subtle lameness may alter thoracolumbar kinematics, potentially contributing to secondary musculoskeletal pain and dysfunction of the back when chronically present (Alvarez et al., 2007; Alvarez et al., 2008). It would be of interest to investigate the long-term effect of asymmetrical motion on the development of musculoskeletal injuries as part of prevention and early recognition of orthopaedic disease in the dressage horse.

Limitations of the study

This study has several limitations that should be considered when evaluating the results. The study population included horses from different breeds, ages and levels. For example, there might be a difference in the locomotor pattern of PRE versus KWPN horses and 3rd level versus grand prix level horses. Furthermore, under saddle measurements of our horses were taken on a soft surface and trot in hand measurements on a hard surface, which could have caused discrepancy between these results. Besides, surfaces that were used for the measurements were not standardized since horses were measured at their currently based farm. In addition, horses were ridden by their usual rider, resulting in a population of different riders with different experience levels. Finally, not all horses were able to perform a clear collected- and/or extended trot according to the FEI, which may have caused fewer clear differences in symmetry parameters between collected- and extended trot.

Conclusion

The main conclusion of this study was that no elite dressage horse will trot perfectly symmetrical, neither in a natural moving trot in hand on the straight nor in collected- and extended trot under saddle. Our sound, elite dressage horses showed asymmetry values greater than the currently recommended symmetry thresholds in trot in hand and these were even greater in collected- and extended trot under saddle, although no significant difference was detected between collected trot and extended trot. Furthermore, total vertical displacement of the upper-body increased in ridden trot compared to trot in hand. Moreover, protraction and retraction patterns of the front limbs were more asymmetrical under saddle but any correlations with upper-body symmetry parameters has yet to be determined in further studies.

It should be investigated in future studies to what degree detectable movement asymmetries in dressage horses can be directly attributed to orthopaedic pain or natural asymmetry in the horse’s locomotor pattern. Finally, studies investigating the long-term effect of asymmetrical motion on the development of musculoskeletal injuries would be appropriate as part of prevention and early recognition of orthopaedic disease in the dressage horse.

References

Alexander, J., Hobbs, S. J., May, K., Northrop, A., Brigden, C., & Selfe, J. (2015). Postural characteristics of female dressage riders using 3D motion analysis and the effects of an athletic taping technique: a randomised control trial. Physical Therapy in Sport, 16(2), 154-161.

Alvarez, C. G., Bobbert, M. F., Lamers, L., Johnston, C., Back, W., & Van Weeren, P. R. (2008). The effect of induced hindlimb lameness on thoracolumbar kinematics during treadmill locomotion. Equine veterinary journal, 40(2), 147-152.

Álvarez, C. G., Wennerstrand, J., Bobbert, M. F., Lamers, L., Johnston, C., Back, W., & Weeren, P. V. (2007). The effect of induced forelimb lameness on thoracolumbar kinematics during treadmill locomotion. Equine veterinary journal, 39(3), 197-201.

Barrey, E. (2013). Biomechanics of locomotion in the athletic horse. Equine Sports Medicine and Surgery: Basic and Clinical Sciences of the Equine Athlete,, 189-211.

Baxter, G. M. (Ed.). (2020). Adams and Stashak's lameness in horses. John Wiley & Sons.

Bosch, S., Serra Bragança, F., Marin-Perianu, M., Marin-Perianu, R., van der Zwaag, B., Voskamp, J., ... & Havinga, P. (2018). EquiMoves: a wireless networked inertial measurement system for objective examination of horse gait. Sensors, 18(3), 850.

Bragança, F. M., Bosch, S., Voskamp, J. P., Marin-Perianu, M., Van der Zwaag, B. J., Vernooij, J. C. M., ... & Back, W. (2017). Validation of distal limb mounted inertial measurement unit sensors for stride detection in Warmblood horses at walk and trot. Equine veterinary journal, 49(4), 545-551.

Bragança, F. S., Rhodin, M., & van Weeren, P. R. (2018). On the brink of daily clinical application of objective gait analysis: What evidence do we have so far from studies using an induced lameness model?. The Veterinary Journal, 234, 11-23.

Buchner, H. H. F., Savelberg, H. H. C. M., Schamhardt, H. C., & Barneveld, A. (1996). Head and trunk movement adaptations in horses with experimentally induced fore-or hindlimb lameness. Equine veterinary journal, 28(1), 71-76.

Buchner, H. H. F., Savelberg, H. H. C. M., Schamhardt, H. C., & Barneveld, A. (1996). Limb movement adaptations in horses with experimentally induced fore-or hindlimb lameness. Equine veterinary journal, 28(1), 63-70.

Buchner, H. H. F., Obermüller, S., & Scheidl, M. (2001). Body centre of mass movement in the lame horse. Equine Veterinary Journal, 33(S33), 122-127.

Byström, A., Egenvall, A., Roepstorff, L., Rhodin, M., Bragança, F. S., Hernlund, E., ... & Clayton, H. M. (2018). Biomechanical findings in horses showing asymmetrical vertical excursions of the withers at walk. PloS one, 13(9), e0204548.

Byström, A., Clayton, H. M., Hernlund, E., Roepstorff, L., Rhodin, M., Bragança, F. S., ... & Egenvall, A. (2020). Asymmetries of horses walking and trotting on treadmill with and without rider. Equine Veterinary Journal.

Chateau, H., Holden, L., Robin, D., Falala, S., Pourcelot, P., Estoup, P., ... & Crevier-Denoix, N. (2010). Biomechanical analysis of hoof landing and stride parameters in harness trotter horses running on different tracks of a sand beach (from wet to dry) and on an asphalt road. Equine Veterinary Journal, 42, 488-495.

Clayton, H. M. (1994). Comparison of the stride kinematics of the collected, working, medium and extended trot in horses. Equine Veterinary Journal, 26(3), 230-234.

Clayton, H. M., Lanovaz, J. L., Schamhardt, H. C., & Van Wessum, R. (1999). The effects of a rider's mass on ground reaction forces and fetlock kinematics at the trot. Equine veterinary journal, 31(S30), 218-221.

Clayton, H. M., & Hobbs, S. J. (2017). The role of biomechanical analysis of horse and rider in equitation science. Applied Animal Behaviour Science, 190, 123-132.

Clayton, H. M., Schamhardt, H. C., & Hobbs, S. J. (2017). Ground reaction forces of elite dressage horses in collected trot and passage. The Veterinary Journal, 221, 30-33.

de Cocq, P., van Weeren, P.R. and Back, W. (2004) Effects of girth, saddle and weight on movements of the horse. Equine Vet. J. 36, 758-763.

Deuel, N. R., & Park, J. J. (1990). The gait patterns of Olympic dressage horses. Journal of Applied Biomechanics, 6(2), 198-226.

Dyson, S., & Greve, L. (2016). Subjective gait assessment of 57 sports horses in normal work: A comparison of the response to flexion tests, movement in hand, on the lunge, and ridden. Journal of Equine Veterinary Science, 38, 1-7.

Fédération Equestre Internationale. FEI Dressage Rules, 25th edition, Lausanne: Fédération Equestre Internationale; 2020.

Hammarberg, M., Egenvall, A., Pfau, T., & Rhodin, M. (2016). Rater agreement of visual lameness assessment in horses during lungeing. Equine veterinary journal, 48(1), 78-82.

Hardeman, A. M., Serra Bragança, F. M., Swagemakers, J. H., van Weeren, P. R., & Roepstorff, L. (2019). Variation in gait parameters used for objective lameness assessment in sound horses at the trot on the straight line and the lunge. Equine veterinary journal, 51(6), 831-839.

Hardeman, A. M., Byström, A., Roepstorff, L., Swagemakers, J. H., van Weeren, P. R., & Serra Bragança, F. M. (2020). Range of motion and between-measurement variation of spinal kinematics in sound horses at trot on the straight line and on the lunge. PloS one, 15(2), e0222822.

Heim, C., Pfau, T., Gerber, V., Schweizer, C., Doherr, M., Schüpbach-Regula, G., & Witte, S. (2016). Determination of vertebral range of motion using inertial measurement units in 27 Franches-Montagnes stallions and comparison between conditions and with a mixed population. Equine veterinary journal, 48(4), 509-516.

Holmström, M., Fredricson, I., & Drevemo, S. (1995). Biokinematic effects of collection on the trotting gaits in the elite dressage horse. Equine Veterinary Journal, 27(4), 281-287.

Keegan, K. G., Dent, E. V., Wilson, D. A., Janicek, J., Kramer, J., Lacarrubba, A., ... & Frees, K. E. (2010). Repeatability of subjective evaluation of lameness in horses. Equine veterinary journal, 42(2), 92-97.

Keegan, K. G., Kramer, J., Yonezawa, Y., Maki, H., Pai, P. F., Dent, E. V., ... & Reed, S. K. (2011). Assessment of repeatability of a wireless, inertial sensor–based lameness evaluation system for horses. American journal of veterinary research, 72(9), 1156-1163.

Kelmer, G., Keegan, K. G., Kramer, J., Wilson, D. A., Pai, F. P., & Singh, P. (2005). Computer-assisted kinematic evaluation of induced compensatory movements resembling lameness in horses trotting on a treadmill. American journal of veterinary research, 66(4), 646-655.

Kramer, J., Keegan, K. G., Kelmer, G., & Wilson, D. A. (2004). Objective determination of pelvic movement during hind limb lameness by use of a signal decomposition method and pelvic height differences. American journal of veterinary research, 65(6), 741-747.

Leach, D.H., Ormrod, K. and Clayton H.M. (1984), Standardised terminology for the description and analysis of equine locomotion. Equine Veterinary Journal, 16: 522-528. doi:10.1111/j.2042-3306.1984.tb02007.x

Licka, T., Kapaun, M., & Peham, C. (2004). Influence of rider on lameness in trotting horses. Equine veterinary journal, 36(8), 734-736.

Maliye, S., & Marshall, J. F. (2016). Objective assessment of the compensatory effect of clinical hind limb lameness in horses: 37 cases (2011–2014). Journal of the American Veterinary Medical Association, 249(8), 940-944.

Martin, P., Cheze, L., Pourcelot, P., Desquilbet, L., Duray, L., & Chateau, H. (2017). Effects of the rider on the kinematics of the equine spine under the saddle during the trot using inertial measurement units: Methodological study and preliminary results. The Veterinary Journal, 221, 6-10.

Meij, H. S., & Meij, J. C. P. (1980). Functional asymmetry in the motor system of the horse. South African Journal of Science, 76, 552-556.

Münz, A., Eckardt, F., & Witte, K. (2014). Horse–rider interaction in dressage riding. Human movement science, 33, 227-237.

Murray, R. C., Dyson, S. J., Tranquille, C., & Adams, V. (2006). Association of type of sport and performance level with anatomical site of orthopaedic injury diagnosis. Equine veterinary journal, 38(S36), 411-416.

Murray, R. C., Walters, J. M., Snart, H., Dyson, S. J., & Parkin, T. D. (2010). Identification of risk factors for lameness in dressage horses. The Veterinary Journal, 184(1), 27-36.

Oosterlinck, M., Royaux, E., Back, W., & Pille, F. (2014). A preliminary study on pressure‐plate evaluation of forelimb toe–heel and mediolateral hoof balance on a hard vs. a soft surface in sound ponies at the walk and trot. Equine veterinary journal, 46(6), 751-755.

Parkes, R.S.V., Weller, R., Groth, A.M., May, S.A. 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 Vet. J. 41, 112-117.

Pfau, T., Jennings, C., Mitchell, H., Olsen, E., Walker, A., Egenvall, A., ... & Rhodin, M. (2016). Lungeing on hard and soft surfaces: Movement symmetry of trotting horses considered sound by their owners. Equine veterinary journal, 48(1), 83-89.

Pfau, T., Noordwijk, K., Sepulveda Caviedes, M. F., Persson‐Sjodin, E., Barstow, A., Forbes, B., & Rhodin, M. (2018). Head, withers and pelvic movement asymmetry and their relative timing in trot in racing Thoroughbreds in training. Equine veterinary journal, 50(1), 117-124.

Persson-Sjodin, E., Hernlund, E., Pfau, T., Haubro Andersen, P., Holm Forsström, K., & Rhodin, M. (2019). Effect of meloxicam treatment on movement asymmetry in riding horses in training. PloS one, 14(8), e0221117.

Rhodin, M., Álvarez, C. G., Byström, A., Johnston, C., Van Weeren, P. R., Roepstorff, L., & Weishaupt, M. A. (2009). The effect of different head and neck positions on the caudal back and hindlimb kinematics in the elite dressage horse at trot. Equine Veterinary Journal, 41(3), 274-279.

Rhodin, M., Pfau, T., Roepstorff, L., & Egenvall, A. (2013). Effect of lungeing on head and pelvic movement asymmetry in horses with induced lameness. The Veterinary Journal, 198, e39-e45.

Rhodin, M., Roepstorff, L., French, A., Keegan, K. G., Pfau, T., & Egenvall, A. (2016). Head and pelvic movement asymmetry during lungeing in horses with symmetrical movement on the straight. Equine veterinary journal, 48(3), 315-320.

Rhodin, M., Egenvall, A., Andersen, P. H., & 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(4), e0176253.

Rhodin, M., Persson‐Sjodin, E., Egenvall, A., Serra Bragança, F. M., Pfau, T., Roepstorff, L., ... & Hernlund, E. (2018). Vertical movement symmetry of the withers in horses with induced forelimb and hindlimb lameness at trot. Equine veterinary journal, 50(6), 818-824.

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. The Veterinary Journal, 207, 99-104.

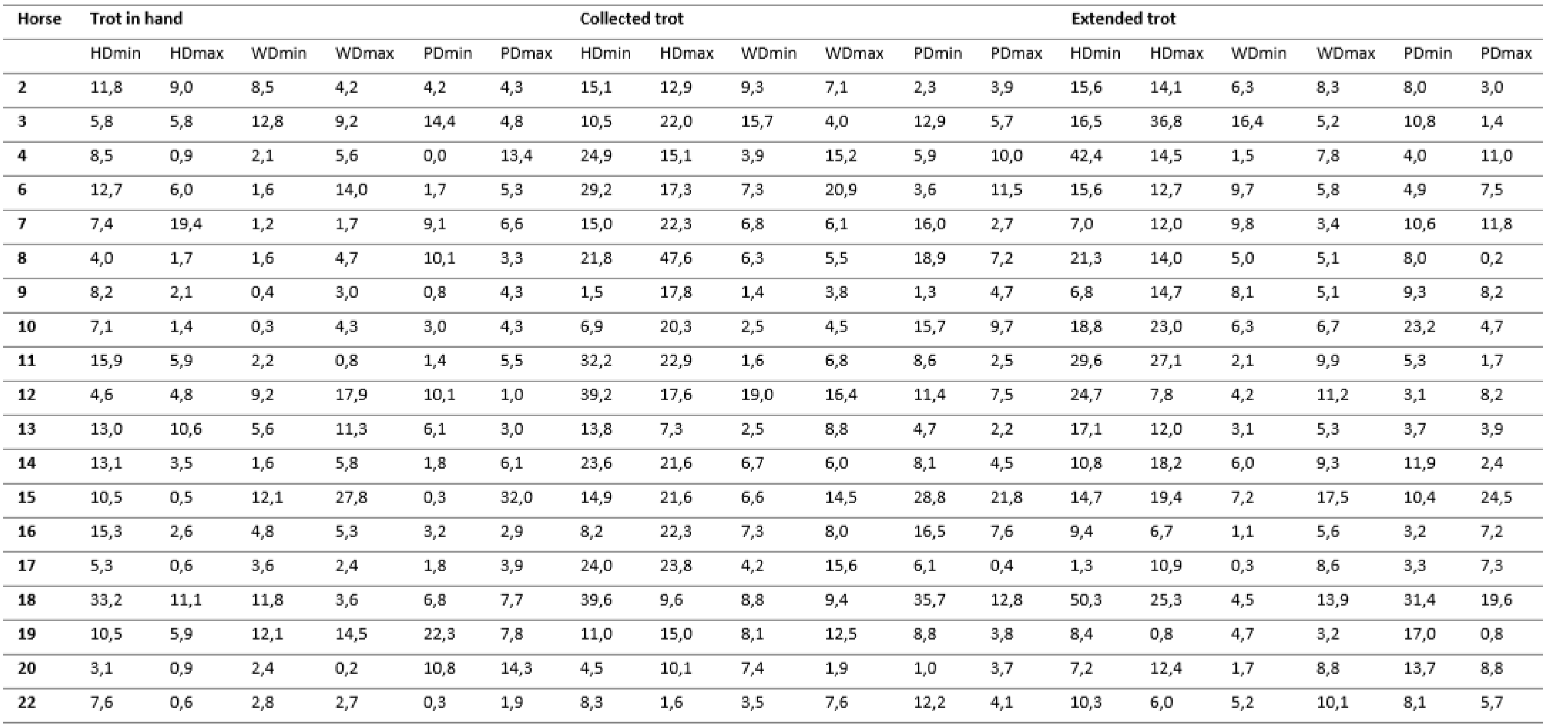
Rhodin, M., Persson‐Sjodin, E., Egenvall, A., Serra Bragança, F. M., Pfau, T., Roepstorff, L., ... & Hernlund, E. (2018). Vertical movement symmetry of the withers in horses with induced forelimb and hindlimb lameness at trot. Equine veterinary journal, 50(6), 818-824.

Starke, S. D., Raistrick, K. J., May, S. A., & Pfau, T. (2013). The effect of trotting speed on the evaluation of subtle lameness in horses. The Veterinary Journal, 197(2), 245-252.

Symes, D., & Ellis, R. (2009). A preliminary study into rider asymmetry within equitation. The Veterinary Journal, 181(1), 34-37.

Van Weeren, P. R., Pfau, T., Rhodin, M., Roepstorff, L., Serra Bragança, F., & Weishaupt, M. A. (2017). Do we have to redefine lameness in the era of quantitative gait analysis?. Equine veterinary journal, 49(5), 567-569.

Appendix



Horse	Trot in hand						Collected trot						Extended trot					
	HDmin	HDmax	WDmin	WDmax	PDmin	PDmax	HDmin	HDmax	WDmin	WDmax	PDmin	PDmax	HDmin	HDmax	WDmin	WDmax	PDmin	PDmax
2	11,8	9,0	8,5	4,2	4,2	4,3	15,1	12,9	9,3	7,1	2,3	3,9	15,6	14,1	6,3	8,3	8,0	3,0
3	5,8	5,8	12,8	9,2	14,4	4,8	10,5	22,0	15,7	4,0	12,9	5,7	16,5	36,8	16,4	5,2	10,8	1,4
4	8,5	0,9	2,1	5,6	0,0	13,4	24,9	15,1	3,9	15,2	5,9	10,0	42,4	14,5	1,5	7,8	4,0	11,0
6	12,7	6,0	1,6	14,0	1,7	5,3	29,2	17,3	7,3	20,9	3,6	11,5	15,6	12,7	9,7	5,8	4,9	7,5
7	7,4	19,4	1,2	1,7	9,1	6,6	15,0	22,3	6,8	6,1	16,0	2,7	7,0	12,0	9,8	3,4	10,6	11,8
8	4,0	1,7	1,6	4,7	10,1	3,3	21,8	47,6	6,3	5,5	18,9	7,2	21,3	14,0	5,0	5,1	8,0	0,2
9	8,2	2,1	0,4	3,0	0,8	4,3	1,5	17,8	1,4	3,8	1,3	4,7	6,8	14,7	8,1	5,1	9,3	8,2
10	7,1	1,4	0,3	4,3	3,0	4,3	6,9	20,3	2,5	4,5	15,7	9,7	18,8	23,0	6,3	6,7	23,2	4,7
11	15,9	5,9	2,2	0,8	1,4	5,5	32,2	22,9	1,6	6,8	8,6	2,5	29,6	27,1	2,1	9,9	5,3	1,7
12	4,6	4,8	9,2	17,9	10,1	1,0	39,2	17,6	19,0	16,4	11,4	7,5	24,7	7,8	4,2	11,2	3,1	8,2
13	13,0	10,6	5,6	11,3	6,1	3,0	13,8	7,3	2,5	8,8	4,7	2,2	17,1	12,0	3,1	5,3	3,7	3,9
14	13,1	3,5	1,6	5,8	1,8	6,1	23,6	21,6	6,7	6,0	8,1	4,5	10,8	18,2	6,0	9,3	11,9	2,4
15	10,5	0,5	12,1	27,8	0,3	32,0	14,9	21,6	6,6	14,5	28,8	21,8	14,7	19,4	7,2	17,5	10,4	24,5
16	15,3	2,6	4,8	5,3	3,2	2,9	8,2	22,3	7,3	8,0	16,5	7,6	9,4	6,7	1,1	5,6	3,2	7,2
17	5,3	0,6	3,6	2,4	1,8	3,9	24,0	23,8	4,2	15,6	6,1	0,4	1,3	10,9	0,3	8,6	3,3	7,3
18	33,2	11,1	11,8	3,6	6,8	7,7	39,6	9,6	8,8	9,4	35,7	12,8	50,3	25,3	4,5	13,9	31,4	19,6
19	10,5	5,9	12,1	14,5	22,3	7,8	11,0	15,0	8,1	12,5	8,8	3,8	8,4	0,8	4,7	3,2	17,0	0,8
20	3,1	0,9	2,4	0,2	10,8	14,3	4,5	10,1	7,4	1,9	1,0	3,7	7,2	12,4	1,7	8,8	13,7	8,8
22	7,6	0,6	2,8	2,7	0,3	1,9	8,3	1,6	3,5	7,6	12,2	4,1	10,3	6,0	5,2	10,1	8,1	5,7

Table 3. *Absolute values of variables HDmin, HDmax, WDmin, WDmax, PDmin, PDmax of all measured horses (n=19) for trot in hand, collected trot and extended trot.*