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GENERAL ARTICLE

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Objectively measured movement asymmetry in yearling Standardbred trotters

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Abstract

Background: Lameness evaluation of Standardbred trotters can be challenging due to discrepancies in observed movement asymmetry between in-hand and track exercise, and between different trotting speeds. There are few studies on objective measurement of movement in Standardbreds, and little knowledge regarding biological variation and clinical significance of measured movement asymmetry in this breed.

Objectives: To quantify the prevalence and magnitude of objectively measured movement asymmetry in young Standardbred trotters, and identify associations with trainer, sex, height, track type and in-hand measurement prior to or after track trials.

Study design: Cross-sectional, observational study.

Methods: A total of 114 Standardbred yearlings were evaluated with a wireless inertial sensor system during trot in-hand and when driven on a track. After exclusions relating to lameness or technical difficulties, 103 horses were included in the study; 77 were evaluated in-hand and on the track, 24 only in-hand and 2 only on the track.

Results: Front and/or hindlimb parameters were above asymmetry thresholds previously established for other breeds during in-hand trials for 94 (93%) horses and during track trials for 74 (94%) horses. Most horses showed mild asymmetry. A minority of horses (20%) switched side of the asymmetry for one or more parameters between in-hand and track trials. Mixed model analyses revealed no significant effects of trial mode (in-hand or track trial, in-hand trial pre- or post-track trial, straight or oval track), trainer or horse height. Females had a significant but small reduction in asymmetry in one front limb parameter (HD_{max}) compared with males (1.7 mm, 95% CI 0.18-3.28, $P = .03$).

Main limitations: High data variability, reflected in large trial standard deviations, relating mainly to a lack of horse compliance.

Conclusions: A high proportion of Standardbred yearlings showed movement asymmetries. There was no group-level effect between in-hand and track trials, however, considerable individual variation was observed.

KEYWORDS
horse, lameness, harness racing, IMU, locomotion

1 | INTRODUCTION

Traditionally, lameness evaluation relies on visually recognising movement asymmetry during walking and trotting in-hand. However, subjective lameness evaluation may be unreliable[1,2] and veterinarians may also show bias when evaluating response to diagnostic analgesia.[3] Subjective assessment of movement irregularities can be particularly challenging in the Standardbred trotter. Reasons for this, as suggested by veterinarians experienced in working with Standardbreds,[4] include that lameness seen at trot in-hand may not correlate with lameness during training, and that the observed degree of lameness may vary with trotting speed. With these challenges of subjective lameness evaluation in mind, developing and refining more reliable, objective methods for equine lameness evaluation continues.

Objective measurement of movement asymmetry is possible with wireless technology using inertial measurement unit (IMU) sensors. Threshold criteria for movement asymmetry exist for a commercially available IMU system, and relate closely to between-trial repeatability.[5] However, difficulties remain regarding interpretation of the clinical relevance of IMU measurements in sports horses[6] and knowledge is lacking for the Standardbred trotter.

The aim of the current study was to describe the prevalence and magnitude of motion asymmetry in young Standardbred trotters beginning their training, evaluated both in-hand and during driven exercise. Our hypothesis was that asymmetry scores would be higher when evaluating horses in-hand vs driven, as trotting-up in-hand would allow the animals to move more freely vs when exercised within the constraints of a harness and sulky. Additionally, we aimed to investigate potential associations between movement asymmetry and trainer, sex, height, track type and measuring in-hand asymmetry prior to or after track trials.

2 | MATERIALS AND METHODS

2.1 | Study design and cohort description

Fifteen trainers were contacted regarding study participation. Twelve agreed to participate. One additional trainer was recruited based on advertisement of the study. Training yard-level inclusion criteria were location (proximity to Oslo, Norway or Stockholm, Sweden), a licensed professional trainer in charge and willingness to participate in the study over time. One additional trainer in southern Sweden was included despite not fulfilling the proximity criteria due to the large number of horses available at the yard.

Horse-level recruitment criteria were breed, age and training level; only Standardbred trotter yearlings that were broken to harness and within the first 6 months of driven exercise were recruited. At each yard, all horses available that fitted the recruitment criteria and were currently in regular training were evaluated. The horses were assessed by their trainer as fit to train, meaning that the trainer had not observed any lameness, or other issues likely to reduce or interrupt training. Horses were excluded if they paced instead of trotted during trials, or there was veterinarian-observed subjective lameness of >2/5 degrees according to the American Association of Equine Practitioners (AAEP) scale (0-5) during the in-hand trial.

2.2 | Clinical examination and measurements of movement asymmetry

All horses underwent a general physical examination and measurement of height at the withers and pelvis at their training yards or local racetrack, performed by one of the authors (A.S.K., E.H.S.H. or M.H.). The horses were evaluated at the trot driven on a track and in-hand (either before or after driven exercise) with a sensor-based objective movement analysis system (Lameness Locator® by Equinosis® LLC). The horses were trotted in-hand in a straight line by their regular handler or one of the investigators (A.S.K., E.H.S.H., M.R. or E.H.) on a firm ground surface, consisting of either gravel, asphalt, packed dirt or hard packed snow/ice, and as even and level as circumstances allowed. The handler was positioned on the left-hand side of the horse and instructed to trot the horse as straight as possible and without interfering with its head carriage. During in-hand trials, the horse was subjectively assessed for lameness by one veterinarian (A.S.K. or E.H.S.H.). For track trials, the horses were exercised by their usual driver, with their regular tack and according to their planned schedule. All tracks were dirt tracks with a surface of packed dirt/sand, mixed with snow during the winter months. A GPS device (Polar M450, Polar Electro) worn by the driver registered speed, distance and route of the trial. Data from both in-hand and track trials were subjectively deemed valid when the horse completed a trial with acceptable straightness and regularity. One in-hand trial and one track trial per horse were used for analysis. As the horses followed their individual scheduled training, the distance trotted per training session varied. For horses exercised over longer distances (>2 km), more than one track trial was collected. If a horse had more than one valid trial, the first trial was used. Default settings (2017 software v1.2r) were used for trial stride selection; preferred stride selection was ≥25 steps.

The movement analysis system sensors were mounted on the poll, pelvis and right front pastern of the horse according to the manufacturers' directions.[7] The pelvis sensor was fastened with extra strong double-sided adhesive tape (Teppeteip, Clas Ohlson) and standard-issue duct tape and covered with additional adhesive tape (Snøgg Animal Polster, Norgesplaster AS) for track trials to prevent loosening. The pastern wrap was secured with elastic tape (Norbind, Norgesplaster AS) to prevent rotation during exercise. The IMU sensors consisted of a tri-axial accelerometer, gyroscope and magnetometer that recorded the vertical acceleration of the head and torso and the angular velocity of the right front limb at 200 Hz with 8-bit digital resolution. A computer tablet with appropriate software received wireless data transmission from the sensors via Bluetooth technology. For trials on oval tracks, the IMU system tablet was placed in a small backpack worn by the driver to ensure continuous connection between the horse-mounted sensors and the receiving computer tablet.

2.3 | Data processing

Software data output consisted of four parameter values for each trial calculated from the mean difference in head minimum (HD_{min}) and head maximum (HD_{max}) positions between the right and left diagonal of each trotting stride, and the mean difference in pelvis minimum (PD_{min}) and pelvis maximum (PD_{max}) positions between the right and left diagonal of each trotting stride.[5] A vector sum ($\sqrt{(HD_{max}^2 + HD_{min}^2)}$) of the mean HD_{max} and HD_{min} values was calculated. Detailed descriptions of the data processing can be found elsewhere.[5,6]

2.4 | Data analysis

2.4.1 | Descriptive data calculations

Criteria for movement asymmetry were based on recommendations for clinical use by the IMU system provider[7] and correspond to published confidence intervals for repeatability of measurements with the system in a variety of non-Standardbred breeds.[5] The asymmetry threshold for the front limb vector sum was 8.5 mm, for front limb HD_{min} and HD_{max} was ±6 mm and for hindlimb PD_{min} and PD_{max} was ±3 mm; values below these thresholds were defined as symmetric. Furthermore, asymmetry was divided into severity categories based on the amplitude of asymmetry in millimetres. Category intervals were based on an increase in millimetre asymmetry by adding the threshold value (8.5, 6 or 3 mm) to each progressing category. The resulting categories were "mild" (vector sum asymmetry 8.5-17 mm/front limb asymmetry 6-12 mm/hind limb asymmetry 3-6 mm), "mild-moderate" (17-25.5 mm/12-18 cm/6-9 mm), "moderate" (25.5-34 mm/18-24 mm/9-12 mm), "moderate-severe" (34-42.5 mm/24-30 mm/12-15 mm) and "severe" (>42.5 mm/>30 mm/>15 mm). Combined scores were created where the horse was classified as either front or hindlimb asymmetric if one front or hindlimb parameter (HD_{min} or HD_{max}, PD_{min} or PD_{max}) was above its respective threshold. Where relevant, horses were included in both front and hind asymmetry categories. For horses with bilateral asymmetry in either the front or the hindlimbs, each horse's combined severity score within the front or hindlimb category was based on the limb with the highest asymmetry score.

Horses which had been successfully measured both in-hand and driven and which had asymmetry identified in the in-hand trial were assigned to one of three categories: Same limb asymmetry present during both in-hand and track trials; limb asymmetry absent in the track trial or limb asymmetry changed during the track trial (left to right or vice versa).

For each limb parameter (HD_{min}, HD_{max}, PD_{min} and PD_{max}), a standard deviation (SD) was reported in the software data output, giving a measure of variability of the strides collected in the trial. Trial SD magnitude is categorised based on distance from the trial mean, where a SD value less than or close to the parameter mean indicates a fairly consistent trial.[7] In our study, SD categories were made based on the distance of the SD value from the respective asymmetry parameter mean. The three SD magnitude categories were (a) trials with an SD of more than 120% of its respective mean (high variability); (b) trials with SD between 50% and 120% of mean (moderate variability) and (c) trials with SD below 50% of mean (low variability). These categories correspond to the levels of evidence (weak, moderate and strong) presented in the IMU system output data (AIDE statement).

2.4.2 | Model building

Movement asymmetry data were analysed using open software (R, version 3.6.1, The R Foundation for Statistical Computing). Mixed models were created using the two-sided lmer function in the lme4 package. Four models were created, where each outcome variable was the absolute values of one of the four asymmetry parameters HD_{min}, HD_{max}, PD_{min} and PD_{max}. In all models, fixed effects were trial mode (with the levels: in-hand or track trial, in-hand trial pre- or post-track trial, straight or oval track), sex (male or female), height at the withers and height difference between the withers and pelvis. Trial speed and surface were not included in the model as these were considered similar for all horses. Horse nested within trainer was entered as a random effect (random intercept) in all models. Normality of residuals was checked using q-q plots and homoscedasticity by plotting the residuals against the fitted values. Evaluation of statistical significance was made using type II *P*-values generated by a Wald *F* test with Kenward-Roger approximated *df* using the ANOVA function in the car package. Post-hoc pairwise comparisons were performed using the lsmeans function with Satterthwaite approximated *df* in the lsmeans package. The level of significance was defined as $P \leq .05$.

3 | RESULTS

3.1 | Study population and measurements

A total of 114 horses were recruited to the study, with a median of 5 horses per trainer (range 1-29 horses). Age in months at the time of measurement was 17.8 ± 1.5, 17.5 (mean ± SD, median). Four horses had been broken for harness within the past 3-6 months, all other horses within 3 months of measurement. A flowchart illustrating the distribution of horses and trials, reasons for exclusion and the number of successful in-hand and track trials is presented in Figure 1. Incomplete data were due to technical issues where the trial for unknown reasons could not be analysed by the system software.

A total of 180 trials from 103 horses were included; 56 males (55 stallions, 1 gelding) and 47 females. Median height at the withers was

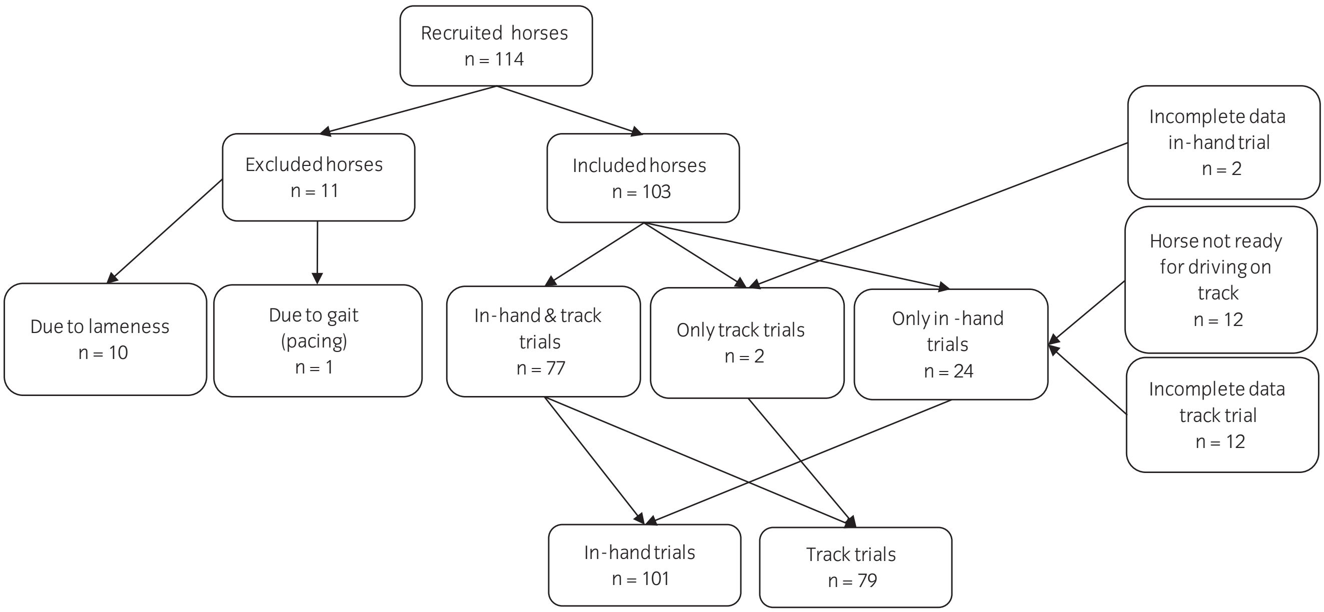

FIGURE 1 Flowchart of number of horses and trials in the study

153 cm (range 139-165 cm), median height at the pelvis was 157 cm (range 145-166 cm) and the median height difference between the withers and pelvis was 4 cm (range 1-9 cm). Data on height were missing for one horse.

Gait was evaluated in-hand before (n = 44) or after (n = 45) driven exercise. For in-hand trials, 37 ± 13.9 strides (mean ± SD) were evaluated, whereas 302 ± 276.2 strides were evaluated for driven trials. In-hand, 20 horses had trials where stride selection was below 25 strides per trial for front and/or hindlimbs. For these horses a minimum of 18 strides were evaluated. Speed in track trials was 5.0 ± 0.6 m/s (18.1 ± 2.3 km/h); speed data were missing for five horses. Horses were driven either on straight (n = 30) or oval (n = 49) tracks. On oval tracks, 30 horses were driven clockwise and 19 anticlockwise. Tracks were either not banked or the horses were driven on a nonbanked part of the track.

3.2 | Descriptive statistics

Of the 103 horses included for analysis, 91 (88%) horses were defined as having asymmetry using the manufacturer-recommended thresholds. None of the 77 horses with both in-hand and track trials were found to be below recommended thresholds for all parameters in both trials. Values for one or more front or hindlimb parameters were above thresholds for 94 of 101 horses (93%) evaluated in-hand. In 79 horses that had data collected during track exercise, 74 horses (94%) had one or more front or hindlimb parameter values defined as above the recommended thresholds. In total, during 180 in-hand and track trials, one or more parameters were above thresholds in 166 trials (92%). For one trial, all standard deviations were lower than their respective parameter mean values (HD_{min}, HD_{max}, PD_{min} and PD_{max}). For all other symmetric and asymmetric trials, at least one asymmetry parameter had a SD greater than its respective mean. An overview of the horses exceeding the recommended thresholds for front and/or hindlimb parameters and in-hand and on the track is detailed in Table 1.

During in-hand trials, contralateral forelimb and hindlimb asymmetry was recorded in 22 horses, and ipsilateral asymmetry in 18 horses. For track trials, 12 horses had contralateral fore and hindlimb asymmetry and 14 horses had ipsilateral asymmetry. An overview of the distribution of asymmetry severity is presented in Figure 2 and distribution of asymmetry categories for individual limbs is presented in Figure S1. In the 71 horses measured both in-hand and driven which had asymmetry in-hand, 14 (20%) horses switched the side of the asymmetry in at least one front or hindlimb parameter between the trials (Figure 3). The remaining 57 horses had asymmetry of the same limb(s) during both trials. Table 2 shows the increase or decrease in asymmetry of horses with same limb asymmetry between in-hand and track trials.

3.3 | Effects of trainer, sex, height and trial mode

For the HD_{min} and PD_{min} models, the residuals deviated from normality and a square root transformation rendered reasonably normally distributed residuals. Females had significantly lower HD_{max} than males (mean difference 1.7 mm, 95% CI 0.18-3.28, $P = .03$) but other asymmetry parameters were not associated significantly with sex. There were no significant associations between trainer, trial mode (in-hand or track trial, in-hand trial pre- or post-track trial, straight or oval track), height at the withers and height difference between withers and pelvis and asymmetry parameters HD_{min}, HD_{max}, PD_{min} and PD_{max}.

4 | DISCUSSION

Our data demonstrate that a large proportion of Standardbred yearlings in regular training display asymmetry at the trot both when

TABLE 1 Trials with one or more parameters exceeding the asymmetry threshold

Parameter, side of asymmetry	Number of trials with asymmetric parameter	Asymmetry mean (mm)	Range of asymmetry mean (mm)	SD mean (mm)	Number of trials with high variability	Number of trials with moderate variability	Number of trials with low variability
In-hand							
HD_{min}, right	25, 27%	14.2	6.3 to 30.0	22.5	19	6	0
HD_{min}, left	23, 24%	−13.6	−6.1 to −27.9	20.6	11	11	1
HD_{max}, right	21, 22%	11.6	6.1 to 21.8	14.4	10	11	0
HD_{max}, left	17, 18%	−11.6	−6.9 to −16.3	18.1	11	6	0
VS, right	24, 26%	18.1	9.6 to 34.8	N/A	N/A	N/A	N/A
VS, left	26, 28%	−16.2	−9.6 to −28.8	N/A	N/A	N/A	N/A
PD_{min}, right	23, 24%	5.9	3.2 to 11.9	7.3	13	10	0
PD_{min}, left	25, 27%	−6.0	−3.3 to −10.4	9.0	14	11	0
PD_{max}, right	30, 32%	5.2	3.0 to 10.4	6.8	14	14	2
PD_{max}, left	27, 29%	−4.9	−3.1 to −11.4	6.6	12	15	0
Track							
HD_{min}, right	22, 30%	10.2	6.0 to 19.8	13.4	10	12	0
HD_{min}, left	12, 16%	−10.0	−6.2 to −17.9	14.6	7	5	0
HD_{max}, right	24, 32%	11.7	6.4 to 20.2	12.6	10	12	2
HD_{max}, left	17, 23%	−10.4	−6.1 to −15.6	15.7	12	5	0
VS, right	31, 42%	13.4	8.5 to 20.5	N/A	N/A	N/A	N/A
VS, left	18, 24%	−13.8	−9.1 to −21.8	N/A	N/A	N/A	N/A
PD_{min}, right	23, 31%	7.4	3.1 to 27.5	7.8	10	11	2
PD_{min}, left	18, 24%	−7.1	−3.1 to −11.2	6.4	5	11	2
PD_{max}, right	18, 24%	5.1	3.2 to 13.0	4.8	6	11	1
PD_{max}, left	23, 31%	−5.9	−3.1 to −11.2	6.3	9	14	0

Note: Data from asymmetric in-hand trials (n = 94) and asymmetric track trials (n = 74) from 103 horses. Left limb side asymmetry = negative values and right limb side asymmetry = positive values.

Abbreviations: HD_{min}/HD_{max}, difference in head minimum/maximum positions between right and left portions of the stride; VS, Vector sum of mean values of HDmin and HDmax; PD_{min}/PD_{max}, difference in pelvis minimum/maximum positions between right and left portions of the stride; SD, standard deviation; NA, not applicable; Trials with high variability, SD > 120% of parameter mean; Trials with moderate variability, SD > 50% and <120% of parameter mean; Trials with low variability, SD < 50% of parameter mean.

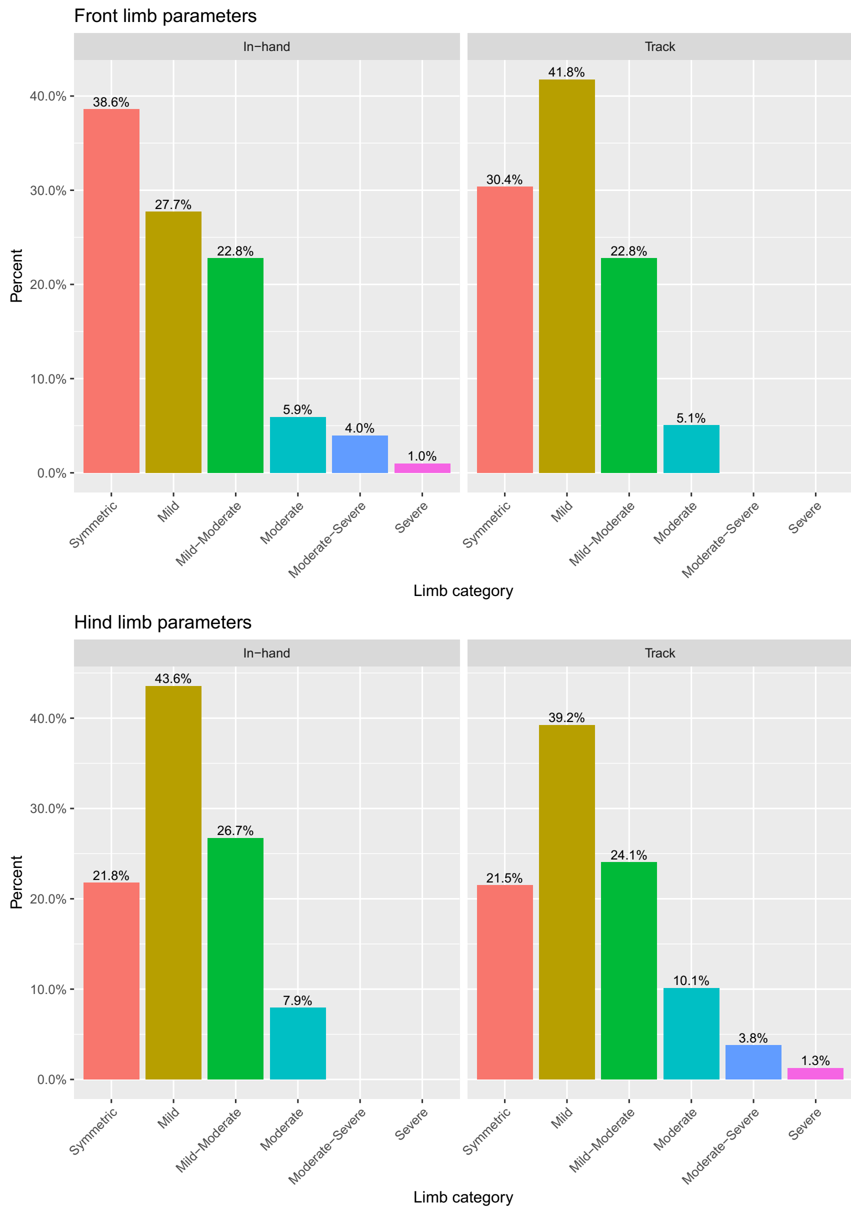

FIGURE 2 Distribution of limb asymmetry categories for combined front or hindlimb parameters. Horses; n = 103, in-hand trials; n = 101, track trials; n = 79. Asymmetry in mm per category for front limb/hindlimb: Symmetric: 0-6/0-3/, mild: 6-12/3-6, mild-moderate: 12-18/6-9, moderate: 18-24/9-12, moderate-severe: 24-30/12-15, and severe: >30/>15

evaluated in-hand and when driven on the track. Our hypothesis that horses would trot more symmetrically when exercised within the constraints of a harness and sulky was not supported by the data we collected. Although no associations between exercise mode and asymmetry parameters were found at the group level, our descriptive data show that evaluating young Standardbreds both in-hand and on the track reveals individual differences in the magnitude of asymmetry and sometimes the side of the asymmetry between the in-hand and track trials.

The large SDs demonstrate substantial within-trial variability, representing a potential source of uncertainty for both visual and objective assessment of movement asymmetry in this population of young horses, also accounting for the main limitation of our study. One of the biggest challenges we encountered in data collection was acquiring acceptable trot-ups in-hand from excitable yearlings. Although this affects our data, it also reflects the clinical reality faced by equine practitioners. We specifically chose to investigate this age group as the results from this study may serve as reference values for expected movement asymmetry in yearling Standardbred trotters. The yearlings were evaluated at the initiation of training to minimise the likelihood that they had accrued training-related injuries. It is not clear whether we are measuring widespread hitherto undetected subclinical, pain-mediated disease or whether the asymmetry documented in this group of young horses represents biological variation which might be different across breeds and disciplines.

In general, horses experiencing unvarying orthopaedic pain show consistent movement asymmetry of the same limb(s) due to offloading of the affected structures through changes in loading and force production.[8] Horses which were subjectively lame at recruitment were excluded. The yearlings found to be asymmetrical in the current study did not undergo further orthopaedic or neurological examination; therefore, we cannot draw any conclusions as to if or to what extent musculoskeletal or neurological disease and/or pain caused

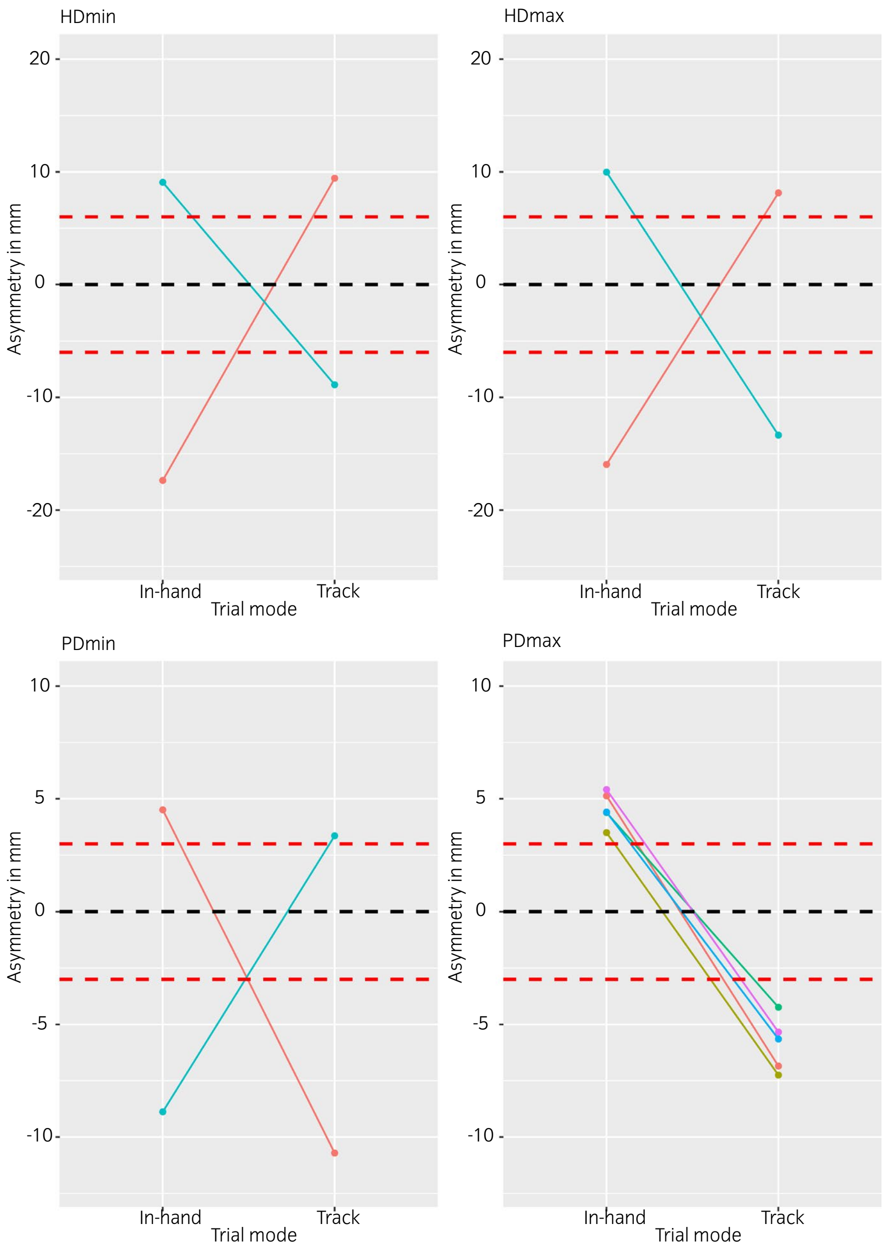

FIGURE 3 Horses (n = 14) that switched sides of limb asymmetry between in-hand and track trials. Each colour in the line plot represents an individual horse. Left limb side asymmetry = negative values and right limb side asymmetry = positive values. Red stippled line denotes the asymmetry threshold for the parameter (HD_{min}/HD_{max} 6 mm, PD_{min}/PD_{max} 3 mm). VS, vector sum of mean values of HD_{min} and HD_{max}; HD_{min}/HD_{max}, difference in head minimum/maximum positions between right and left portions of the stride; PD_{min}/PD_{max}, difference in pelvis minimum/maximum positions between right and left portions of the stride. Data for VS not shown (n = 3)

the measured asymmetry. The data collected and presented here are aimed at describing the prevalence and magnitude of movement asymmetry in young Standardbreds in training, and not its underlying causes. One might argue that it is improbable that almost all yearlings in a cohort could be affected by orthopaedic pain, especially at such an early age and prior to any substantial training. The young age of the horses in this study may influence the measurements. Varying degrees of locomotor incoordination and inconsistent asymmetric movement were observed during subjective assessment of the horses. As in young children,[9] stabilisation of movement frequency and pattern might increase with maturation and increased neuromuscular control in young horses. The horses in this study were not specifically assessed regarding potential ataxia relating to neurological disease. Although the incidence of clinical signs related to cervical vertebral disease is higher in young horses,[10] Standardbreds are less likely to be affected than other breeds such as Thoroughbreds.[10,11]

Horses were included in this study on a presumption of being 'fit to train', implying 'soundness'. It is debatable whether 'soundness' as assessed by non-veterinary professionals is an appropriate criterion for selecting nonlame horses.[12] Keeping in mind that 'sound' horses are not necessarily expected to be perfectly symmetrical, our cohort nevertheless show mean asymmetries close to those from horses with induced lameness[13] and horses with clinical lameness that responded to diagnostic analgesia.[14,15] In our study, objective asymmetry data were collected from all yearlings that fulfilled the recruitment criteria at the respective training yards, avoiding any intentional selection bias, for example, by the trainer selecting horses that were suspected to have a locomotor issue. The yearlings had recently been introduced to harness and light training pulling a driver and sulky. This adjustment may influence the locomotion pattern, however, it does not seem to represent a systematic effect, as horse asymmetry either

TABLE 2 Increase or decrease in limb asymmetry from in-hand to track trials

Parameter, side of asymmetry	In hand trial	Track trial		
	No. of horses with values above recommended thresholds in-hand	No. of horses with values above recommended thresholds in hand and during track exercise with an increase in asymmetry from in-hand to track trial	No. of horses with values above recommended thresholds in hand and during track exercise with a decrease in asymmetry from in-hand to track trial	No. of horses with increased values in hand which decreased to below recommended thresholds during track trial
HD_{min}, right	19	3	4	12
HD_{min}, left	15	3	4	8
HD_{max}, right	17	8	3	6
HD_{max}, left	11	1	2	8
VS, right	16	5	6	5
VS, left	16	5	5	6
PD_{min}, right	19	7	4	8
PD_{min}, left	18	6	4	8
PD_{max}, right	19	7	3	9
PD_{max}, left	18	7	2	9

Note: Change in asymmetry of horses (n = 57) that were classified as asymmetrical based on recommended thresholds for each parameter during in-hand trials and did not switch the side of asymmetry between in-hand and track trial.

Abbreviations: HD_{min}/HD_{max}, difference in head minimum/maximum positions between right and left portions of the stride; PD_{min}/PD_{max}, difference in pelvis minimum/maximum positions between right and left portions of the stride; VS, vector sum of mean values of HD_{min} and HD_{max}.

increased or decreased when driving on the track. Consideration should also be given to the effect of the handler of the horse during in-hand trials. Handlers as well as drivers of the horses differed between the yards, and this could potentially influence the measurements. Although a firm surface footing was available for in-hand trials at all yards, material composition was not identical, and weather conditions influenced the firmness of both in-hand and track surfaces. This may have influenced the collected gait data. The material composition and maintenance routines of the trotting tracks in this study were in all cases similar. The focus on compacting the material to create a solid substrate that will allow both horse and sulky to move easily over the surface make these types of tracks less variable between each other than many other horse sport surfaces.[16]

Movement asymmetries in Standardbreds were studied in the early 1980s by use of a novel high-speed cinematographic technique.[17–21] In one study[21] asymmetries in the locomotion patterns of younger Standardbreds were proposed to be a further manifestation of congenital laterality or sidedness. It is not currently known whether movement asymmetry increases, decreases or stabilises with age and training. In 16 Swedish Standardbred trotter yearlings followed over 2.5 years, vertical displacement asymmetry increased during intensified training periods.[22] Alternatively, in a group of French Standardbred horses, younger horses were more asymmetrical across various parameters than older horses.[23] However, without unexercised control groups, it is not possible to differentiate an effect of age from the effect of training in horses. In young horses, the effect of growth on locomotion patterns must also be considered. In our study, neither height at the withers nor the individual height difference between withers and pelvis, calculated as a potential proxy measure of intensity of growth or growth spurts, were significantly associated with asymmetry variables.

Our data are similar to those of Rhodin et al,[6] where 72.5% of 222 'owner-sound' Warmblood riding horses of different ages had at least one asymmetry parameter above the same asymmetry thresholds applied in our study. Although the magnitude of mean asymmetries of the riding horses matched well with the Standardbreds in our study, the trials in the cited study were included for analysis only if the standard deviation value was below that of its respective trial mean. Objective studies of movement asymmetry have included 'owner-sound' Warmblood riding horses,[6,24,25] polo ponies in training[26] and Thoroughbreds.[27] A shared finding in these studies is that most horses in regular exercise perceived by their owners/riders/trainers as sound show substantial asymmetries during in-hand straight line trot.

We found no associations between asymmetry variables and in-hand vs track trials or straight vs oval tracks. However, as there was large individual variation between in-hand and track trials and the possible influence of young age on the results, future studies looking at associations between track design and gait in an older cohort of horses would be interesting. The significant effect of sex on the HD_{max} parameter was small and with relatively wide confidence intervals and it is of questionable biological significance. Further studies are needed to replicate this finding, and if so, determine what clinical importance it may have.

In the current study, we used the predetermined, manufacturer-recommended thresholds to define and describe the distribution and magnitude of asymmetry. As has been pointed out by others,[27] the value in applying thresholds may not lie in making a dichotomous assessment of whether a horse is 'diseased' or not, as this can only be decided by a complete clinical evaluation; rather, thresholds might aid in removing clinical bias. It could be argued that it would be better not to apply thresholds to describe the findings in our study to avoid 'mislabelling' or misinterpreting the health status of these horses. However, thresholds allow for easier comparison of the changes in asymmetry between in-hand and track measurements and are also in common use with the measurement system applied in this study for both clinical and research purposes.

Our study adds to the scientific knowledge base on movement asymmetries in horses, and specifically young Standardbred trotters. Movement asymmetry was prevalent in our cohort of Standardbred trotter yearlings, with considerable individual variation between trials. Within-trial variability was high, influencing the reliability of the data. Future studies with a longitudinal design are required to provide information on changes in asymmetry over time and to explore potential associations between measured movement asymmetry and the development of clinical lameness.

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CONFLICT OF INTERESTS

No competing interests have been declared.

AUTHOR CONTRIBUTIONS

M. Rhodin and E. Hernlund designed the study and A. Kallerud, E. Hendrickson, M. Hammarberg, M. Rhodin and E. Hernlund collected the data. A. Kallerud, E. Persson-Sjodin and E. Hernlund performed data analysis and statistics. A. Kallerud and C. Fjordbakk wrote the manuscript. All authors contributed to data interpretation and revising the manuscript, as well as read and approved the final manuscript.

ETHICAL ANIMAL RESEARCH

The study was approved by the ethics committee at the Faculty of Veterinary Medicine, Norwegian University of Life Sciences (approval number 14/04723-47).

OWNER INFORMED CONSENT

A signed consent form was obtained from trainers of all horses included in the study.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publo n/10.1111/evj.13302.

DATA ACCESSIBILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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