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GENERAL ARTICLE

Non-banked curved tracks influence movement symmetry in two-year-old Standardbred trotters

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Abstract

Background: Little is known regarding how trotting through curves affects locomotion symmetry in Standardbred trotters.

Objectives: To investigate differences in objectively measured Standardbred trotter vertical motion symmetry between straight and non-banked, curved sections of oval trotting tracks during exercise warm-up, using a wireless inertial measurement unit (IMU) system.

Study design: Cross-sectional, observational study.

Methods: Sixteen horses were included. Mixed models were used to assess associations between symmetry, track segment (straight vs curve) and stride duration.

Results: Significant results for forelimb parameters were dependent on interactions between track segments and stride duration. At mean stride duration (0.611 second), during the curved track segment horses showed a lower maximum vertical position of the head after push-off of the outside forelimb (estimate −2.3 mm, $P < 0.0001$, 95% CI −1.7 to −2.9) and higher minimum vertical position of the head during stance of the outside forelimb (estimate −1.8 mm, $P < 0.0001$, 95% CI −1.2 to −2.5) compared to straight track, mimicking outside forelimb impact and push-off asymmetry during track curves. For hindlimb parameters, during the curve there was a decreased downward motion of the pelvis during outer hindlimb stance (estimate−0.7 mm, $P < 0.0001$, 95% CI −0.4 to −1.0), mimicking outside hindlimb impact asymmetry.

Main limitations: Horses were evaluated going in one direction only on the track (clockwise).

Conclusions: Systematic differences between straight and curved track segments were found but did not fully correspond to previously described findings for horses lunged in circles. Effect sizes were overall small. Data in our study were collected from horses trotting on 1000 m tracks with curve radii of 80-85 m. On non-banked tracks of this size, collecting IMU symmetry data at jogging speeds without distinguishing between straight and curved parts is unlikely to adversely affect clinical decision-making.

KEYWORDS

horse, asymmetry, circle, IMU, turn

1 | INTRODUCTION

Standardbred trotters are raced and often trained on oval tracks and therefore regularly trot through curves. Evaluating trotters (and pacers) during oval track exercise is recommended in several veterinary textbooks as a valuable routine part of the lameness work-up.[1,2] Assessing movement asymmetries in horses on a circle is challenging[3]; during lungeing horses cope with the circular track in a way that induces known vertical motion asymmetries of the head and pelvis, such as a reduced upward push of the outer hindlimb with a concurrent smaller descent on the inner hindlimb.[4,5] In a model of induced lameness, moving on a circle influenced both the pattern and the magnitude of vertical movement symmetry parameters obtained using a horse-mounted inertial measurement unit (IMU) system.[6] IMU systems have the capacity to accurately describe (a)symmetric locomotion[7] and are increasing in popularity amongst equine veterinarians as an aid in lameness examinations. However, while there are multiple studies[4–6,8–12] describing the effect of circling on objectively measured locomotion symmetry in riding horses, little knowledge exists regarding the effect of curves on locomotion symmetry in Standardbred trotters. A deeper understanding of how curves, as well as the use of common harness tack such as an overcheck, affect the normal motion pattern is of importance for subjective gait evaluation as well as for clinicians incorporating objective symmetry measurements during track exercise as part of their routine lameness work-up in this breed.

The aims of our study were to (a) describe the difference in objectively determined vertical movement symmetry of the head and pelvis in Standardbred trotters while trotting at jogging speed on the straight vs the curved part of a non-banked oval track, and (b) to explore the effect of stride duration on the degree of symmetry in these horses. Our hypothesis was that trotting through curves would induce a consistent change in symmetry patterns, as previously seen in riding horses being lunged.

2 | MATERIALS AND METHODS

2.1 | Study design and data collection

Standardbred trotters in their second year of training (ie approximately 2 years of age) were recruited to the study; these horses were enrolled in a larger, ongoing longitudinal study. Data on locomotion symmetry from their first training season as well as detailed information on cohort recruitment have been reported previously.[13] Data collection for the current study was conducted within the time period May – October 2018 at three training yards in Norway and Sweden. Included horses were in regular training which entailed oval track trotting exercise. Movement symmetry data was collected using an IMU system (Lameness Locator® by Equinosis LLC) as described below.

On the day of data collection, one of the investigators (A.S.K.) performed a general physical examination of all horses prior to exercise and measured the height at the withers and at the tubera sacrale (pelvis height). The horses wore their regular trotting harness and additional gear such as boots as per the trainers' preference. None of the included horses wore an overcheck, limb hobbles, head poles or side poles. Horses were instrumented with IMUs on the poll, pelvis and right front pastern as previously described.[14] To reduce interference from the back strap of the harness as well as to prevent sensor loosening during exercise, the pelvis sensor was fastened with extra strong double-sided adhesive tape (Teppeteip, Clas Ohlson) and standard-issue duct tape, then covered with additional adhesive tape (Snøgg Animal Polster, Norgesplaster AS). To prevent rotation of the neoprene pastern wrap, two rounds of elastic, adhesive cloth tape (Norbind, Norgesplaster AS) was applied to secure the wrap to the limb of the horse.

The IMU sensors each contain an accelerometer, gyroscope and magnetometer, and record the vertical acceleration of the head and torso and the angular velocity of the right front limb, sampling at 200 Hz with 8-bit digital resolution. Bluetooth technology provided wireless data transmission between the IMU sensors and a computer tablet running the proprietary system software. During data collection, the driver of the horse carried a small backpack with the receiving tablet to ensure continuous connection to the horse-mounted sensors. The driver also wore a GPS device (Polar M450, Polar Electro) that registered speed, distance and route of the training session.

IMU data were collected as horses were driven at a trot around the non-banked part (ie the flat, outer part) of the oval tracks at their regular warm-up speed in a clockwise direction of travel. Horses were evaluated on the track at their respective yards. All tracks were regularly maintained packed dirt tracks. Information on track length and curve radius was either collected from official sources,[15] from the trainer, or determined from the GPS data collected during trials. For the latter, curve radius (r) was calculated by the formula $r = \frac{circumference}{2\pi}$ where circumference was defined as 2x the GPS recorded curve distance. A representative exercise trial was defined as trotting through a minimum of one complete round of the oval track, resulting in data from a minimum of two straight long sides and two curves. As exercise distance and number of trials collected per horse varied between horses and trainers, the first representative trial collected for each horse was used for data analysis. Only one day of data collection was performed per horse.

2.2 | Data processing

The IMU system measures acceleration along the vertical axis of the IMU sensor. Using a double integration process the system software then calculates the minimum and maximum head and pelvic height differences between the right and left sides for every stride in the trial.[14] This results in four symmetry parameters; head minimum (HDmin) and head maximum (HDmax) difference, and pelvis minimum (PDmin) and pelvis maximum (PDmax) difference, describing the right-left step symmetry of the horse in millimetres (mm). For example, the HDmin difference is calculated as the minimum head height during right forelimb stance minus the minimum head height during left forelimb stance, while the HDmax difference is calculated as the maximum head height before right forelimb weight-bearing minus the maximum head height before left forelimb weight-bearing. The same principle is used for the movement of the pelvis to calculate PDmin and PDmax. A parameter value of 0 mm indicates perfect symmetry, with no difference in symmetry between the two halves of a stride. As defined by the system software, asymmetries indicating a right limb asymmetry were recorded as positive values, whereas asymmetries indicating a left limb asymmetry were recorded as negative values. Further descriptions of parameter calculations have been published elsewhere.[14]

Default settings (Lameness Locator® 2017 software v1.2r) were used for stride selection from each trial. Raw data for the selected strides was exported from the system software and processed in MATLAB (Release 2019a, The MathWorks Inc).[16] A custom-written MATLAB-script was used to plot the Y- and X- components of the pelvis sensor magnetometer as well as pelvic sensor yaw-data. To determine when the horse was travelling in a straight line and when the horse was going through a curve a visual inspection of these components was performed, focusing on whether the data tracings were horizontal or sloping, indicating a constant or changing direction of motion. Consistent segments with good agreement between yaw- and magnetometer data were extracted for use. No thresholds were used for stride selection. An example of the stride selection process is provided in Figure S1. Outlier removal for head parameters was performed, where each stride value was compared to the average value of all strides using Mahalanobis distance; strides where the parameter value exceeded three standard deviations from the mean (for the respective parameter) were removed. Trials were excluded from data analysis when technical difficulties with the IMU system such as sensor loosening during exercise or incomplete data acquisition resulted in inadequate data recordings. For descriptive results symmetry means, standard deviations, medians and ranges were calculated. Horse symmetry was further classified based on published thresholds for asymmetry in Thoroughbred racehorses.[17] These suggested thresholds are based on data from a study utilising a different system than the one used in the current study; comparison of these two systems show existing but small differences in symmetry value magnitude.[18] Horses were classified as asymmetric if they had one or more mean parameter values above ±14.5 mm (HDmin, HDmax) or ±7.5 mm (PDmin, PDmax) on the straight part of the track. Furthermore, asymmetric horses were divided into categories depending on which parameter was above threshold value, as well as which limb was affected; eg a horse with a mean HDmin value more positive than 14.5 mm would be classified as having right forelimb asymmetry for the HDmin parameter; conversely, a horse with a mean PDmin value more negative than −7.5 mm would be classified as being left hindlimb asymmetric for the PDmin parameter etc.

2.3 | Model building

Data were analysed using R open software (Version 4.0.06, The R Foundation for Statistical Computing).[19] Two-tailed hypothesis testing was performed by creating mixed models using the lmer function in the lme4 package. To evaluate the effect of the curve on vertical movement symmetry, four models with each symmetry parameter defined as outcome, were created using stride level data where signs were kept (negative indicating left and positive indicating right). The entered fixed effects were track segment (straight or curve) and stride duration, as well as two-way interactions of these. Stride duration was included as a proxy for speed (increase in stride duration corresponding to a decrease in speed). Horse was entered as a random effect to adjust for clustering. For 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 III p-values generated by a Wald F-test with Satterthwaite approximated *df* using the ANOVA function in base R. The level of significance was defined as $P < 0.05$. Full models were reduced to contain only significant main effects and interactions. Post-hoc pairwise comparisons were performed using the emmeans function and simple slopes for interactions were calculated using the emtrends function from the emmeans package with Kenward-Roger approximated *df*. Estimated marginal means were computed at stride duration grand mean, across all horses, trials and selected strides. P-values were adjusted by Tukey's method.

3 | RESULTS

3.1 | Descriptive findings

Trials from 38 horses were evaluated and 16 horses were included for analysis. Included horses were trained by four different trainers, two of which were based in Norway and two in Sweden. The median number of horses per trainer was three (range 1-9; two trainers had only 1 horse included, two trainers had 5 and 9 horses, respectively). The horses were trained on three different tracks; two training tracks and one official racing track. All tracks were 1000 m in length. The curve radius for training track A was approximately 80 m (length of curve = approximately 250 m), and for training track B and the official racing track approximately 85 m (length of curve = approximately 270 m). A flowchart of the number of included and excluded horses, reasons for exclusion and the number of horses exercised on the different tracks is presented in Figure 1.

Included horses comprised nine males (four stallions, five geldings) and seven mares. Median height at the withers was 160 cm (range 154-167 cm) and median height at the pelvis was 160 cm (range 155-166 cm). Data on height was missing for two horses. Median age was 28.0 months (range 23.4-29.9 months). Mean speed during the trials was 5.7 ± 0.7 m/s (mean ± SD). Mean stride duration in seconds ± SD was 0.611 ± 0.031 (straight track segments: 0.611 ± 0.032; curved track segments: 0.612 ± 0.031). A mean of 152 ± 70 strides was evaluated per horse (straight track segments: 143 ± 71 strides, curved track segments: 161 ± 70 strides). A median of three separate straight parts and three separate curved parts (range 2 – 5 for both track segments) of the track were analysed per

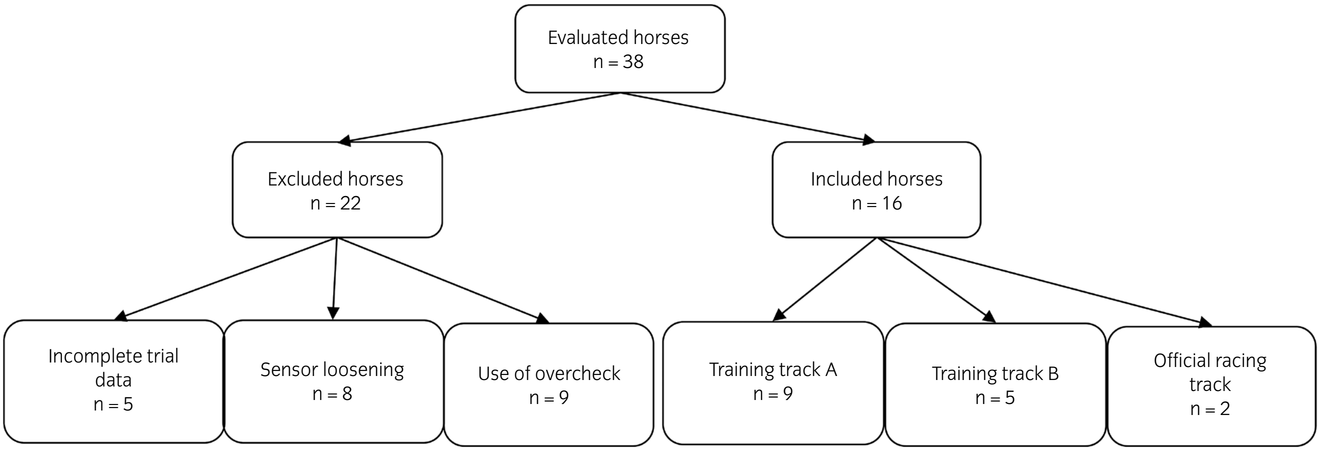

FIGURE 1 Flowchart of included/excluded horses and distribution of tracks

horse. Descriptive data for straight track segments are detailed in Table 1. Individual changes in symmetry values between straight and curved track segments are illustrated in Figure 2.

For individual horse parameter means for straight and curved track segments see Data S1. When implementing threshold values, seven horses were classified as symmetric and nine horses as asymmetric; six of the asymmetric horses had mean values above threshold for only one parameter. The remaining three horses had either contralateral asymmetry, ipsilateral asymmetry or asymmetry in one limb only but was above threshold for two parameters in the same limb. More details on the distribution of limb asymmetry is provided in Table S1 and Figure S2.

3.2 | Model results

Residuals were normally distributed in all models, and untransformed data were used. The four models demonstrated significant effects on fore- and hindlimb symmetry parameters as outlined below; estimated marginal means and pairwise comparisons are presented in Table 2 and full ANOVA results are listed in Data S2. Interaction plots for all parameters with significant interactions (HDmax, HDmin, PDmax) are illustrated in Figure 3.

3.2.1 | Forelimb parameters

For HDmax there was a significant two-way interaction between track segment (straight vs curve) and stride duration ($P < 0.001$). In the post-hoc pairwise comparison (Table 2), at group mean stride duration (0.611 second), the effect of the curve compared to the straight track was −2.3 mm ($P < 0.001$, 95% CI −1.7 to −2.9), indicating a relatively lower maximum vertical position of the head after push-off of the outside forelimb during curves. There was a negative linear relationship between stride duration and symmetry during curves (slope: −49.3 mm per s, SE 9.5, 95% CI −67.9 to −30.7) suggesting a lesser height reached by the head after outside forelimb push-off in the curve with increasing stride duration. The slope value demonstrates the change in symmetry in mm per 1 second change in stride duration; −49.3 mm per second corresponds to a change in symmetry of −4.93 mm per 100 ms change in stride duration (eg a change in stride duration from 0.5 to 0.6 second). On the straight track segment there was a positive but non-significant linear relationship between stride duration and symmetry (slope 6.0 mm per s [0.6 mm per 100 ms], SE 9.3, 95% CI −12.2 to 24.1).

For HDmin there was a significant two-way interaction between track segment and stride duration ($P < 0.001$). In the post-hoc pairwise comparison, at group mean stride duration (0.611 second), the effect of the curve compared to the straight track was −1.8 mm ($P < 0.001$, 95% CI −1.2 to −2.5), indicating a relatively higher minimum vertical position of the head during stance of the outside forelimb during curves. During the curve, a negative linear relationship (slope −39.6 mm per s (−3.96 mm per 100 ms), SE 10.5, 95% CI −60.1 to −19.1) was found between stride duration and HDmin symmetry, indicating a lesser downward motion of the head during outer forelimb stance phase with increasing stride duration. On the straight, a positive but non-significant linear relationship (slope 2.3 mm per s (0.23 mm per 100 ms), SE 10.2, 95% CI −17.8 to 22.3) was found between HDmin symmetry and stride duration.

3.2.2 | Hindlimb parameters

For PDmax the same two-way interaction as for the forelimb parameters was significant in the main ANOVA output (track segment and stride duration, $P = 0.003$), however, in the post-hoc analysis no significant difference was detected in symmetry between curved and straight track segments (for post-hoc analysis values see Table 2). For stride duration, there was a positive linear relationship with PDmax symmetry for both curved segments (slope 29.1 mm per s (2.91 mm per 100 ms), SE 4.1, 95% CI 21.1 to 37.1) and straight segments (slope 17.2 mm per s (1.72 mm per 100 ms), SE 4.0, 95% CI 9.3 to 25.0), suggesting an increase in the upward vertical movement of the pelvis after outer hindlimb push-off with increasing stride

TABLE 1 Mean, SD, median and range of symmetry for all 16 horses

Parameter	Side of asymmetry	Number of horses	Mean	SD	Median	Range
HDmax	All trials	16	6.2	NA	−1.4	−12.1 to 61.1
	Left	8	−6.5	2.7	−5.7	−3.3 to −12.1
	Right	8	18.8	19.7	12.9	0.6 to 61.1
HDmin	All trials	16	5.1	NA	2.7	−17.8 to 43.2
	Left	5	−8.2	6.5	−8.4	−0.7 to −17.8
	Right	11	11.2	12.3	8.2	0.2 to 43.2
PDmax	All trials	16	−2.8	NA	−2.6	−14.2 to 7.9
	Left	11	−5.9	4.4	−5.4	−0.6 to −14.2
	Right	5	4.0	2.6	3.2	0.8 to 7.9
PDmin	All trials	16	−1.2	NA	−1.3	−15.4 to 18.4
	Left	11	−4.7	4.7	−2.9	−0.8 to −15.5
	Right	5	6.5	7.0	4.2	1.0 to 18.4

Note: Trial values (in mm) from the straight part of the track. Side of asymmetry: Left = parameter mean <0 mm; right=parameter mean >0 mm.

Abbreviations: HDmin/HDmax, difference in head minimum/maximum positions between right and left portions of the stride; PDmin/PDmax, difference in pelvis minimum/maximum positions between right and left portions of the stride; NA, not applicable; SD, standard deviation.

duration, with a steeper slope for the curved track segment than the straight.

For PDmin there was no significant interaction between track segment and stride duration; of the two main effects track segment was significant ($P < 0.001$) whilst stride duration was not ($P = 0.9$). In the post-hoc pairwise comparison the effect of curve compared to straight track was −0.7 mm ($P < 0.001$, 95% CI −0.4 to −1.0), indicating a decreased downward motion of the pelvis during outer hindlimb stance on the curved track.

4 | DISCUSSION

Our cohort of two-year-old Standardbred trotters showed significant systematic differences in movement symmetry between trotting exercise on straight vs non-banked curved parts of an oval track, however, these differences are only in partial agreement with changes seen in lunged horses. Our hypothesis is therefore only partially supported by our findings. Horses being lunged on a 6-10 m diameter circle lean inward[8,9] and body lean increases with decreasing circle radius as well as increasing speed.[11] Starke et al. reported that inside forelimb lameness may be mimicked on the circle through a mild downward head nod during the outside forelimb stance phase,[5] representing a HDmin-type (impact) asymmetry of the inner forelimb. However, in a larger sample of lunged horses, Rhodin et al. reported that the majority of horses had a curve-induced increased downward nod during inside forelimb stance (mimicking outside forelimb impact asymmetry),[4] while a lesser number of horses in the same study showed an opposite pattern, with apparent inside forelimb impact asymmetry on the lunge.[4] Some of the discrepancy of the reported results for the effect of circling on forelimb symmetry may stem from different measurement systems being used, where Starke et al. utilised a system that corrects for the tilting of the sensor in relation to the true, global vertical through the gravitational acceleration, while the system being used in the study by Rhodin et al. and in the current study does not.[18] In our Standardbreds navigating curves, for the parameter HDmin there was a decreased downward motion of the head during outer forelimb stance (mimicking outside forelimb impact asymmetry), in accordance with findings in lunged horses.[4] For HDmax, during curves the Standardbreds in our study showed a decrease in push-off on the outside forelimb, while a decrease in inside forelimb push-off has been reported in lunged riding horses.[4]

One recurrent finding in lunged and ridden horses is that measured asymmetry when travelling on a circular path may mimic inside hindlimb lameness.[4–6,11] This occurs as the pelvis drops to a lower minimum position during the stance phase of the outside hindlimb and movement of the inside tuber coxae increases,[11] possibly due to the horse having to flex the inside hindlimb more and/or lift it higher in order to facilitate ground clearing during the swing phase of the inside hindlimb,[11] mimicking a PDmin-type (impact) asymmetry of the inner hindlimb. In our study, the opposite was found, with PDmin asymmetry manifesting in the outer hindlimb; there was a reduced downward vertical movement of the pelvis during the outer hindlimb stance phase, mimicking an outside hindlimb impact asymmetry during the curve. For PDmax measurements, a decrease in the upward motion of the pelvis on the outside hindlimb after push-off has been reported in lunged riding horses,[4] mimicking outside hindlimb push-off lameness. In our study, there were no significant differences in PDmax symmetry detected during post-hoc analysis between curved and straight track segments. In our study, there are highly significant differences between straight and curved track segments for most parameters, however, the effect sizes are overall small.

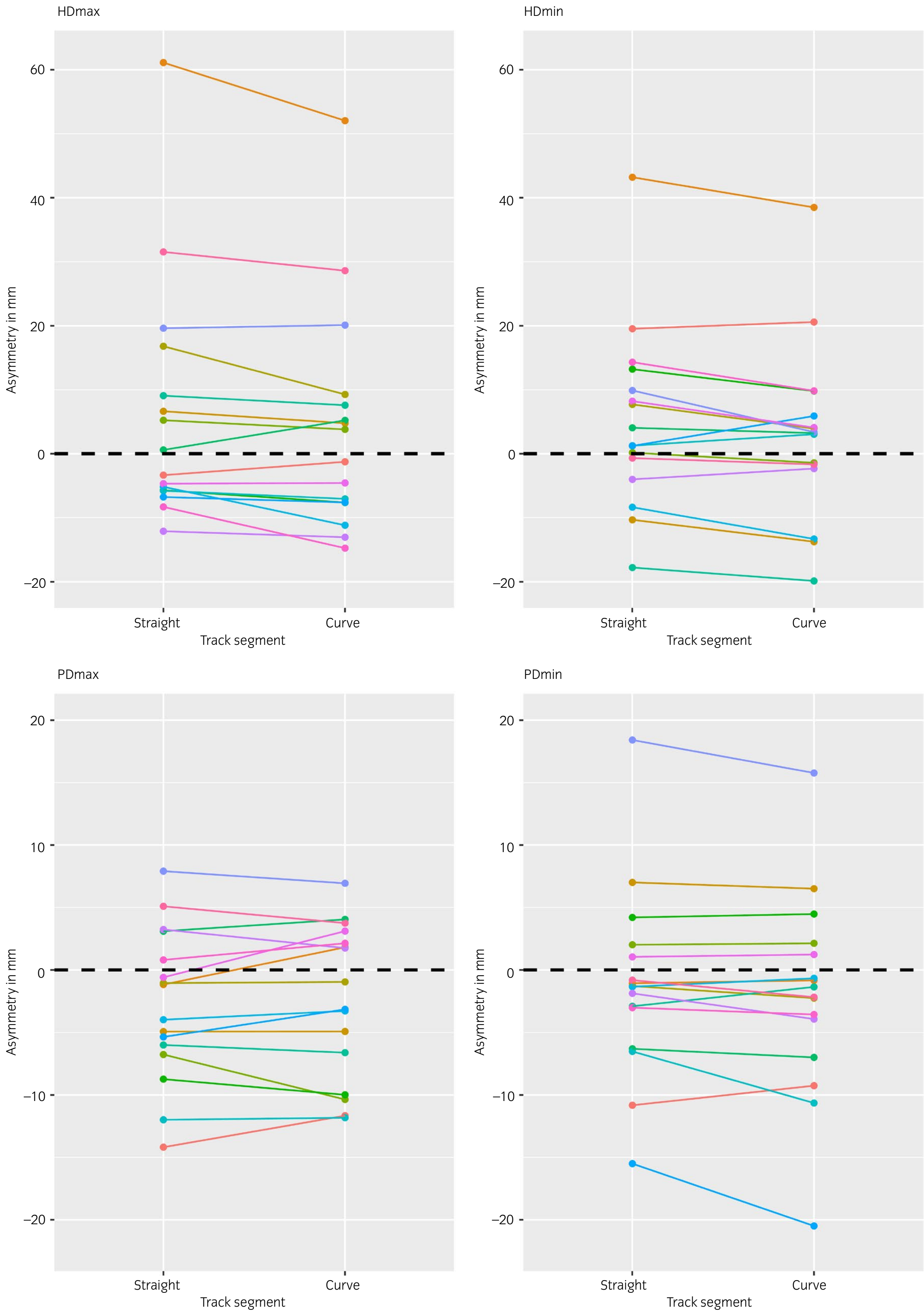

FIGURE 2 Line plot of symmetry values on straight and curved track segments. Data for all horses, n = 16. Each colour in the line plot represents an individual horse. Black stippled line at 0 mm elucidates the dividing line between left (negative values) and right (positive values) side asymmetry for the parameter. HDmin/HDmax = difference in head minimum/maximum positions between right and left portions of the stride, PDmin/PDmax = difference in pelvis minimum/maximum positions between right and left portions of the stride.

TABLE 2 Estimated marginal means and contrasts from post-hoc analysis

Model	Track segment	Estimate	SE	*df*	95% CI	t-ratio	*P*-value
Estimated marginal means							
HDmax	Straight	6.27	4.5	15	−3.3 to 15.9	1.39	0.2
	Curve	3.99	4.5	15	−6.6 to 13.6	0.89	0.4
HDmin	Straight	4.98	3.54	15	−2.6 to 12.5	1.41	0.2
	Curve	3.14	3.54	15	−4.4 to 10.7	0.89	0.4
PDmax	Straight	−2.76	1.5	15	−6.0 to 0.4	−1.84	0.09
	Curve	−2.52	1.5	15	−5.7 to 0.7	−1.68	0.1
PDmin	Straight	−1.09	1.9	15	−5.2 to 3.0	−0.57	0.6
	Curve	−1.78	1.9	15	−5.8 to 2.3	−0.94	0.4
Contrasts							
HDmax	Straight - curve	2.28	0.29	4,874	1.7 to 2.9	7.78	**<0.001**
HDmin	Straight - curve	1.84	0.32	4,875	1.2 to 2.5	5.69	**<0.001**
PDmax	Straight - curve	−0.24	0.13	5,107	−0.5 to 0.01	−1.86	0.06
PDmin	Straight - curve	0.69	0.14	5,108	0.4 to 1.0	4.98	**<0.001**

Note: Data from all 16 horses.

Abbreviations: HDmin/HDmax, difference in head minimum/maximum positions between right and left portions of the stride; PDmin/PDmax, difference in pelvis minimum/maximum positions between right and left portions of the stride; SE, standard error; *df*, degrees of freedom; 95% CI, 95% confidence interval.

Bold font is used when $P<0.05$.

There are several differences between riding horses being lunged and Standardbreds trotting on an oval track, such as the much wider curve radius of a trotting track; increased trotting speed of Standardbreds on the track; as well as the unknown effect of how pulling a sulky and driver may constrain the horses' ability to adapt to a curved path. In our study the horses were not driven by the same driver but exercised with their usual driver in the sulky. Different drivers may drive their horses slightly differently through the track curve, eg by positioning the horse's head more towards the inside or outside during the curved track, which may have influenced our measurements. In horses being lunged there are conflicting reports on whether there is a systematic influence of curve direction on symmetry[9,10] or not,[4,5,8] or whether this is due to the presence of lameness.[20] Horse-specific adaptations may cause differences in symmetry when lungeing in opposite directions.[4,5,10] In our study the horses travelled only in a clockwise direction on the track, as per the trainers' customary warm-up routine, therefore we could not investigate any potential effect of curve direction. Additionally, we cannot rule out that some of the more asymmetric horses in our study were experiencing orthopaedic pain, which may have influenced how they navigated the curved track segments.

In riding horses lunged on a 10 m circle, inward body lean was greater on a flat surface than on a banked surface.[8] In the 1970s, Dalin et al.[21] looked at Standardbreds trotting through curves as part of a collection of studies that lead to revised guidelines for the degree of banking of trotting track curves.[22,23] Sound two- and three-year old Standardbreds trotting at lower speeds (7.6 m/s) on two mildly banked (3.5 vs 4.5 degrees) oval tracks had symmetric movement through curves as judged by hoof landing patterns, diagonal patterns, extremity adduction and inward inclination as evaluated by high-speed cinematography.[21] With increased speed (13.3 m/s) there were significant contralateral (diagonal) differences for most parameters including increased inward body lean as well as a swinging or drifting of the hindquarters to the outside of the track while travelling through the curve.[21] This suggests that speed may be of greater importance than the curve radius itself for some curve-induced asymmetries, as centripetal acceleration is calculated by dividing velocity squared by the radius: $a_c = \frac{v^2}{r}$. Another aspect particular to horses exercising on oval tracks, when comparing these with horses ridden or lunged in circles, is that while the radius of an oval trotting track can be varied slightly by driving the horse along the outside or inside boundaries of the track, it is relatively constant and unchangeable. For the Standardbred trotter exercising on an oval track, speed rather than radius may be the more influencing factor. Once speed increases, banking is a key factor for Standardbred locomotion when navigating the curve. How trotting through banked track curves at greater speeds affects objectively measured symmetry parameters remains to be studied. In our study, changes in most symmetry parameters were coupled to stride duration. Stride duration was included as a proxy for speed, assuming that an increase in stride duration would mean a decrease in speed. However, stride duration by itself is not identical to speed of the horse as velocity is influenced by stride length in addition to stride frequency. Mean stride duration was almost the same for both straight and curved track segments in our study, however, the significant interactions of symmetry parameters, stride duration and track segment warrant further investigation.

In summary, we identified systematic curve-induced asymmetries in our Standardbred cohort. This is of importance both for subjective gait evaluation as well as for clinicians using this type

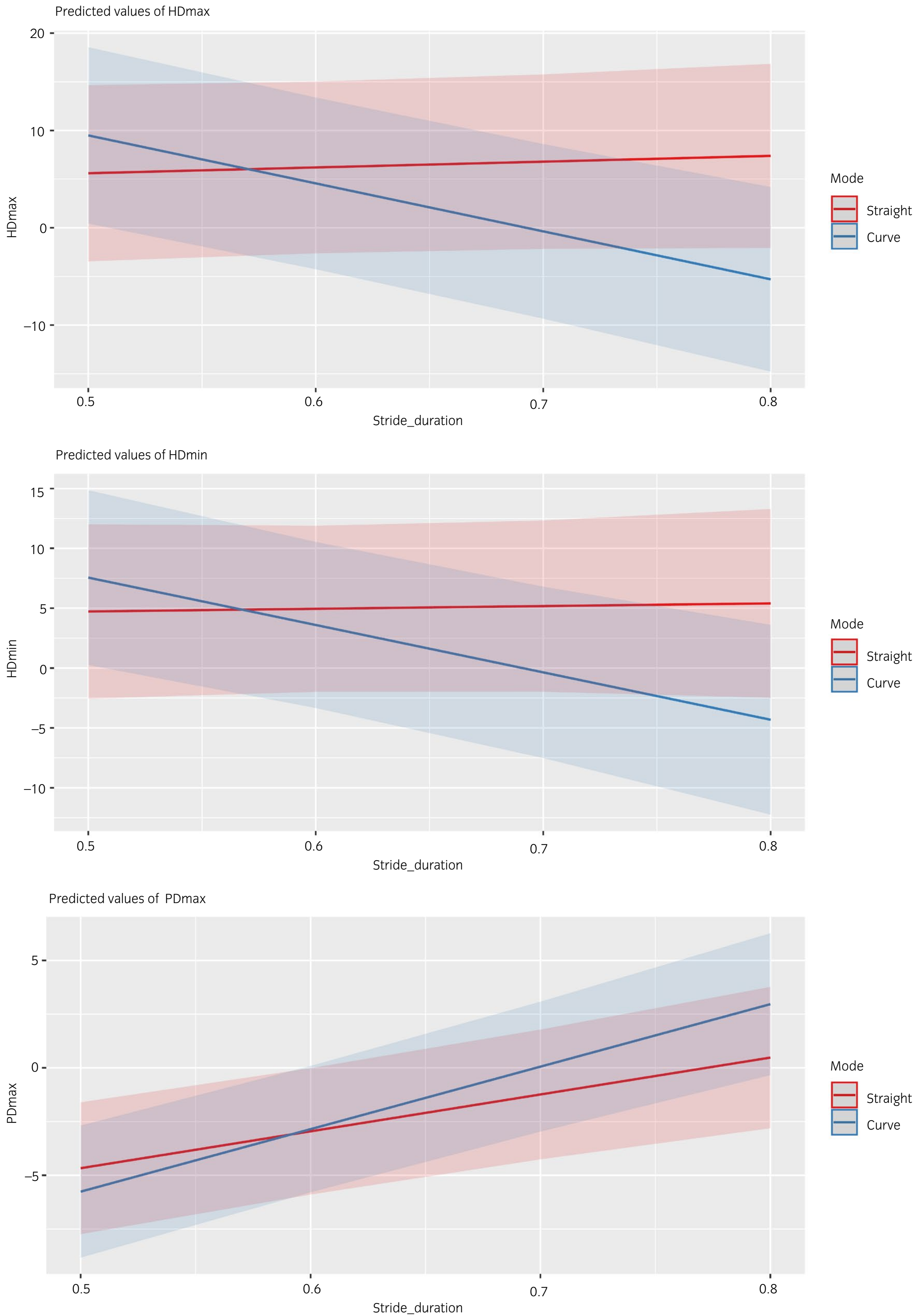

FIGURE 3 Two-way interaction plots for track segment and stride duration. Data for all horses, n = 16. Slope values: HDmax; curve: −49.3 mm per s, SE 9.5, 95% CI −67.9 to −30.7, straight: 6.0 mm per s, SE 9.3, 95% CI −12.2 to 24.1, HDmin; curve: −39.6 mm per s (−3.96 mm per 100 ms), SE 10.5, 95% CI −60.1 to −19.1, straight: 2.3 mm per s, SE 10.2, 95% CI −17.8 to 22.3, PDmax; curve: 29.1 mm per s, SE 4.1, 95% CI 21.1 to 37.1, straight: 17.2 mm per s, SE 4.0, 95% CI 9.3 to 25.0. PDmin not included as no significant interaction for this parameter. HDmin/HDmax = difference in head minimum/maximum positions between right and left portions of the stride, PDmin/PDmax = difference in pelvis minimum/maximum positions between right and left portions of the stride

of IMU systems to evaluate Standardbred horses on the track. In our relatively small cohort of horses with a wide range of existing asymmetries, with data collected from horses trotting on 1000 m tracks with curve radii of 80-85 m, effect sizes were small; under these conditions, collecting IMU symmetry data at jogging speeds without distinguishing between straight and curved parts of a non-banked track is unlikely to adversely affect clinical decision-making.

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CONFLICT OF INTERESTS

No competing interests have been declared.

AUTHOR CONTRIBUTIONS

M. Rhodin, E. Hernlund and E. H. S. Hendrickson conceptualised the study and A. S. Kallerud collected the data. A. Byström developed the data analysis MATLAB scripts. A. Byström, E. Hernlund, A. S. Kallerud and E. Persson-Sjodin performed data analysis and statistics. A. S. Kallerud, C. T. Fjordbakk and E. Hernlund wrote the manuscript. All authors contributed to data interpretation and revising the manuscript, as well as read and approved the final manuscript. A. S. Kallerud had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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).

INFORMED CONSENT

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

DATA ACCESSIBILITY STATEMENT

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

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1111/evj.13409.

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SUPPORTING INFORMATION

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

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