Received: 9 September 2019 | Accepted: 20 September 2020

DOI: 10.1111/evj.13367

GENERAL ARTICLE

Equine Veterinary Journal WILEY

# Upper body movement analysis of multiple limb asymmetry in 367 clinically lame horses

Suphannika Phutthachalee[1,2] | Kathrin Mählmann[1] | Suvaluk Seesupa[2] | Christoph Lischer[1]

[1]Equine Clinic, Department of Veterinary Medicine, Freie Universität Berlin, Berlin, Germany

[2]Faculty of Veterinary Medicine, Khon Kaen University, Khon Kaen, Thailand

**Correspondence**
Suphannika Phutthachalee, Equine Clinic, Department of Veterinary Medicine, Freie Universität Berlin, Berlin, Germany
Email: phuttsu@zedat.fu-berlin.de

**Funding information**The authors received no financial support for the research and/or authorship of this article.

## Abstract

**Background:** Compensatory lameness is common in horses and evaluation can be challenging.

**Objectives:** To investigate patterns of compensatory movements in clinical cases with fore- or hindlimb lameness before and after diagnostic analgesia.

**Study design:** Retrospective clinical study.

**Methods:** Multiple limb lameness of 367 horses was characterised by type (push-off, impact or mixed), limb (fore- or hindlimb in predominant lameness) and side (ipsi- or contralateral in concurrent lameness) using a body-mounted inertial sensor (BMIS). Diagnostic analgesia was performed until the percentage improvement of the vector sum in forelimb lameness and the mean difference of the maximum or minimum pelvic height ($PD_{max}$ or $PD_{min}$) in hindlimb lameness was ≥50%. Linear mixed model and post-estimation of effects were performed by contrast command with multiple comparisons adjusted by Bonferroni method. Correlation of pre- and post-analgesia of all head and pelvis asymmetry parameters was tested with Spearman's rank correlation.

**Results:** Improvement in vector sum per mm after diagnostic analgesia in forelimb impact lameness positively correlated with decrease in PDmax in contralateral mixed lameness (0.187 mm, $r = .58$, $P < .05$). Improvement in $PD_{min}$ per mm after diagnostic analgesia in hindlimb mixed and $PD_{max}$ in hindlimb push-off lameness decreased vector sum in ipsilateral forelimb impact lameness by 0.570 and 0.696 mm, respectively ($P < .05$), with no positive correlation.

**Main limitations:** A variety of cases with inhomogeneous distribution of lameness patterns was investigated retrospectively, therefore, it is impossible to distinguish between true multiple limb lameness and compensatory lameness in this clinical material.

**Conclusions:** Various asymmetry patterns of concurrent lameness were seen in horses with naturally occurring primary forelimb impact lameness with contralateral compensatory hindlimb lameness with a mixed component being the most common. In horses with hindlimb lameness, compensatory movements were seen in ipsilateral forelimbs, mostly as an ipsilateral impact lameness during straight line trot.

KEYWORDS
contralateral, horse, ipsilateral, objective examination, type of lameness

## 1 | INTRODUCTION

Multiple limb lameness is a common finding during orthopaedic examination of horses. Although lameness can be present independently in more than one limb, compensatory movements can be misinterpreted as a true lameness. To achieve definitive diagnosis and initiate therapy, it is important to identify the site of the primary lameness.[1-4] Compensatory movement is caused by weight-shifting from the primary painful limb. In consequence, there is convincing evidence of a "compensatory" or "false" lameness if it improves simultaneously with positive analgesia of the predominant lameness which can be called "primary" or "true" accordingly.[1,5] Patterns of compensatory movements have been comprehensively evaluated in experimental studies.[1,6-10] In a small number of horses with naturally occurring forelimb lameness, maximum pelvic height difference decreased after diagnostic analgesia in horses with contralateral compensatory hindlimb lameness,[11] whereas head movement asymmetry decreased significantly in horses with hindlimb lameness and ipsilateral compensatory forelimb lameness.[12] The type of the primary and associated compensatory lameness, namely, impact (during weight-bearing phase of the stride), push-off and mixed (impact and push-off, occurring at different moments of the stride cycle)[13,14] has not been investigated in detail. A body-mounted inertial sensor system, BMIS (Lameness locator™), has been used previously to objectively assess lameness, effects of diagnostic analgesia and patterns of compensatory lameness.[11,15-18]

The aim of this study was to objectively evaluate compensatory patterns of primary fore- or hindlimb lameness in a large number of clinical cases, characterise lameness by the phase of the stride and analyse the effect before and after diagnostic analgesia. We hypothesised, (I), vertical pelvic movement asymmetry, due to compensation of a predominant forelimb lameness, decreases after positive diagnostic analgesia in the affected forelimb and, (II), vertical head movement asymmetry, due to compensation of a predominant hindlimb lameness, decreases after positive diagnostic analgesia in the affected hindlimb.

## 2 | MATERIALS AND METHODS

### 2.1 | Animals

Data were analysed retrospectively from clinical cases presented to the Equine Clinic, Freie Universität Berlin, Germany, from April 2011 to December 2015 for lameness investigation. Horses were included in the study, if (1) evaluation in trot could be performed with the initial body-mounted inertial sensor system (BMIS), (2) two or more limbs had asymmetry values calculated by the BMIS equipment equal or higher than the threshold values described below. In an asymmetric horse, the threshold of the absolute mean is greater than 8.5 mm for vector sum, 6 mm for $HD_{min}$, $HD_{max}$ and 3 mm for $PD_{min}$, $PD_{max}$. These thresholds might represent at least weak evidence lameness,[19,20] (3) the percentage improvement of the vector sum in forelimb lameness and the mean difference of the maximum or minimum pelvic height ($PD_{max}$ or $PD_{min}$) in hindlimb lameness were more than 50% and (4) the asymmetry did not switch to another limb following diagnostic analgesia. Horses were excluded from the analysis if predominant lameness was not definable (ie BMIS did not identify a predominant lameness). Inclusion and exclusion criteria are summarised in a flow chart (Figure 1).

### 2.2 | Lameness evaluation

Lameness examination was performed subjectively by a veterinarian specialising in orthopaedics and objectively with a BMIS (LAMENESS LOCATOR™: EQUINOSIS®) system.[16,17,21] Horses were trotted in a straight line over a concrete surface and at least 25 strides were included in each data trial.

The vertical acceleration of the head was recorded and the mean difference in maximum head height ($HD_{max}$) and the mean difference in minimum head height ($HD_{min}$) during the stance phase of the left and right limbs. The displacement differences were calculated in millimetres. The vector sum was calculated as a measure of head movement asymmetry.[20] In hindlimbs, the mean difference in maximum pelvic height ($PD_{max}$) and the minimum pelvic height ($PD_{min}$) during the stance phase of the left and right limb were calculated accordingly.[20] The sensor on the right forelimb contains a gyroscope and is used for step division. The side, type and grade of lameness were defined by positive and negative values of head or pelvic height differences respectively.[20] The predominant lameness was determined by an algorithm combining an evidence score respecting the stride-by-stride variability and the amplitude of the lameness by the software provided by Equinosis.[15] Diagnostic analgesia was performed on the predominantly lame limb confirmed by objective and subjective assessment, such as trot in straight line, circle on hard or soft surface flexion test. Limb (**F: forelimb** or **H: hindlimb**) and type (push-off (p), impact (i) or mixed (m)) of predominant and the side (**I: ipsi** or **C: contralateral**) and type (push-off (p), impact (i) or mixed (m)) for the concurrent lameness were documented and combined in an abbreviation designating the different combinations as, for example, **FiC**i assigning predominant forelimb impact, concurrent contralateral impact lameness (Table 1, Figure 2).

The percentage improvement after diagnostic analgesia in both fore- and hindlimb was calculated as: [(Parameter before analgesia−Parameter after analgesia)/Parameter before analgesia].[11,22] Diagnostic analgesia was performed until it was considered positive

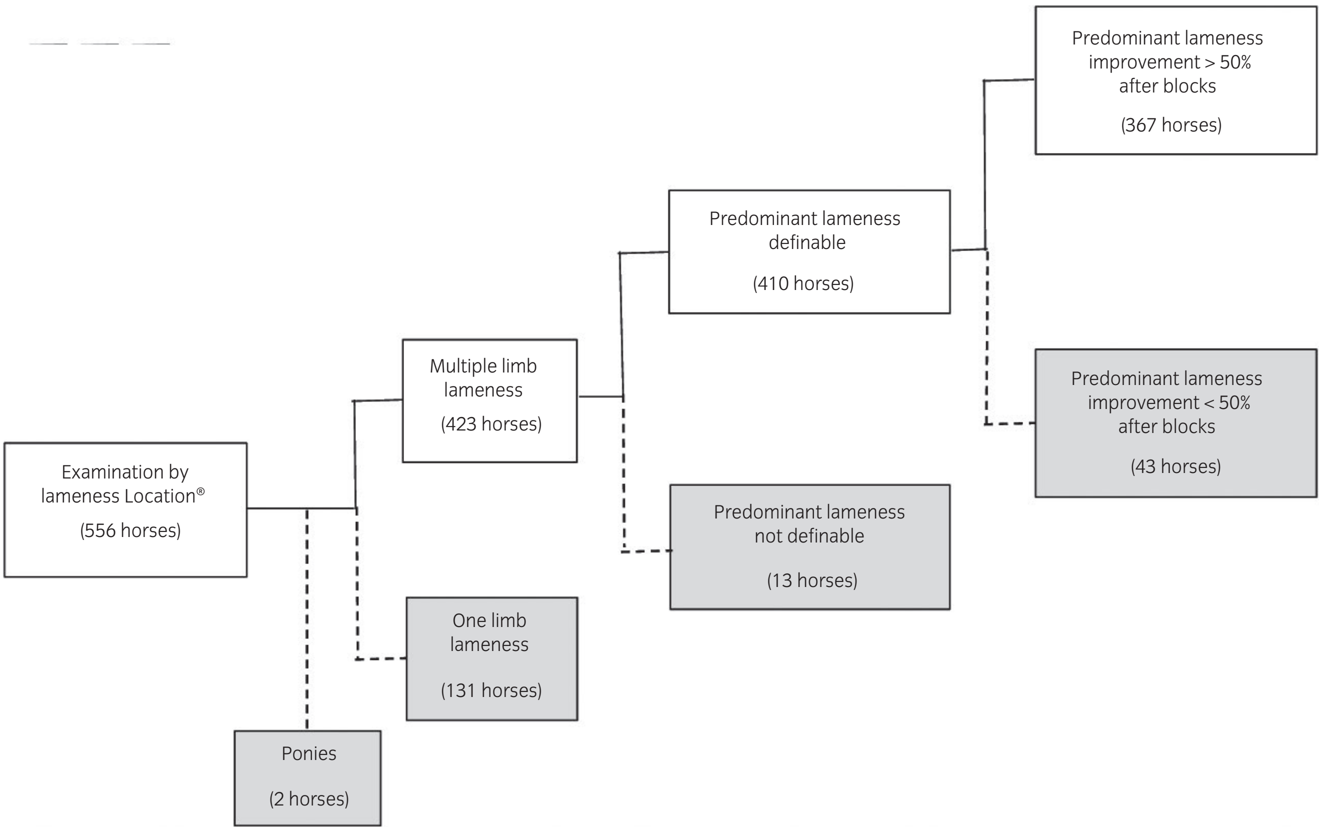


**FIGURE 1** Flow chart showing the inclusion and exclusion criteria of horses in this study

**TABLE 1** Comparison of kinematic variables following forelimb analgesia in 186 horses presented with predominant forelimb impact lameness and concurrent lameness in other limbs

| | | Comparison of variables (mm) between before – after analgesia (*P*-value)[c] following forelimb analgesia | | | | | Percentage improvement in predominant lameness | Percentage improvement in concurrent lameness | |
|---|---|---|---|---|---|---|---|---|---|
| | | Predominant | | | Concurrent | | | | |
| Group | No. | Vector Sum | $HD_{max}$ | $HD_{min}$ | $PD_{max}$ | $PD_{min}$ | Vector sum | $PD_{max}$ | $PD_{min}$ |
| Forelimb impact | 186 | | | | | | | | |
| Two limb lameness | | | | | | | | | |
| FiCi | 19 | .0002 | .0004 | .0015 | .6413 | .0776 | 63.37 | NA | 10.84 |
| FiCp | 41 | <.0001 | <.0001 | <.0001 | <.0001 | .1864 | 61.46 | 43.53[a] | NA |
| FiCm | 40 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 57.22 | 53.48[a] | 40.85 |
| FiIi | 24 | .0006 | .0072 | .0012 | 1.0000 | .0001 | 52.96 | NA | 34.91[b] |
| FiIp | 23 | .0005 | .0041 | .0033 | 1.0000 | 1.0000 | 61.21 | 2.72 | NA |
| FiIm | 10 | .0086 | .0189 | .4147 | .0449 | .0128 | 55.03 | 51.05[a] | 41.79 |
| Three limb lameness | | | | | | | | | |
| FiCiIp | 9 | .0085 | .0195 | .0244 | 1.0000 | .0411 | 62.25 | 7.71 | 39.97 |
| FiCpIi | 20 | <.0001 | <.0001 | <.0001 | .0358 | 1.0000 | 61.31 | 22.47 | 16.19 |

Abbreviations: Capital letter – **F**, predominant forelimb lameness; **C**, concurrent contralateral lameness; **I**, concurrent ipsitateral lameness; Lowercase letter – i, impact; p, push-off; m, mixed lameness; $PD_{max}$, maximum pelvic height difference; $PD_{min}$, minimum pelvic height difference; $HD_{min}$, minimum head height difference

[a]Positive correlation (tested by Spearman's rank analysis) of improvement of vector sum and $PD_{max}$

[b]Positive correlation (tested by Spearman's rank analysis) of percentage improvement between vector sum and $PD_{min}$ ($p < 0.05$).

[c]Analysis the effect of before and after diagnostic analgesia on asymmetry variables with adjusted covariates (sex, breed, age) by Linear Mixed model.

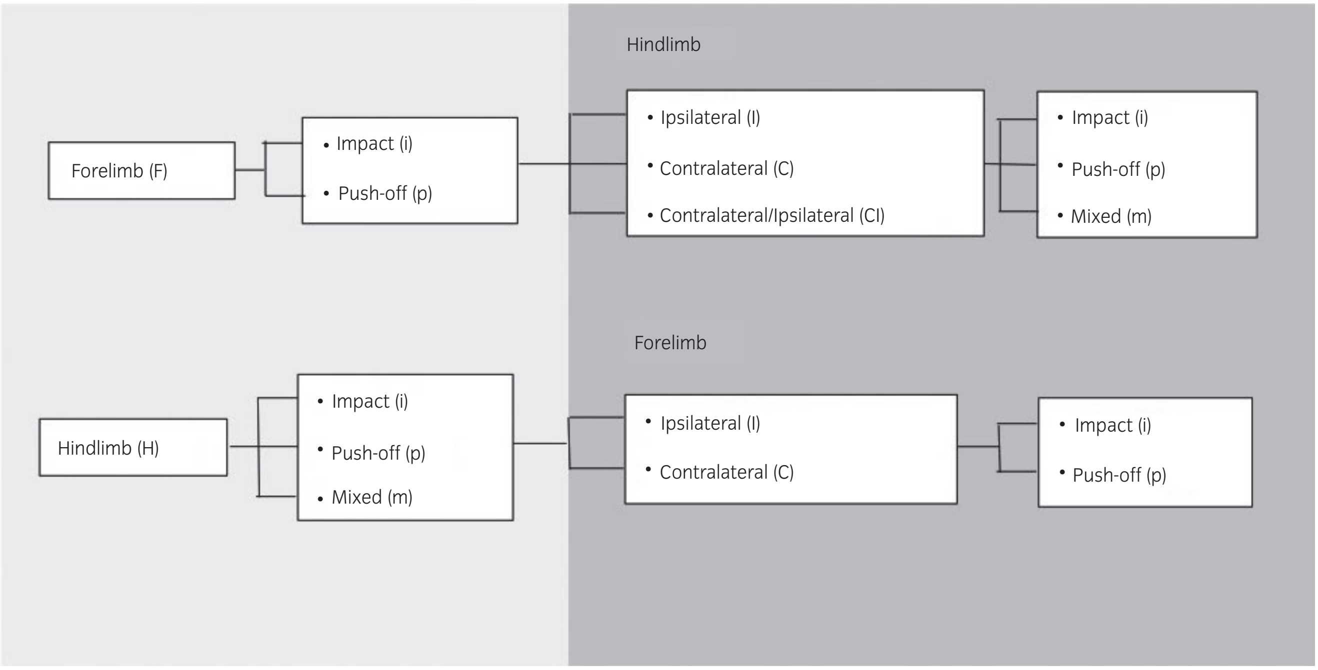


**FIGURE 2** Combination of predominant and concurrent lameness patterns and corresponding abbreviations

with the percentage improvement of vector sum in forelimb lameness and $PD_{max}$ or $PD_{min}$ in hindlimb lameness were more than 50%.[20]

### 2.3 | Data analysis

Data analysis was performed by linear mixed modelling and post-estimation of effects were done by contrast command with multiple comparisons adjusted by Bonferroni method. The first model included the fixed effects of diagnostic analgesia (before and after) nested with lameness categories (8 groups in forelimb, 12 groups in hindlimb) on asymmetry parameters ($HD_{max}$, $HD_{min}$, vector sum, $PD_{max}$ and $PD_{min}$). All negative values were multiplied by −1 to convert into positive values, therefore, there was no need to distinguish the left or right origin of the lameness. Horse was assigned to be a random effect. The second model explored the effect of decrease in dominant head movement asymmetry parameter (mean difference of $HD_{max}$, $HD_{min}$ and vector sum) on the concurrent movement asymmetry variables of the pelvis (mean difference of $PD_{max}$ and $PD_{min}$) for predominant forelimb lameness and vice versa for hindlimb lameness, decrease in dominant pelvic movement asymmetry on the concurrent head movement asymmetry. Covariates in the analysis of both models were sex (male, female or gelding), breed (Warmblood, Quarter horses, Appaloosa, Paint, American Saddlebred, Arabian, Morgan, Standardbred and draught horses) and age (year). For the primary forelimb push-off lameness group, statistical analysis could not be performed because of the low sample size. All head and pelvis movement asymmetry parameters pre- and post-analgesia and percentage improvement was tested for correlation with Spearman's rank correlation. Variables were analysed using commercial software (STATA, Version 13.0, StataCorp™). Significance was considered at $P < .05$ for all analyses.

## 3 | RESULTS

The inclusion criteria were met by 367 horses of which 199 had predominant forelimb and 168 had predominant hindlimb lameness. Cases included 159 females, 32 males and 176 geldings with a mean age of 11 years (SD 5.1 years). Warmblood horses represented 68% of the study population and there was a range of other breeds.

Predominant forelimb with concurrent hindlimb lameness was seen in 15 patterns (Table 1). The most common type in forelimbs was impact lameness (94%), with the concurrent hindlimb lameness found contralaterally (54%) and these are described in more detail in Table 1. Forelimb push-off lameness as observed in 13 horses, which were not analysed further. Predominant hindlimb lameness was present as impact (16.7%), push-off (17.8%) and mixed (65.5%) type. The most common concurrent forelimb lameness was ipsilateral (72.6%) (Table 2).

### 3.1 | Predominant forelimb lameness after diagnostic analgesia (The results of the linear mixed model, first model)

#### 3.1.1 | Forelimb lameness with concurrent hindlimb lameness

Only a small number of horses showed **F**p lameness (13/199) and were, therefore, excluded from statistical analyses. Concurrent hindlimb lameness was detected contralateral (**FiC**, n = 100), ipsilateral (**FiI**, n = 57) and combined ipsilateral and contralateral (**FiIC**, n = 29).

After diagnostic analgesia of the forelimb lameness, the $PD_{min}$ of concurrent hindlimb lameness decreased significantly in all three patterns (**FiC**, **FiI** and **FiIC**; $P < .05$), $PD_{max}$ significantly decreased in the **FiC** group ($P < .001$).

**TABLE 2** Comparison of kinematic variables following hindlimb analgesia in 168 horses with predominant hindlimb lameness and concurrent lameness in other limbs

| | | Comparison of variables (mm) between before – after analgesia (*P*-value)[c] following hindlimb analgesia | | | | | Percentage improvement of predominant | | Percentage improvement of concurrent |
|---|---|---|---|---|---|---|---|---|---|
| | | Predominant | | Concurrent | | | | | |
| Group | No. | $PD_{max}$ | $PD_{min}$ | Vector Sum | $HD_{max}$ | $HD_{min}$ | $PD_{max}$ | $PD_{min}$ | Vector Sum |
| Hindlimb impact | 168 | | | | | | | | |
| HiCi | 6 | NA | 1.0000 | 1.0000 | .0995 | .09 | NA | 93.06 | 35 |
| HiCp | 4 | NA | 1.0000 | 1.0000 | 1.0000 | 1.0 | NA | 90.31 | 17 |
| HiIi | 13 | NA | .0211 | .9127 | .2153 | <.05 | NA | 77.74 | 28 |
| HiIp | 5 | NA | 1.0000 | 1.0000 | 1.0000 | .685 | NA | 91.07 | 16 |
| Push-off | | | | | | | | | |
| HpCi | 3 | 1.0000 | NA | 1.0000 | 1.0000 | .285 | 73.53 | NA | 6 |
| HpCp | 3 | .3057 | NA | 1.0000 | 1.0000 | .593 | 94.23 | NA | 17 |
| HpIi | 12 | .0188 | NA | .3721 | .8933 | <.05 | 87.46 | NA | 29 |
| HpIp | 12 | .0315 | NA | .3285 | .0503 | .753 | 78.62 | NA | 24 |
| Mixed | | | | | | | | | |
| HmCi | 23 | <.0001 | .0022 | .7703 | .0654 | .532 | 91.22 | 74.02 | 24 |
| HmCp | 7 | .0511 | .0074 | .8635 | .4322 | .445 | 86.79 | 64.77 | 22 |
| HmIi | 51 | <.0001 | <.0001 | .0182 | .0049 | <.0001 | 76.81[a] | 65.12 | 43 |
| HmIp | 29 | <.0001[b] | .0006 | .2011 | .0730 | <.0001 | 98.11 | 57.08 | 13 |

Abbreviations: Capital letter – **H**, predominant hindlimb lameness; **C**, concurrent contralateral lameness; **I**, concurrent ipsitateral lameness; Lowercase letter – i, impact; p, push off; m, mixed lameness; $PD_{max}$, maximum pelvic height difference; $PD_{min}$, minimum pelvic height difference; $HD_{min}$, minimum head height difference; NA, not applicable.

[a]A positive correlation (tested by Spearman's rank analysis) of percentage improvement between $PD_{max}$ and $HD_{min}$.

[b]Positive correlation (tested by Spearman's rank analysis) of improvement of $PD_{max}$ and $HD_{min}$ ($P < .05$).

[c]Analysis of the effect of before and after diagnostic analgesia on asymmetry variables with adjusted covariates (sex, breed, age) by Linear Mixed model.

#### 3.1.2 | Predominant forelimb lameness and the type of concurrent hindlimb lameness

$PD_{max}$ of concurrent hindlimb lameness decreased significantly in **F**i**C**p, **F**i**C**m, **F**i**I**m and **F**i**C**p**I**i and the $PD_{min}$ in **F**i**C**m, **F**i**I**i and **F**i**I**m after diagnostic analgesia of the primary forelimb lameness (Table 1, Table S1). The change in vector sum and $PD_{max}$ was positively correlated in **F**i**C**m ($r = .58$, $P = .007$).

#### 3.1.3 | The percentage improvement of fore- and concurrent hindlimb lameness

After a positive analgesia of forelimb lameness, the percentage improvement was >50% of $PD_{max}$ in groups **F**i**C**p, **F**i**C**m and **F**i**I**m, and of $PD_{min}$ in all groups were less than 50% improvement (Table 1). There was a positive correlation between the percentage improvement of vector sum and $PD_{max}$ in **F**i**C**p ($r = .30$, $P < .05$) and **F**i**C**m ($r = .36$, $P < .05$), and $PD_{min}$ in **F**i**I**i ($r = .43$, $P < .05$).

### 3.2 | Predominant hindlimb lameness after diagnostic analgesia (The results of the linear mixed model, first model)

#### 3.2.1 | Hindlimb lameness with concurrent forelimb lameness

Hindlimb lameness included impact (**H**i, n = 28), push-off (**H**p, n = 30) and mixed (**H**m, n = 110) types. The $PD_{min}$ significantly decreased in groups **H**i**I**, ($P < .05$), **H**i**C**, **H**m**I** and **H**m**C** ($P < .0001$). $PD_{max}$ decreased significantly in **H**p**C**, **H**p**I**, **H**m**I** and **H**m**C** ($P < .0001$) (Table S2). The concurrent ipsilateral forelimb lameness significantly decreased in $HD_{max}$, $HD_{min}$ and vector sum ($P < .05$) of **H**m**I**. There was no significant decrease in vector sum in contralateral (**C**) forelimb lameness.

#### 3.2.2 | Predominant hindlimb lameness with the type of concurrent forelimb lameness

When the type of concurrent forelimb lameness was considered, the $HD_{max}$, $HD_{min}$ and vector sum of compensatory forelimb lameness decreased significantly in **H**m**I**i (Table 2, Table S3). $HD_{max}$ only decreased in **H**i**C**i and **H**p**I**p. $HD_{min}$ was significantly decreased in **H**i**I**i, **H**p**I**i, **H**m**I**i and **H**m**I**p. There was a significant positive correlation after hindlimb diagnostic analgesia between $HD_{min}$ and the decrease in $PD_{max}$ (Table 2, $r = .44$, $P < .05$) in **H**m**I**p. No further correlations were identified between the change in $PD_{max}$, $PD_{min}$ and vector sum or $HD_{max}$ after hindlimb diagnostic analgesia in any group.

#### 3.2.3 | The percentage improvement of predominant hindlimb and concurrent forelimb lameness

After a positive analgesia of hindlimb lameness, the percentage improvement of vector sum of concurrent forelimb lameness improved <50% in all groups (Table 2) and there was no correlation between percentage improvement of $PD_{max}$ or $PD_{min}$ and vector sum, but there was a positive correlation of percentage improvement between $PD_{max}$ and HD min in **H**m**I**i.

### 3.3 | The results of the linear mixed model, second model

The effect of decrease in predominant asymmetry on the concurrent asymmetry variables is presented in Table S4 and Table S5. A decrease in vector sum by 1 mm in **F**i**C**p was associated with a decrease in $PD_{max}$ by 0.086 mm (95% confident interval, CI = 0.052-0.119). In **F**i**C**m, $PD_{max}$ decreased 0.187 mm (95% CI = 0.140-0.233) and $PD_{min}$ 0.042 mm ($P < .001$) (95% CI = 0.023-0.062). A decrease in $PD_{min}$ by 1 mm in **H**m**I**i was associated with a decrease in vector sum by 0.570 mm (95% CI = 0.162-0.978). A decrease in $PD_{max}$ by 1 mm in **H**p**I**i was associated with a decrease in $HD_{max}$ by 0.696 (95% CI = 0.050-1.342) ($P < .05$).

## 4 | DISCUSSION

Assessment of large number of clinical cases during BMIS evaluation of horses trotting in a straight line revealed that combined fore and hindlimb lameness is much more common than identification of forelimb-only and hindlimb-only lameness.[18] In our study, we only included horses with a combined fore- and hindlimb lameness pattern. In our cases, predominant impact lameness was more common in forelimbs than in hindlimbs and forelimb impact lameness 186/199 (93.5%) was more frequent than push-off lameness 13/199 (6.5%). Horses are likely prone to be injured at the impact phase of the stride as larger forces act on the musculoskeletal system during the stance phase on the forelimb.[23] During the stance phase, the forelimb is loaded with 60%-65% of the bodyweight.[13,24] The version of the LAMENESS LOCATOR™ used in this study does not indicate mixed lameness in forelimb as $HD_{max}$ and $HD_{min}$ are considered as a single value (the vector sum) in determination of side and type of lameness. In hindlimb lameness, impact and push-off are determined and reported separately, and mixed lameness can be registered.

In predominant forelimb lameness and concurrent hindlimb lameness, the most obvious reduction in pelvic movement asymmetry after the positive forelimb analgesia occurred in the push-off and mixed type of lameness of the contralateral hindlimb. These were also the most common patterns and there were significant positive correlations between the percentage improvement in vector sum and $PD_{max}$ following diagnostic analgesia for these patterns. The $PD_{max}$ improved more than 50% in both groups providing evidence that the hindlimb asymmetry was a compensatory movement in these horses. The consistent improvement of $PD_{max}$ in compensatory lameness with a push-off component (**F**i**C**p, **F**i**C**m) indicates that the primary forelimb impact lameness is compensated by decreased push-off of the contralateral hindlimb which is in agreement with previous studies.[11,16] This compensatory pattern results when the load is shifted from the lame forelimb backward to the contralateral hindlimb.[7,25] With positive diagnostic analgesia of the lame forelimb $PD_{max}$, representing pelvic height difference after the stance phase of the hindlimb, decreased. $PD_{max}$ associated with a transfer of vertical to horizontal propulsive force in the second half of the stance.[26] The impulse in forelimb lameness was redistributed in the sound diagonal to the contralateral fore- and in the lame diagonal to the contralateral hindlimb with increase in peak vertical forces[7] and horizontal deceleration forces.[24] In addition, there was an increased horizontal propulsive force in the contralateral and reduced in the ipsilateral hindlimb, thus, lowering of the sacrum of the contralateral hindlimb. Buchner et al[27] also reported a decrease in vertical amplitude of the sacrum during the contralateral and an increase during the ipsilateral hindlimb stance phase.

In the current study, forelimb impact lameness was also seen in combination with other types of hindlimb lameness. In horses showing a contralateral mixed (**F**i**C**m) lameness, the $PD_{min}$, representing the impact component of hindlimb lameness, improved after predominant forelimb analgesia. It is possible that this is in fact a secondary lameness.

In a smaller number of horses, an ipsilateral hindlimb lameness improved after diagnostic analgesia in the forelimb suggesting a compensatory movement (**F**i**I**i, **F**i**I**m). Other studies also reported different compensatory patterns for forelimb lameness including both contralateral and ipsilateral compensatory hindlimb lameness.[7,9-11]

Our results are in contrast to the study by Maliye et al,[11] in which horses with naturally occurring forelimb lameness did not show improvement of an ipsilateral weight-bearing hindlimb lameness after forelimb analgesia. This difference may be explained by the larger number of horses evaluated in the current study. Maliye et al[11] discuss that in horses with a forelimb and ipsilateral hindlimb lameness, diagnostic analgesia is often performed in the hindlimb, with respect to the "law of sides". This defines that a horse, lame in the forelimb and contralateral hindlimb, has a primary forelimb lameness and a horse lame in the forelimb and ipsilateral hindlimb, has a primary hindlimb lameness. Although this law of sides does not describe the type of lameness, the LAMENESS LOCATOR™ integrates algorithms

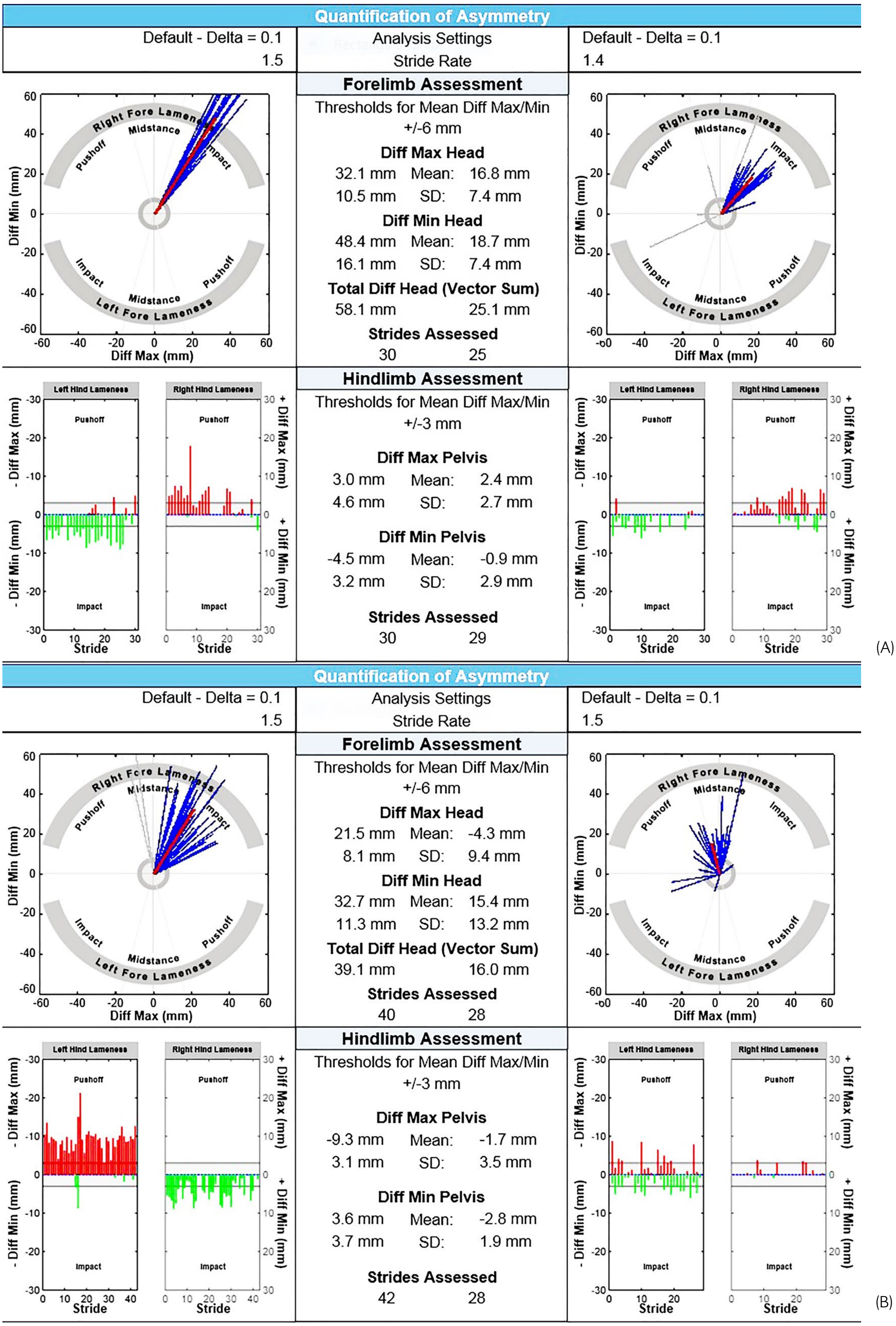


**FIGURE 3** The graph showing the predominant and concurrent lameness patterns before and after lame limb analgesia: (A) Forelimb impact with contralateral impact and ipsilateral push-off hindlimb (**FiCiIp**) lameness, and (B) Forelimb impact with contralateral push-off and ipsilateral impact hindlimb (**FiCpIi**) lameness (EQUINOSIS®/LAMENESS LOCATOR™ software)

in the straight line that consider both of law of sides and type of lameness. Even though this is a common scenario, in the current study the predominant lameness was defined by other parameters by the LAMENESS LOCATOR™ which might have prevented a subjective bias based on a preliminary assumption.

In 29 horses with combined ipsilateral/contralateral concurrent hindlimb lameness only the contralateral component improved, with $PD_{min}$ representing the impact component in **FiCiI**p and $PD_{max}$ representing the push-off component in **FiCpI**i, (Figure 3A,B). The ipsilateral component may represent a true lameness. Further studies are needed to investigate patterns in which more than one concurrent lameness, that is, multiple limb lameness, is observed. Components of concurrent hindlimb lameness which did not change significantly after forelimb analgesia could be either independent problems or problems caused by long-term compensation. No further workup of these components was performed in the current study.

In predominant hindlimb lameness, there was a significant decrease in $PD_{max}$, $PD_{min}$ and vector sum in **HmI** group, but no correlations were identified after diagnostic analgesia of predominant hindlimb lameness. These results are in accordance to the study by Maliye and Marshall[12] and suggest that hindlimb lameness causes ipsilateral compensatory forelimb lameness only. The most common compensatory pattern in the current study was **HmI**i (26.4%) with a positive correlation between percentage improvement of $PD_{max}$ and $HD_{min}$. In horses with **HmI**p, there was a positive correlation between the reduction in $PD_{max}$ and $HD_{min}$ following hindlimb lameness analgesia. The results suggest that primary mixed hindlimb causes ipsilateral impact or push-off forelimb lameness. In hindlimb lameness, a head nod can be observed frequently during the stance phase of the contralateral forelimb.[4,28] The weight is shifted from the hindlimb to the diagonal forelimb by the movement of the head, leading to the impression of an ipsilateral forelimb lameness.[1,14,29] A compensatory ipsilateral forelimb lameness could be reproduced under experimental conditions after induction of hindlimb lameness.[10,27]

Vector sum did not decrease in concurrent forelimb lameness after diagnostic analgesia in hindlimbs in our study. However, Maliye and Marshall[12] recognised a significant improvement of vector sum in the concurrent ipsilateral forelimb lameness after diagnostic analgesia of the hindlimb but no correlation. They suggested that other kinematic parameters might provide an explanation and, therefore, further examinations are required. Horses could respond to hindlimb lameness by decreasing the push-off phase of stride of the lame hindlimb more than by increasing the load of the compensatory limb.[30] Keegan[29] described differences in head movement asymmetry between horses with predominant hindlimb lameness and suggested that this can be caused by an individual body conformation.

The results of the current study indicate that at least a part of the concurrent forelimb lameness observed with predominant hindlimb lameness is caused by a true lameness. The lameness may be independent from the hindlimb lameness or represent a secondary injury caused by longstanding compensation. In our cases no further workup of the forelimb lameness was performed because the lameness was very mild to moderate.[19]

In horses with multiple limb lameness, with subjective evaluation, it is challenging to determine which are the lame limbs or if there is a compensatory lameness present. Examination is usually conducted on a straight line and circle to combine as much information as possible.[31] Evaluation is particularly difficult if the horse moves with a short, shuffling gait rather than overt lameness.

The retrospective design was a limitation of this study and the data could not be controlled. In horses presented with lameness in more than one limb, a primary and a compensatory lameness was identified with the help of diagnosis analgesia. However, there is a risk that horses with a true multiple limb lameness were included because in some cases a certain degree of asymmetry persisted after positive diagnosis analgesia of the primary lameness. There were many subgroups with variable numbers of horses of naturally occurring lameness patterns combined with concurrent lameness. Some of these subgroups were small, limiting the power of statistical analysis.

## 5 | CONCLUSIONS

Various asymmetry patterns of concurrent lameness were seen in horses with naturally occurring primary forelimb impact lameness, contralateral compensatory hindlimb lameness with a push-off and mixed component being the most common. In horses with hindlimb lameness, compensatory movements were seen in ipsilateral forelimbs, mostly as an ipsilateral push-off or impact lameness, during straight line trot was classified by the sensor system algorithm based on motion analysis.

### ETHICAL ANIMAL RESEARCH

This study was approved by the Ethics Committee of the Freie Universität Berlin.

### OWNER INFORMED CONSENT

Owners gave consent for their animals' inclusion in the study.

### ACKNOWLEDGEMENTS

We would like to thank our colleagues who were involved with helping during lameness examinations undertaken at Equine Clinic, Freie Universität Berlin. Open access funding enabled and organized by ProjektDEAL.

### CONFLICT OF INTERESTS

No competing interests have been declared.

### AUTHOR CONTRIBUTIONS

S. Phutthachalee; principal author, study design, data collection, preparation of the manuscript and final approval of the manuscript, K. Mählmann; manuscript preparation and revising the content, and final approval of the manuscript, S. Seesupa; study design, data analysis and interpretation, C. Lischer; senior author, contributed to the study design, revising the content and final approval of the manuscript.

## 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.13367.

## ORCID

*Suphannika Phutthachalee* https://orcid.org/0000-0003-1742-4005

## REFERENCES

1. Uhlir C, Licka T, Kubber P, Peham C, Scheidl M, Girtler D. Compensatory movements of horses with a stance phase lameness. Equine Vet J. 1997;29(Suppl 23):102–5.
2. Merkens HW, Schamhardt HC. Evaluation of equine locomotion during different degrees of experimentally induced lameness. I: lameness model and quantification of ground reaction force patterns of the limbs. Equine Vet J. 1988;20(Suppl 6):99–106.
3. Ratzlaff MH, Grant BD, Adrian M. Quantitative evaluation of equine carpal lamenesses. J Equine Vet Sci. 1982;2:78–88.
4. Clayton HM. Cinematographic analysis of the gait of lame horses. J Equine Vet Sci. 1986;6:70–8.
5. Ross MW. Chapter 7 - movement. In: Ross MW, Dyson SJ, editors. Diagnosis and management of lameness in the horse. St Louis: W.B. Saunders, 2003; p. 60–73.
6. Weishaupt MA, Wiestner T, Hogg HP, Jordan P, Auer JA. Compensatory load redistribution of horses with induced weightbearing hindlimb lameness trotting on a treadmill. Equine Vet J. 2004;36:727–33.
7. Weishaupt MA, Wiestner T, Hogg HP, Jordan P, Auer JA. Compensatory load redistribution of horses with induced weight-bearing forelimb lameness trotting on a treadmill. Vet J. 2006;171(1):135–46.
8. Weishaupt MA. Adaptation strategies of horses with lameness. Vet Clin North Am Equine Pract. 2008;24:79–100.
9. Kelmer G, Keegan KG, Kramer J, Wilson DA, Pai FP, Singh P. Computer-assisted kinematic evaluation of induced compensatory movements resembling lameness in horses trotting on a treadmill. Am J Vet Res. 2005;66:646–55.
10. Rhodin M, Pfau T, Roepstorff L, Egenvall A. Effect of lungeing on head and pelvic movement asymmetry in horses with induced lameness. Vet J. 2013;198(Suppl 1):e39–e45.
11. Maliye S, Voute LC, Marshall JF. Naturally-occurring forelimb lameness in the horse results in significant compensatory load redistribution during trotting. Vet J. 2015;204(2):208–13.
12. Maliye S, Marshall JF. Objective assessment of the compensatory effect of clinical hind limb lameness in horses: 37 cases (2011–2014). J Am Vet Med Assoc. 2016;249:940–4.
13. Baxter GM, Stashak TS. Examination for Lameness: History, visual exam, palpation, and manipulation. In: Baxter GM, editor. Adams and Stashak's lameness in horses, 6th edn. Ames, Iowa: Wiley-Blackwell, 2011; p. 109–50.
14. Keegan KG. Pelvic movement pattern in horses with hindlimb and forelimb lameness. Proc Am Assoc Equine Practnrs. 2005;51:121–7.
15. Keegan KG, Kramer J, Yonezawa Y, Maki H, Pai PF, Dent EV, et al. Assessment of repeatability of a wireless, inertial sensor-based lameness evaluation system for horses. Am J Vet Res. 2011;72:1156–63.
16. Maliye S, Voute L, Lund D, Marshall JF. An inertial sensor-based system can objectively assess diagnostic anaesthesia of the equine foot. Equine Vet J. 2013;45(Suppl 45):26–30.
17. McCracken MJ, Kramer J, Keegan KG, Lopes M, Wilson DA, Reed SK, et al. Comparison of an inertial sensor system of lameness quantification with subjective lameness evaluation. Equine Vet J. 2012;44:652–6.
18. Reed SK, Kramer J, Thombs L, Pitts JB, Wilson DA, Keegan KG. Comparison of results for body-mounted inertial sensor assessment with final lameness determination in 1,224 equids. J Am Vet Med Assoc. 2020;256:590–9.
19. Equinosis. Straight line AIDEs: a details look at evidence and amplitude. In: Tyrrell-Schroeder L , editor The equinosis with lameness locator. Columbia, MO: Equinosis; 2018.
20. Equinosis. The equinosis with lameness locaator: user manual. Veterinary Services, In: The Equinosis with Lameness Locator LL2017 vol 1.0 edn. Columbia, MO: Equinosis; 2017. p. 1–61.
21. Keegan KG, Dent EV, Wilson DA, Janicek J, Kramer J, Lacarrubba A, et al. Repeatability of subjective evaluation of lameness in horses. Equine Vet J. 2010;42:92–7.
22. Keegan KG, Wilson DA, Kramer J, Reed SK, Yonezawa Y, Maki H, et al. Comparison of a body-mounted inertial sensor system-based method with subjective evaluation for detection of lameness in horses. Am J Vet Res. 2013;74:17–24.
23. Merkens HW, Schamhardt HC, Van Osch GJ, Van den Bogert AJ. Ground reaction force patterns of Dutch warmblood horses at normal trot. Equine Vet J. 1993;25:134–7.
24. Morris E, Seeherman H. Redistribution of ground reaction forces in experimentally induced equine carpal lameness. Equine Exerc Physiol. 1987;2:553–63.
25. Buchner HHF. Gait adaptation in lameness. In: Back W, Clayton HM, editors. Equine locomotion. Edinburgh, Scotland: Saunders Elsevier; 2013. p. 175–97.
26. Bell RP, Reed SK, Schoonover MJ, Whitfield CT, Yonezawa Y, Maki H, et al. Associations of force plate and body-mounted inertial sensor measurements for identification of hind limb lameness in horses. Am J Vet Res. 2016;77:337–45.
27. Buchner HH, Savelberg HH, Schamhardt HC, Barneveld A. Head and trunk movement adaptations in horses with experimentally induced fore- or hindlimb lameness. Equine Vet J. 1996;28:71–6.
28. Stashak TS. Examination for lameness. In: Stashak TS, editors. Adams' Lameness in Horses, 5th edn. Philadelphia, Pennsylvania: Lippincott Williams & Wilkins, 2002; p. 113–83.
29. Keegan K. Head movement pattern in horses with forelimb and hindlimb lameness. Proc Am Assoc Equine Practnrs. 2005;51:114–20.
30. Khumsap S, Lanovaz JL, Rosenstein DS, Byron C, Clayton HM. Effect of induced unilateral synovitis of distal intertarsal and tarsometatarsal joints on sagittal plane kinematics and kinetics of trotting horses. Am J Vet Res. 2003;64:1491–5.
31. Keegan KG. How to use lunging and flexion tests to assist, but not detract from your lameness evaluation (Proceedings), dvm360.com. 2015.

## SUPPORTING INFORMATION

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

**How to cite this article:** Phutthachalee S, Mählmann K, Seesupa S, Lischer C. Upper body movement analysis of multiple limb asymmetry in 367 clinically lame horses. *Equine Vet J*. 2021;53:701–709. https://doi.org/10.1111/evj.13367