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Original Research

Riding Soundness—Comparison of Subjective With Objective Lameness Assessments of Owner-Sound Horses at Trot on a Treadmill

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ABSTRACT

Lameness is a symptom indicative of pain or injury of the locomotor apparatus. Lame horses generally should not be ridden. However, owners' ability to assess lameness has been questioned. This study's aim was to use subjective lameness assessments and objective gait analysis to generate a descriptive overview of movement and weight-bearing asymmetries of owner-sound riding horses. 235 horses were subjectively assessed in a field study, and the owner's perception of their horse's orthopedic health was recorded through an online survey. 69 horses were re-evaluated by gait analysis at an equine hospital. During trot on an instrumented treadmill, the gait was scored by a veterinarian using lameness grades from 0/5 (sound) to 3/5 (moderate lameness visible at trot). Movement asymmetry of the head (HDmin) and pelvis (PDmin) and weight-bearing asymmetry were quantified simultaneously. The prevalence of subjectively scored lameness grade ≥2/5 in one or more limbs was 55% during study part 1 and 74% during study part 2. Movement asymmetry of the head and/or pelvis exceeding HDmin ≥12 mm and/or PDmin ≥6 mm was found in 57% of the horses. 58% showed weight-bearing asymmetries between contralateral front and/or hind limbs of ≥3% body mass. Gait analysis showed considerable variability of movement and weight-bearing asymmetry values, sometimes independent of the clinical lameness grade, especially in the forehand. Several horses with lameness grade ≤1/5 had asymmetry values greater than mentioned thresholds. The analysis of movement and weight-bearing asymmetry revealed that these objective variables did not necessarily act uniformly and therefore should be interpreted with caution.

1. Introduction

The detection of mild lameness in horses can be challenging as alterations of the gait and signs of pain are often subtle. Based on previous studies, it is suggested that pain-related gait irregularities might go unnoticed in many riding horses [1–3]. It is a question of current research if owners are capable of noticing signs of illness in their equine companions. A recent study revealed that owners of geriatric horses generally underestimate the horses' health problems such as dental abnormalities, cardiac murmurs, lameness, and hoof abnormalities [2]. Accordingly, 75% of 57 and 46% of 506 owner-sound sports horses were deemed as noticeably lame in comprehensive subjective lameness examination [1,4].

However, visual lameness assessment appears less reliable for detecting subtle movement asymmetries when compared with objective movement analysis [5] and is hampered by interobserver disagreement [6–9]. Objective techniques to quantify gait asymmetries include optical motion capture (OMC) systems or inertial measurement units (IMUs), which consider the asymmetric movement patterns of the head, withers, and pelvis, analog to the anatomical areas observed during visual assessment, whereas ground reaction force (GRF) measurements consider the weight-bearing asymmetries between contralateral limbs.

Animal welfare/ethical statement: The experimental protocol was approved by the Animal Health and Welfare Commission and the Ethical Commission of the Canton of Zurich, Switzerland (TVB-Nr. ZH003/17-28698; BASEC-Nr. 2017-00188). All owners and/or participants gave written consent for their animals to be included in this study.

Conflict of interest statement: The authors declare no potential conflicts of interest. None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the article.

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In a study of 25 Thoroughbreds, the visual lameness scoring matched with IMU gait analysis with a specificity of 89% and 93% and a sensitivity of 69% and 90% for head and pelvic minDiff (differences between displacement minima), respectively [6]. Results of other studies objectively evaluating horses' motion patterns via IMUs indicated that 73% of 222, 56% of 201, and 61% of 23 owner-sound riding horses and >60% of 60 polo horses showed movement asymmetries greater than set lameness thresholds [3,10–12]. The definition of thresholds above which objectively measured movement asymmetries are classified as lameness needs careful consideration as it remains unclear to what extent asymmetries are related to pain, mechanical abnormalities, or laterality [13]. This leads to potential welfare problems: if threshold values are too high, lame horses might go unnoticed, whereas low threshold values could result in many orthopedically healthy horses being categorized as lame. False-positive identification of lame limb(s) can have wide-ranging effects when the horse is subjected to unnecessary and expensive procedures, for example, nerve-block anesthesia or diagnostic imaging.

This study aims to (1) provide an overview of the occurrence of lameness/gait irregularities in a riding-sound Swiss horse population, (2) determine the agreement in the identification of a presumably affected limb between subjective and objective gait assessments, and (3) assess how well the objectively measured data correlate with the subjectively determined lameness grades, and between each other. We hypothesize that the more subtle an asymmetry is, the lower is the subjective lameness grade and the agreement between the three assessments. Furthermore, we assume that front limb lameness can be detected more reliably than hind limb lameness.

2. Material and Methods

2.1. Study Design

In the context of a nationwide equine health study in Switzerland [14,15], a voluntary online survey was completed by 248 horse riders/owners (defined as the horse's main rider) regarding *i.a.* their horse's orthopedic health, previous injuries, fitness, well-being, and performance level. Participants were recruited through print media (Swiss horse magazines), and horse owners registered with the official Swiss database were contacted by email. Inclusion and exclusion criteria, recruitment process, and details of included horses have been published previously [14,15]. Of 420 interested owners, 248 registered for one of the offered appointments and were given access to the survey 10 days before the examination day. The questionnaire had to be completed within the 5 days before the examination day. For this study, only two questions regarding orthopedic issues were considered: (1) "Does your horse show a lameness or gait irregularity?" (answer options: "*yes, sometimes*"/"*no*") and (2) "Can you observe a lameness in your horse?" (answer options: "*yes*"/"*no*"/"*uncertain*").

237 of these participants presented their horses for an examination at one of eight different equestrian centers across Switzerland (part 1), with the prerequisite that the horses were in regular use without limitations and therefore deemed "riding-sound" based on the assessment by their owners. Two of these horses had to be excluded because of lameness greater than grade 3/5, which resulted in 235 horses undergoing the full examination. The field study comprised *i.a.* a subjective gait assessment at walk and trot in hand, on hard and level surface. 69 of the participants followed the invitation to a second, more detailed examination (part 2) including *i.a.* an objective gait assessment at the Equine Hospital at the University of Zurich. On this occasion, the owners were asked again, if their horses were sound and in normal use, before evaluating the gait subjectively, and with synchronized OMC and GRF measurements on an instrumented treadmill at walk and trot. The veterinarian was blinded for the outcome of the lameness examination of study part 1 and the objective data of movement and weight-bearing asymmetries while evaluating the horses' gait subjectively. Exactly the same sequence of steps in steady state was considered as taken into account for kinetic (GRF) and kinematic (OMC) measurements. Owing to logistic reasons, the time span between study parts 1 and 2 varied between horses (mean = 130 ± 58 days, range: 5–266 days).

2.2. Horses

In the second study part, 75.4% (n = 52 of 69) of the horses were warmblood type horses (others: three Quarter Horses, three Pura Raza Español, two Franches-Montagnes, two Ponies, two Arabians, one Partbred-Arabian, one American Paint Horse, one Icelandic Horse, one Mix-Breed, and one Thoroughbred). There were 36 geldings, 31 mares, and 2 stallions with an age distribution of 5–18 years (mean ± SD: 10.1 ± 2.8), withers height of 140–178 cm (164 ± 7.2), and a body mass (BM) of 362–693 kg (549 ± 62.1). A proportion of 58% (n = 40) of horses competed regularly at equestrian competitions and were ridden by self-declared ambitious sports riders of various disciplines. The others were owned by self-declared leisure riders.

2.3. Subjective Gait Assessment

In study part 1, each horse was presented in hand on a straight line, on hard surface at walk and trot. Two experienced veterinarians (diplomates of the American College of Veterinary Sports Medicine and Rehabilitation) assessed the horses simultaneously and agreed on a grade for each limb ranging from 0/5 (sound) to 3/5 (moderate lameness). The exact definition of each lameness grades is described elsewhere [16,17]. Horses with clinical lameness greater than grade 3/5 were excluded from the study (n = 2 in study part 1). In study part 2, the subjective lameness grades included in the analysis were based on a visual assessment on the treadmill, which happened simultaneously to the kinetic and kinematic measurements.

2.4. Gait Analysis and Data Processing

Before the measurements, horses were habituated to walk and trot on a treadmill (Mustang 2200, Ansorix Systems AG, Switzerland) using a standardized protocol [18]. Vertical movement of the head (poll marker) and pelvis (tuber sacrale marker) were measured with an OMC system (Oqus 7+, Qualisys AB, Sweden) and vertical GRFs with an instrumented treadmill [19]. Data collection was performed with Qualisys Track Manager, (QTM, Qualisys AB, Sweden) for OMC at a sampling frequency of 240 Hz and with HP2 (University of Zurich, Switzerland) for GRF at 480 Hz. Measurement systems were started synchronously as soon as the horse trotted calmly in steady state at 3.6 m/second, aligned and centered on the treadmill using lead ropes attached on either side of the halter [20]. Measurements during which the horse stumbled or visibly changed its relative position on the treadmill were rejected. For each horse, data of approximately 15–31 (25 ± 2.6) continuous strides were collected during a 20-second measurement. Technical details of the instrumented high-speed treadmill and raw data processing are described elsewhere [19], and this methodology has been applied in numerous previous studies [8,16,17,19–21]. Weight-bearing asymmetry between contralateral limbs was calculated as difference of the mean vertical force peaks (dFz_{peak}) and expressed as a percentage of the BM. Movement asymmetry variables HDmin and

PDmin were calculated as the differences (D) between displacement minima (min) of the head (H) and pelvis (P) during contralateral stance phases. Asymmetric head movement, quantified by HDmin, is commonly used as an indicator for front limb lameness and asymmetric pelvis movement, quantified by PDmin, as indicator for hind limb lameness [22–24]. For both kinetic and kinematic data, negative values indicated that the (presumably) affected limb was on the left side, positive values indicated that the (presumably) affected limb was on the right side. However, based on this method, even minute deviations from zero resulted in the identification of a presumably affected limb, although the magnitude of the asymmetry might not have been clinically distinctive. Therefore, the data were additionally analyzed by applying thresholds to exclude cases with minute asymmetries. Based on published data of sound horses [20] and horses with induced lameness [16,17], a kinetic threshold of ≥3% $|dFz_{peak}|$ for front and hind limbs was applied.

The previously suggested kinematic thresholds of ≥6 mm |HDmin| and ≥3 mm |PDmin| [25] have been used for an IMU-based system in various studies. The algorithm used when these thresholds were determined is not publicly known and might therefore not be directly applicable to our OMC-based calculations. However, another IMU system that has had its positional calculation validated against an OMC has been compared with the system used by McCracken et al., 2012 [25]. This comparison revealed that the variable calculations were approximately doubled [26,27]. Based on this, we defined ≥12 mm for |HDmin| and ≥6 mm for |PDmin| as the OMC kinematic threshold, which were applied to distinguish between objectively sound and asymmetric horses.

2.5. Statistical Analysis

Agreements and associations between measurement methods were calculated separately for front and hind limbs. To calculate the agreement of the identification of the side of a presumably affected limb between the subjective and the objective assessments, horses which were deemed sound during the subjective assessment (grade 0/5) were excluded from the analysis (n = 13 in the front; n = 13 in the hind). For the remaining horses, it was determined if the presumably affected limb was on the left (L) or the right (R) based on the subjective assessment. A directional subjective grade was assigned to each horse, where negative grades (-1 or -2) indicated that the left limb was affected, whereas a positive grade (1 or 2) indicated that the right limb was affected. Agreement of the identification between subjective and objective measurements was calculated with and without the application of aforementioned thresholds.

The correlation of different asymmetry variables (subjective grade, kinematic and kinetic variables) was tested with linear models. Correlations for front and hind limbs were tested separately. Directional subjective lameness grade of the front or hind limb was used as dependent variable, whereas dFz_{peak} of the front/hind limb or HDmin/PDmin were used as a fixed factor. To test for correlation between objective values, we used HDmin/PDmin as a dependent variable and the dFz_{peak} of front/hind limbs as a fixed factor. To determine if the magnitude of the subjective lameness grade correlated with the objective measurements, all objective measurements from horses, which were subjectively deemed to have a presumably affected left limb, were mirrored by multiplying them by -1. For horses graded with 0/5, data remained untransformed.

Finally, we calculated how many horses subjectively graded as sound or slightly irregular (grades 0/5 and 1/5) showed objectively measured values greater than the mentioned thresholds and how many horses graded as mildly or moderately lame (grade 2/5 and 3/5) showed objective values less than the thresholds.

All analyses were carried out in R Studio, 3.4.4. Significance levels were set to $P = .05$.

3. Results

3.1. Descriptive Results of Study Parts 1 and 2

3.1.1. Owners' Awareness

42.6% of the owners held a license of the Swiss Equestrian Sport Federation, and 73.6% reported that they regularly visited informational events on equine topics. The participants had started riding at an average age of 10.3 ± 6.7 years, and on average, they had been riding for 25.6 ± 10.2 years at the time of the study and 71.9% of them reported that they rode at least 5 times per week. 31.5% stated that their horse had been diagnosed with an orthopedic issue in the past. In the online survey, 22.6% (n = 53 of 235) of owners/riders reported that their horse sometimes showed lameness or gait irregularity (question 1, answer option: "*yes, sometimes*"). However, no one answered question 2 ("Can you observe lameness?") with "*yes*" and only 4.7% (n = 11 of 235) answered "*uncertain*".

In comparison with the results of the subjective lameness examination (study part 1), these horses suspected as occasionally lame by their owners were indeed scored with a lameness grade ≥2/5 in 52.8% (n = 28 of 53) of the cases. The horses considered sound by their owners (as they answered question 1 with "*no*") were subjectively scored ≥2/5 in 54.9% (n = 100 of 182) of the cases, including two horses with grade 3/5.

3.1.2. Prevalence of Lameness/Gait Irregularities

Subjectively assessed lameness grade ≥2/5 in at least one limb was found in 54.5% of the horses examined in study part 1 (n = 128 of 235). Detailed results of the lameness assessment are presented in Table 1.

3.1.3. Descriptive Results of Study Part 2

The equestrian experience of the subgroup of owners in study part 2 was comparable to the one of study part 1: 43.5% held a license of the Swiss Equestrian Sport Federation and 75.3% of them reported that they regularly visited informational events on equine topics. The participants had started riding at an average age of 10.1 ± 7.0 years, and on average, they had been riding for 26.77 ± 10.4 years at the time of the study, while 76.8% of them reported that they rode at least 5 times per week. 46.4% stated that their horse had been diagnosed with an orthopedic issue in the past. An overview of the results of the subjective assessment and the mean

Table 1
Prevalence of subjective lameness grades of 235 horses assessed in study part 1; n (%).

Lameness Grade	Front	Hind	Overall
Not more than 0/5	118 (50.2%)	51 (21.7%)	25 (10.6%)
Not more than 1/5	66 (28.1%)	84 (35.7%)	82 (34.9%)
Not more than 2/5	50 (21.3%)	98 (41.7%)	125 (53.2%)
Not more than 3/5	1 (0.4%)	2 (0.8%)	3 (1.3%)

The columns Front and Hind denote the number of horses, where the highest grade of subjectively recorded lameness for the limb pair(s) did not exceed the lameness grade stated in the first column. The column Overall denotes the number of horses, where the highest grade of subjectively recorded lameness for either limb pair did not exceed the lameness grade stated in the first column. Therefore, this is not necessarily the sum of the numbers of Front and Hind. For example, 25 horses were sound on all four limbs, whereas 51 horses were sound in the hind limbs but not necessarily in the front limbs.

values of the objective measurements of horses in study part 2 are presented in Table 2. For the average objective values in relation to subjective lameness grade, see Supplementary Item 1. The prevalence of lameness grade ≥2/5 in at least one limb was 73.9% (n = 51 of 69). There were 15 horses with findings grade ≥2/5 only in one front limb and 22 horses with findings grade ≥2/5 only in one hind limb. 14 horses had findings grade ≥2/5 in one front and one hind limb. The remaining horses had grades ≤1/5. In the subjective lameness assessment, there was no case of bilateral lameness observed.

56.5% (n = 39 of 69) of horses showed movement asymmetries greater than mentioned thresholds for HDmin and/or PDmin, and 58% (n = 40 of 69) showed weight-bearing asymmetries greater than the 3% BM threshold. In total, 68.1% (n = 47 of 69) of the horses exceeded the thresholds for kinematic and/or kinetic values.

3.2. Agreement in the Identification of the Presumably Affected Limb

Without applying the thresholds to the objective data, the presumably affected front limb identified during the subjective assessment corresponded in 79.2% of the cases (n = 42 of 53), with the presumably affected front limb based on HDmin. For PDmin, the agreement with subjective assessment was 80.4% (n = 45 of 56). For dFz_{peak}, the agreement with subjective assessment in the front was 77.4% (n = 41 of 53) and in the hind 66.1% (n = 37 of 56) (Fig. 1).

Fig. 2 visualizes agreement between different methods including thresholds. After applying the aforementioned thresholds to kinetic and kinematic data, 25 of 69 horses remained for HDmin, 23 for PDmin, 27 for dFz_{peak} front, and 21 for dFz_{peak} hind. In the front limbs, the subjective identification of a presumably affected limb agreed in 84% (n = 21 of 25 horses) with the OMC measurement and in 82% (n = 22 of 27 horses) with the GRF measurement. In the hind limbs, the agreement for subjective assessment with OMC was 87% (n = 20 of 23) and 71.4% (n = 15 of 21) with GRF.

3.3. Correlation Between Subjective and Objective Assessments

3.3.1. Correlation of Objective Measurements With Subjectively Assessed Lameness Grades

The values of movement and weight-bearing asymmetry in relation to clinical lameness grades are presented in Fig. 3. Absolute values of objective variables are described in Table 3.

There was a positive correlation of directional subjective lameness grading (ranging from -3 to +3) with HDmin in the front limbs ($P < .001$, $R^2 = 0.40$) and with PDmin in the hind limbs ($P < .001$, $R^2 = 0.44$). Based on this correlation, an increase in one lameness grade in the front or hind limb corresponded to an average increase of 6.6 mm in HDmin and 3.2 mm in PDmin.

Similarly, there was a positive correlation of directional subjective lameness grades with dFz_{peak} in the front ($P < .001$, $R^2 = 0.42$) and hind limbs ($P < .001$, $R^2 = 0.22$). Based on this correlation, an increase in one lameness grade in the front or hind limb corresponded to an average increase of 1.7% BM in the front and 1.1% BM in the hind limbs.

3.3.2. Correlation of Kinetic and Kinematic Data

There was a positive correlation between the two objective measurements HDmin and dFz_{peak} in the front limbs ($P < .001$, $R^2 = 0.42$) and for PDmin and dFz_{peak} in the hind limbs ($P < .001$, $R^2 = 0.55$) (Fig. 4). Based on these correlations, a shift of 1% BM between contralateral front limbs corresponded to an average increase of 2.6 mm in HDmin and between hind limbs to an average increase of 1.5 mm in PDmin.

The comparison of both objective methods had several cases of disagreement in identifying the affected limb: 32% in the front and 18.8% in the hind.

3.3.3. Relationship of Thresholds for Objective Data With Subjectively Assessed Lameness Grades

The direct comparison of kinetic (dFz_{peak}) and kinematic (HDmin, PDmin) values in Fig. 4 revealed that there were several grade ≥2/5 horses (front: 31.3%, n = 10 of 32 horses within threshold box; hind: 38.5%, n = 15 of 39). Outside the objective threshold box were numerous horses subjectively graded as ≤1/5 (front: 48.6%, n = 18 of 37 horses outside threshold box; hind: 30%, n = 9 of 30).

4. Discussion

4.1. Owner Awareness

Owner's perception of their horse's orthopedic health appeared to deviate from the results of subjective and objective lameness assessments. One quarter of the owners reported an occasional lameness in their horse, but only half of these horses actually showed lameness grade ≥2/5, whereas approximately half the horses deemed sound by their owners were subjectively scored ≥2/5, including two horses with grade 3/5. However, the result of this study should be interpreted with caution. Some horses that were sound based on the veterinary assessment might have had an orthopedic problem that only manifested during riding, whereas some horses that presented with mild lameness might have moved symmetrically when ridden.

Table 2
Results of subjective assessment and absolute mean values of objective measurements of the 69 horses in study part 2.

	Front	Hind	Overall
Prevalence of subjective lameness grades; n (%)			
Not more than 0/5	16 (23.3%)	13 (18.8%)	3 (4.3%)
Not more than 1/5	24 (34.8%)	20 (29%)	15 (21.7%)
Not more than 2/5	27 (39.1%)	33 (47.8%)	46 (66.7%)
Not more than 3/5	2 (2.9%)	3 (4.3%)	5 (7.2%)
Kinematic data; mean ± SD (range)			
HDmin (mm)	11.2 ± 9.3 (0.1-41.4)	—	—
HDmax (mm)	12.0 ± 8.6 (0.7-36.9)	—	—
PDmin (mm)	—	5.3 ± 5.0 (0.1-24.4)	—
PDmax (mm)	—	5.9 ± 5.6 (0.02-26.3)	—
Kinetic data			
dFz_{peak} (%BM)	2.9 ± 2.3 (0.02-10.8)	2.7 ± 2.1 (0.03-11.3)	—

Abbreviation: BM, body mass.

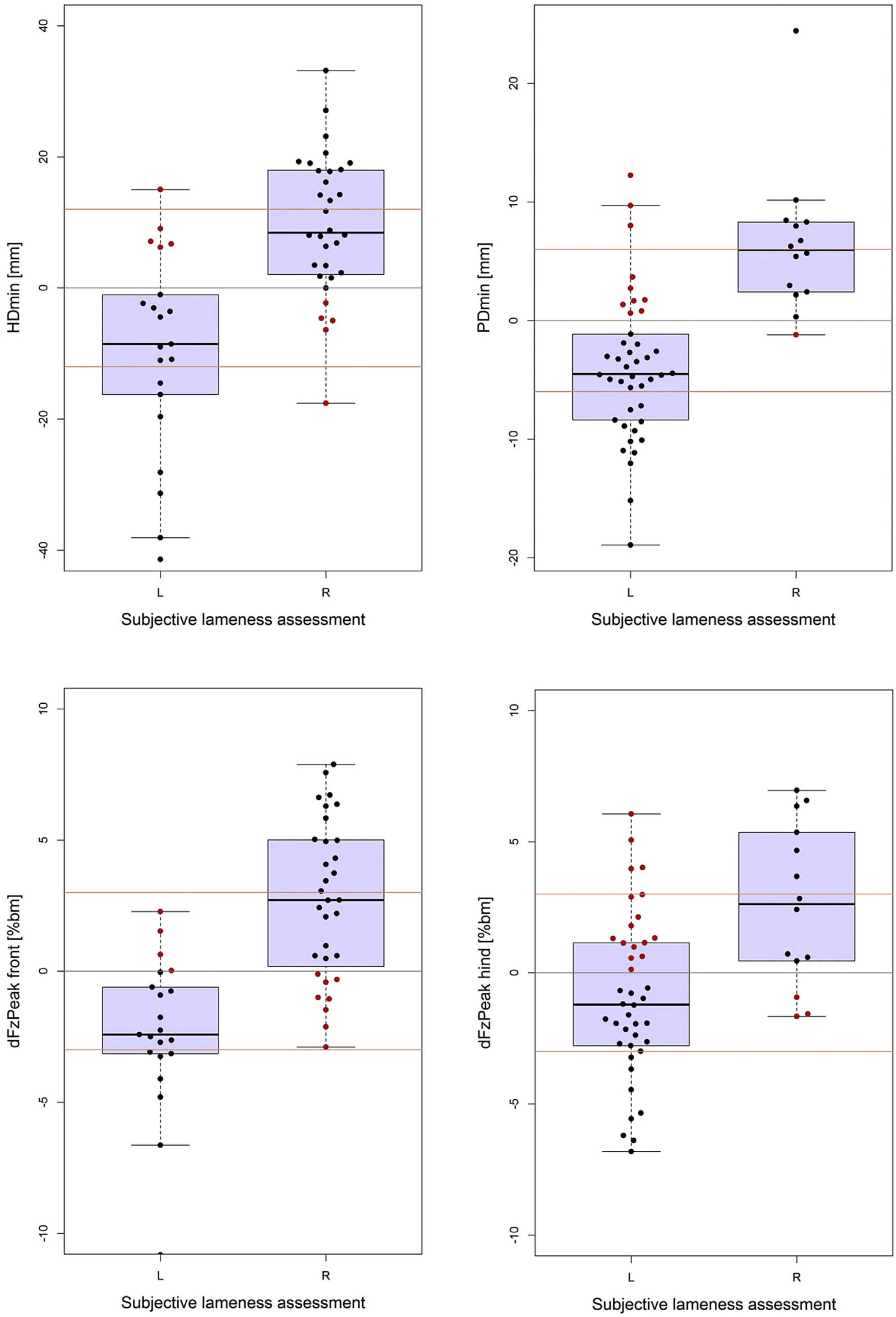

Fig. 1. Agreement of subjectively assigned affected limb with the corresponding objective data of OMC and GRF. Data points colored in red indicate cases of disagreement between subjective and objective assessment. Subjectively assessed sound horses (grade 0/5) were excluded in this graph; n = 53 for horses with findings in the front limbs; n = 56 for horses with findings in the hind limbs. The upper and the bottom lines of the box indicate the 25th and 75th percentiles, respectively. The whiskers mark 1.5 time the quartile's range. The thick black line indicates the median. L, left-sided lameness grade 1-3/5; R, right-sided lameness grade 1-3/5; GRF, ground reaction force; OMC, optical motion capture.

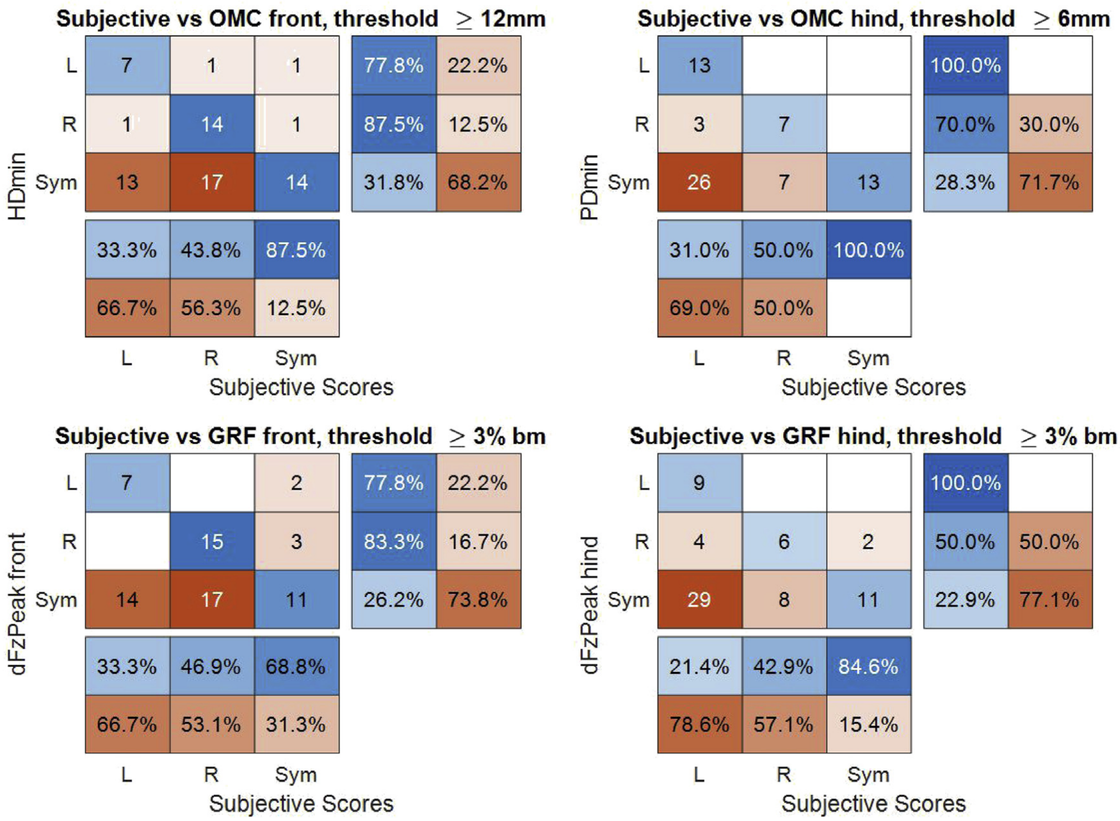

Fig. 2. Agreement of subjective lameness assessment with OMC and GRF measurements for the front and hind limbs (n = 69). Horses classified as L or R in the objective measurements exceeded the respective thresholds; horses classified as Sym had values less than the thresholds. Blue fields indicate agreement of assessment, and red fields indicate disagreement of assessments. The darker the shading, the higher the percentages. L, left-sided lameness; R, right-sided lameness; Sym, symmetric gait; GRF, ground reaction force; OMC, optical motion capture.

The sample of participants might also have been biased by the exclusion criteria of the study. On the one hand, owners who correctly suspected a severe orthopedic issue in their horses would not have been able to participate because of the exclusion criteria of the study (horses not grade >3/5 lame, ≤18 years, ridden at least twice a week, free of acute diseases). On the other hand, some owners might have been aware of an orthopedic issue, which they belittled because of their motivation to participate in the study. It has previously been shown that online surveys are prone to a self-selection bias of the respondents [28]. There is evidence that persons who suspect to suffer from a disease are more likely to participate in a study about the disease [29] and one can expect that the same applies with regard to their animal's health. Subtle lameness or gait irregularities might have motivated some riders to participate to clarify the orthopedic status, in particular with regard to the comprehensive check-up in study part 2. The group of horses subjectively scored grade ≥2/5 in one or more limbs increased from 54% in study part 1 to nearly 75% in study part 2 and the proportion of owners who stated that their horse had been diagnosed with an orthopedic issue in the past, rose from 32% in study part 1 to 46% in study part 2. This would imply that owners of lame horses had a stronger interest in further diagnostics and results of this study might therefore not be directly transferrable to the national population. Actively inviting a randomly selected sample of the national population might have yielded different and more representable results.

Another explanation for the higher proportion of horses scored ≥2/5 in the second study part could be observer bias. It is well known that an experimenter's expectation of the study's outcome can impact the results (e.g., discussed in the study by Tuyttens et al [30]). The aim of study part 1 was merely a description of the population's general health, whereas it was obvious to the veterinarian that the focus of study part 2 was on detecting gait irregularities. The assessing veterinarian might therefore have been more critical than in the general health examination in study part 1. It should also be noted that the subjective lameness assessment in study part 2 was carried out with the horse on the treadmill, where it was moving at a constant speed and in direct, constant proximity of the assessor, which would have enabled the veterinarian to detect even subtle irregularities that might have been undetectable during the over ground assessment.

If the prevalence of grade ≥2/5 is representative for the Swiss horse population, it would be of similar magnitude as the prevalence published in previous studies in the United Kingdom [1,4]. However, in contrast to these publications, this study excluded horses with lameness greater than grade 3/5, which means that the number of owner-sound horses with orthopedic findings could in fact been even higher [1–4,12].

A prevalence of 54% (study part 1), respectively nearly 75% (study part 2) of grade ≥2/5 lameness indicates that this extent of lameness is poorly recognized by the owners. To set this in relation, one should consider that riders hardly ever see their horse trotting in hand on a straight line, which would enable them to validate soundness as a matter of routine. It would be interesting to compare the awareness of riding horse owners to that of driving horse owners, who can regularly observe their horse moving in a straight line from behind. It should also be noted that many horse owners have never had appropriate training in the recognition of

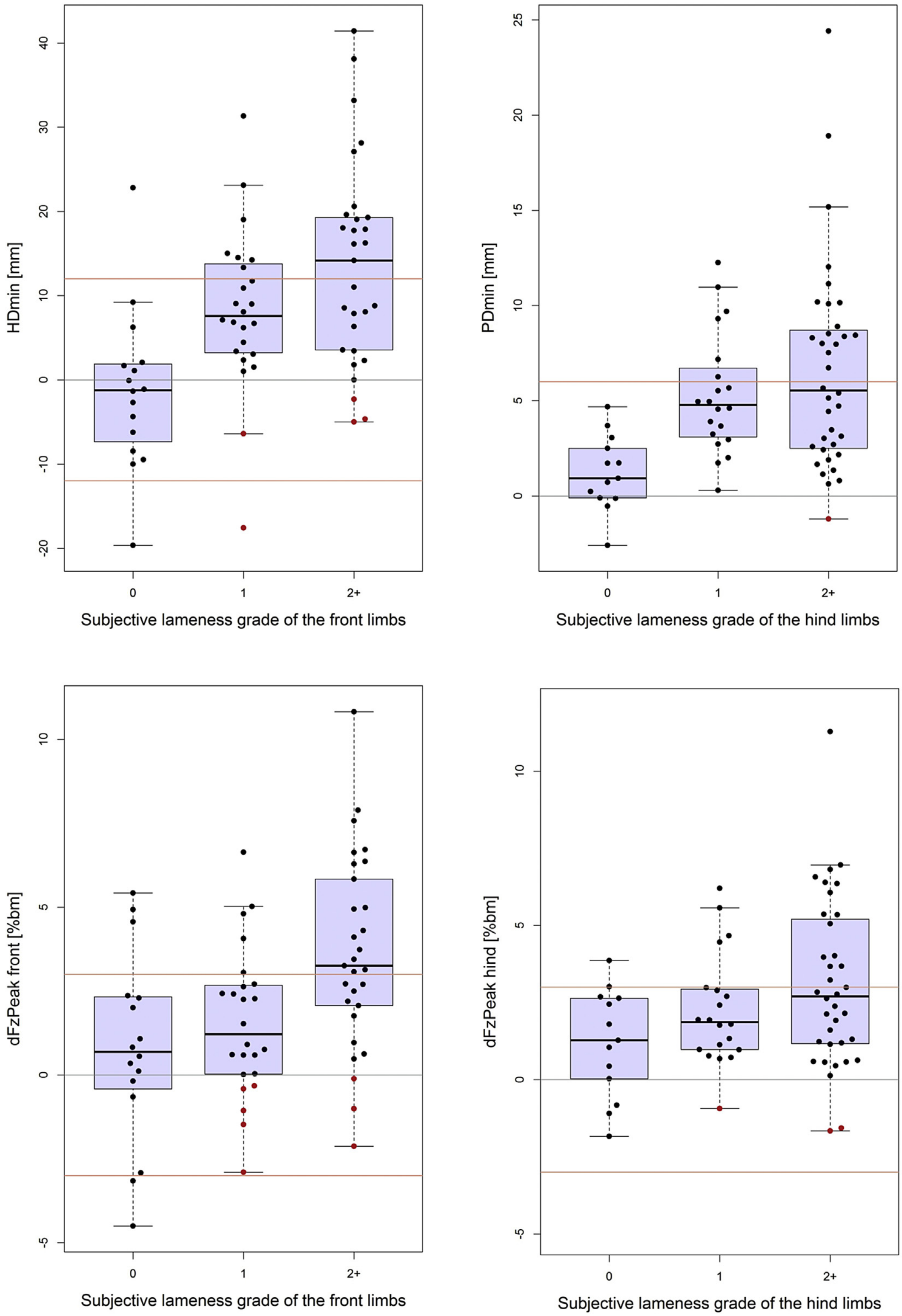

Fig. 3. Association between objective OMC and GRF measurement and subjective lameness assessment of the front and the hind limbs. Red-colored data points indicate cases of disagreement in identifying a presumably affected limb. GRF, ground reaction force; OMC, optical motion capture.

lameness. Research in various livestock species has shown that the interrater agreement in gait scoring improves with experience and training [31–34]. Taken together, this implies that educating horse owners in gait scoring could improve their ability to recognize mild lameness.

From a veterinary perspective, it is a fact that intermittent mild lameness in everyday life is usually not examined further and it should also be considered that the degrees of lameness in the Swiss riding horse population is not nearly comparable with, for example, severe health issues of working horses in less wealthy regions of

Table 3
Absolute values (mean ± SD) of the objective measurements per lameness grade (n = 69 horses).

	Front			Hind		
Lameness Grade	N	|HDmin|	|dFz_{peak}|	N	|PDmin|	|dFz_{peak}|
0/5	16	6.7 ± 6.4 mm	2.2 ± 1.8% BM	13	1.7 ± 1.4 mm	1.8 ± 1.1% BM
1/5	24	10.2 ± 7.2 mm	2.1 ± 1.7% BM	20	5.3 ± 3.1 mm	2.3 ± 1.6% BM
2/5	27	13.3 ± 9.9 mm	3.8 ± 2.6% BM	33	6.0 ± 4.8 mm	3.0 ± 2.1% BM
3/5	2	30.3 ± 11.1 mm	5.4 ± 1.3% BM	3	13.7 ± 3.8 mm	6.5 ± 3.8% BM

Abbreviation: BM, body mass.

the world [35]. However, we did not consider the full range of clinically lame horses but focused on riding-sound horses only. Investigating a random sample of the Swiss horse population, regardless of their owner's perception of their health, and including broodmares, racing horses and driving horses might have changed the outcome.

4.2. Correlation of Methods

4.2.1. Agreement Between Subjective and Objective Methods

The results of the three lameness examination methods correlated positively with each other. Asymmetries exceeding the objective thresholds of OMC and/or GRF agreed well with the subjective assessment in identifying a presumably affected limb in at least 71% of the cases. The applied thresholds corresponded closely to the mean asymmetry values in horses with grade ≥2/5: HDmin 14.5 mm (threshold ≥12 mm), dFz_{peak} front 3.9% BM (threshold ≥3% BM), PDmin 6.6 mm (threshold ≥6 mm), dFz_{peak} hind 3.3% BM (threshold ≥3% BM). This implies that horses with objectively quantified asymmetry values greater than the threshold should receive further attention from the veterinarian and possibly undergo further diagnostics. However, the question of how much objectively measured asymmetry is acceptable remains unanswered. For example, it has been suggested that small amounts of measured head and pelvic asymmetries should not automatically be regarded as a sign of lameness [10] but could relate to conformational asymmetries or laterality. The cases in which even the objective methods disagreed in identifying a presumably affected limb demonstrated that threshold values alone must not be the only criterion based on which the horse's outcome is decided. Small asymmetries less than the thresholds require careful interpretation too, as in three quarters of the horses with less than the threshold values, the classification of either a presumably affected limb on the left or right side or soundness was not congruent between objective and subjective methods.

Whereas the subjective lameness assessment could be biased by a setting of expected high prevalence (i.e., a veterinarian assessing a horse with report of lameness in the clinic or in this case with focus

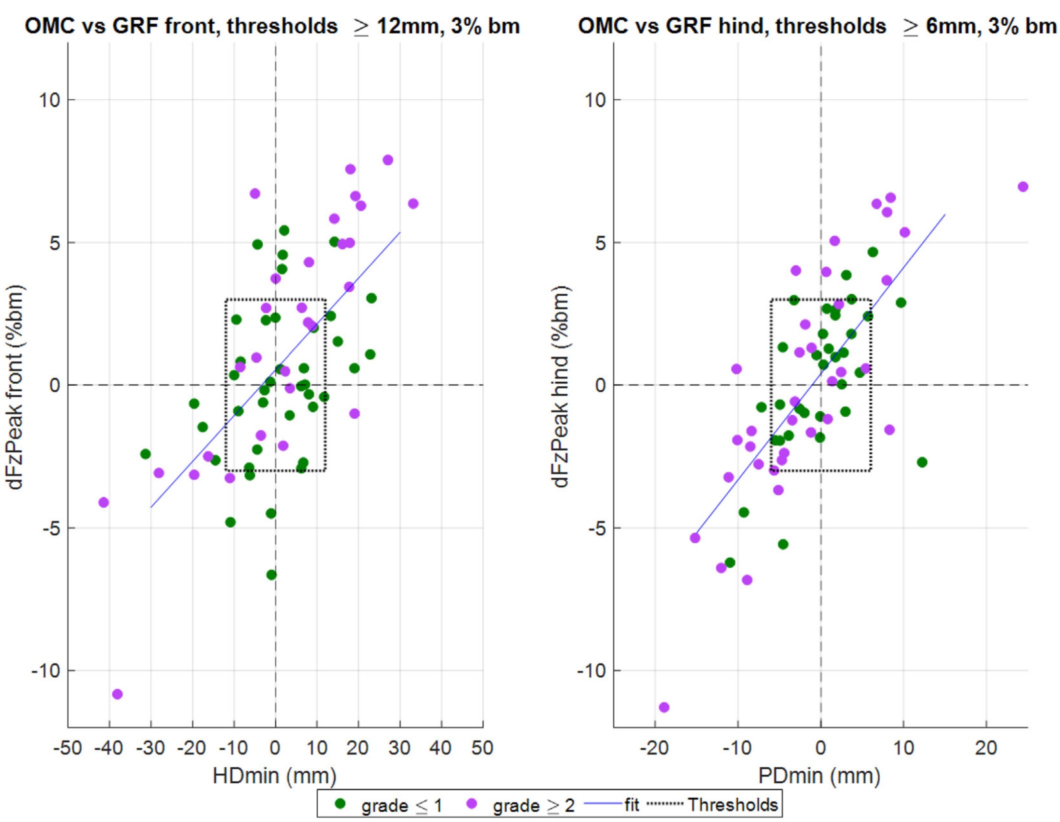

Fig. 4. OMC versus GRF of the front (left) and hind limbs (right), considering the thresholds. The box indicates the mentioned thresholds, which were applied to the data: 3% BM for GRF, 12 mm for HDmin, 6 mm for PDmin. Data points are further categorized and color-coded by lameness grades: grade ≤1/5 (green) versus grade ≥2/5 (purple). BM, body mass; GRF, ground reaction force; OMC, optical motion capture.

on a comprehensive gait analysis), the objective asymmetry screening using OMC or GRF enables the unbiased identification of horses exceeding the expected normal variation. Figs. 2 and 4 revealed that there are several horses, which were deemed as sound based on the objective thresholds, but which were deemed as lame by the veterinarian. This further supports the presence of an observer expectancy bias in the setting of a gait laboratory.

The agreement in identifying the more asymmetric limb was slightly higher between subjective grades and OMC than between subjective grades and GRF. This can be explained by the fact that both methods (subjective, OMC) focus on movement asymmetries in the form of compensatory patterns in the same anatomical regions (poll, croup), while GRF measurements quantify the actual weight-bearing asymmetries, which cannot be directly assessed by the observer.

Contrary to the hypothesis that hind limb lameness might be more difficult to assess, the agreement of methods in hind limb lameness was slightly better than in the forehand. There was considerable variability of movement and weight-bearing asymmetry values in the forehand, sometimes independent of the clinical lameness grade. We suspect that the reduced agreement in the forehand might be due to the measurable mobility of the head and neck, and the absolute longer distance between front limbs and the poll, whereas the marker on the croup is situated in short distance directly above the hind limbs [36].

Some disagreement between objective and subjective assessment might be explained by the general constitution of the human visual system, which has limitations in detecting changes [37] and by the fact that visual assessment is often less sensitive than technology [25]. It has been shown that at least around 20% relative asymmetry of movement is needed for consistent visual detection of lameness [5]. These might be the main reasons why subtle lameness are inherently difficult to quantify. We believe that the subjective lameness assessment on the treadmill is advantageous to straight-line lameness assessment over ground as the horses move more regularly in close proximity to the observer. Although a slight modification of gait is possible, there is no source for distraction for the horse and acceleration and deceleration can be controlled.

4.2.2. Agreement Between Kinetics and Kinematics

The two objective methods had several cases of disagreement in identifying the presumably affected limb (32% in the front and 18.8% in the hind). Rather than considering this as an error, it should be acknowledged that the two systems measure different things. As horses shift a variable amount of BM from a painful limb to the contralateral unaffected limb, weight-bearing asymmetries in GRF can be seen as a direct quantification proportional to the degree of discomfort or pain [16,17], which is why GRF is considered the gold standard. However, the degree of compensatory movement as a consequence of this weight shift might differ between individual horses and the origin of pain, which would explain some deviation from a perfect correlation between movement and weight-bearing asymmetries.

4.3. Clinical Relevance and Outlook

The results of this study demonstrate the importance of the interaction between qualitative and quantitative assessment and the need for a systematic approach to reliably diagnose lameness. With regard to animal welfare and to avoid misleading treatment, the highest priority of a lameness assessment should be to prevent false identification of the affected limb. Considering that the inter-rater reliability of equine veterinarians in subjective lameness evaluation is 76.6% [7], applying only one assessment method in mildly lame horses appears insufficient. Whenever possible, more than one diagnostic method should be applied to double check if the presumably affected limb is identified correctly, to minimize treatment errors. While we had the comfortable situation to simultaneously assess the horses subjectively and with two complementary gait analysis systems, other measurement systems such as IMU might be more applicable in other clinical settings.

Further investigations on how the different measurements of asymmetry change in horses with subtle lameness after nerve blocking or treatment [38] could help distinguish pain-related gait irregularities from natural asymmetries such as laterality.

5. Conclusions

Approximately half of the owners were not able to identify low to moderate grade lameness in their own horses. This suggests that there is a need for training owners in lameness recognition.

In general, there was moderate agreement and positive correlation of subjective with objective methods, but there were also cases of disagreement. Subjective data for subtle lameness grade $\leq$1/5 did not always have low objective asymmetries. The analysis of movement and weight-bearing asymmetry revealed that the two objective parameters did not necessarily act uniformly and therefore should be interpreted with due consideration. However, the more obvious a gait irregularity was, the better was the agreement of methods.

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Supplementary Data

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