An objective study into the effects of an incline on naturally occurring lameness in horses

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Abstract
Background: The clinical examination of lame horses in real world settings often requires the use of sloped surfaces.
Objectives: This pilot study aimed to evaluate the effects of uphill and downhill locomotion on asymmetry in horses with naturally occurring lameness affecting forelimbs and hindlimbs.
Methods: Ten horses (8–19 years) with forelimb lameness and eight horses (7–16 years) with hindlimb lameness were fitted with inertial sensors at the poll, withers, sacrum and both tuber coxae. Data were collected whilst the horses were trotted in hand on a level surface (<0.7%), as well as up and down a minor slope of 2.4%. Data were collected for a minimum of 25 strides at each incline type. Effect of incline was compared using a repeated measures ANOVA and, where significant, a subsequent Bonferroni’s multiple comparisons.
Results: Of the horses with hindlimb lameness, there were reductions in asymmetry seen during downhill locomotion when compared with trotting on the flat (flat: 6.6 ± 4.4 mm to downhill: 1.9 ± 2.9 mm; p = 0.015) and when compared with uphill locomotion (8.4 ± 4.3 mm; p = 0.007). Horses with forelimb lameness showed no significant difference in asymmetry. However, there were considerable changes in poll asymmetry (>20 mm) among conditions in individual horses. Two horses with hindlimb lameness and two horses with forelimb lameness switched asymmetry between left and right by changing incline.
Conclusions: These results confirm that incline can be an influential factor in the assessment of lame horses. Further work is justified to elucidate the types of pathology associated with the most relevant changes in asymmetry which would allow the use of an incline to prioritise a list of differential diagnoses.

KEYWORDS
equine, biomechanics, lameness, incline
1 | INTRODUCTION

A thorough and comprehensive lameness examination is a key component of the investigation of poor performance in horses (Davidson, 2018; Mitchell, 2012). Mild or bilateral lameness is a common differential diagnosis for poor performance in an equine athlete and its accurate diagnosis can be challenging. There are many factors affecting the ability and reliability of the detection of lameness. Understandably, the degree of lameness has a marked impact on the ability of clinicians to correctly identify the affected limb (Fuller et al., 2006). For horses with mild lameness, agreement between clinicians was achieved in 93.1% of cases but for more severe lameness, agreement was only found in 61.9% of cases (Keegan et al., 2010). The experience of the clinician performing the examination has also been identified as significant in the ability to detect and identify lameness (Arkell et al., 2006; Parkes et al., 2009). Experienced clinicians have been shown to have better agreement with objective gait analysis (Leelamankong et al., 2020) and with each other (Hammbarge et al., 2016). Differences between the ability to detect forelimb vs. hindlimb lameness have also been demonstrated with clinicians consistently finding hindlimb lameness detection more challenging (Hammbarge et al., 2016; Keegan et al., 2013).

Objective gait analysis has become a relatively common diagnostic tool to negate many of these difficulties. We now have a broad evidence base correlating the results of sensor based gait analysis with subjective assessment (Donnell et al., 2015; Keegan et al., 2013; McCracken et al., 2012; Pfau, 2019) and we assume that it adds most value to our ability to diagnose and localise the pain causing mild lameness without the implications of confirmation bias (Arkell et al., 2006). Further to this, investigations including sensor-based analyses and force plate data have linked asymmetry measures to ground reaction forces (Bell et al., 2016; Donnell et al., 2015; Keegan et al., 2012). Ground reaction forces are accepted as the ‘gold standard’ for objective lameness detection (Weishaupt et al., 2006, 2004) and with correlations to asymmetry measures, inertial sensor systems are established as an appropriate objective method for clinical use. Along with its real-time benefits for case management it also allows for objectivity in clinical research, and it is both strengths that it brings to this study.

To overcome some of the aforementioned difficulties (in situations where objective assessment is unavailable or inappropriate), horses are usually subjected to a variety of surfaces, conditions, and exacerbations (including flexion and stress tests) to help identify the affected limb and define the severity of lameness (Baxter, 2021; Hinchcliff et al., 2013; Ross, 2011). Ross (2011) describes the use of slopes to exacerbate lameness and suggests some specific pathologies it can help to diagnose, however objective evidence to this effect is lacking. This aim of this pilot study was to test the hypothesis that horses trotting up and down an incline would have significant changes to objective asymmetry parameters of the sacrum and poll.

2 | MATERIALS AND METHODS

A convenience sample of horses with naturally occurring lameness who were current inpatients at an equine referral hospital were recruited to the study. Eighteen horses (six mares and 12 geldings, all Irish Sports Horses) with mild lameness were evaluated in a straight line by two experienced clinicians. Horses were at various stages in their farriery cycles and were fitted with open heeled shoes on both forelimbs and were unshod on both hind limbs. Eight horses (7–16 years) with hindlimb lameness and 10 horses (8–19 years) with forelimb lameness were fitted with five inertial measurement units (Xsens Technologies BV, Enschede, The Netherlands) attached at the poll, withers, sacrum and both tuber coxae using double sided tape. Data were streamed wirelessly to a laptop (EquiGait software) whilst the horses were trotted in hand on a level surface (<0.7%), as well as up and down a slope of 2.4%. All trotting surfaces were covered with asphalt. Horses were all trotted by the same handler using a headcollar and rope from each horse’s left-hand side. Horses moved immediately from surface to surface without re-instrumentation. Recordings were started and stopped at each end of the trial area, with data collected at a steady speed. Data were collected for a minimum of 25 strides at each incline type. Speed was visually assessed and trials with a visible change in speed were discarded from the datasets.

Post test data processing was performed using custom MATLAB software to calculate established objective lameness parameters. For the forelimb lame group, the difference in millimetres between the two minima in vertical displacement of the poll were determined (Poll Min Diff) and for the hindlimb lame group the same parameter was calculated but based on data from the sacrum (Sacrum Min Diff); as used in previous studies (Bell et al., 2016; Pfau, 2019). Using the MinDiff data and MaxDiff data (difference between the two maxima in vertical displacement), an upwards difference (UpD) was calculated as a marker of push off lameness (Pfau, 2019). As well as providing laterality to the asymmetry data, the sensors at the tuber coxae were also used to calculate the hip hike difference (HHD, difference between the upwards movement of each sensor prior to the stance phase of each hind limb). The raw data outputs present left and right forelimb asymmetries as negative and positive values, respectively. Left limb asymmetries were multiplied by −1 to transform data to represent the magnitude of asymmetry regardless of most affected limb. Where data for a particular horse contained both negative and positive asymmetry values (representing a shift from one limb to another between test conditions) the asymmetries of the greatest magnitude were kept as positive values and the asymmetry of the lesser asymmetry was negative. Mean values for poll and sacrum MinDiff were calculated and plotted against test condition. Normal distribution was confirmed by visual inspection of a histogram and the effect of incline was compared using a repeated measures ANOVA and where significant a Bonferroni’s multiple comparisons test was performed. Significance was assumed where p < 0.05.
FIGURE 1  Mean asymmetry displacement determined from sacral inertial sensors normalised (multiplied by $-1$) to account for direction of asymmetry from 10 horses with low grade hindlimb lameness when trotted on a flat surface (FLAT), an incline (UP) or decline (DOWN). *$p = 0.014$ **$p = 0.0013$ ns = not significant.

Subsequent diagnostic information is not available for this population, limiting this study to a biomechanical pilot study.

3 | RESULTS

All horses had visually determined lameness scores (based on trotting in hand in a straight line) of 1 or 2 out of 5 according to a previously published numerical lameness scale (Hewetson et al., 2006).

3.1 | Hindlimb group

Plots of mean sacrum MinDiff against test condition are presented in Figure 1. The average asymmetry in this group when trotting on a flat surface was $6.6 \pm 4.4$ mm. When trotting up the incline mean asymmetry was $8.4 \pm 4.3$ mm and when trotting downhill mean asymmetry was $1.9 \pm 2.9$ mm. A repeated measures ANOVA identified significant differences between groups ($p = 0.025$). Post hoc Bonferroni’s multiple comparisons tests revealed significant differences between the flat and downhill data sets ($p = 0.014$) and between the uphill and downhill data sets ($p = 0.0013$).

There were no significant differences in UpD of the sacral mounted sensor ($p = 0.6$) or any significant difference in HHD ($p = 0.07$) among test conditions.

3.2 | Forelimb group

For this group no significant differences were seen between the mean asymmetry in each condition, however marked differences ($>20$ mm) in asymmetry were seen in individual horses (Figure 2).

There were no significant differences in UpD of the poll mounted sensor among test conditions ($p = 0.416$).

4 | DISCUSSION

This study demonstrates that a relatively minor incline or decline can have a significant effect on naturally occurring lameness. A 10% incline results in increased forces experienced by the hindlimbs compared to a flat surface at trot (Dutto et al., 2004) and the inverse is likely experienced during downhill locomotion. Although from a different study with different test conditions (7% incline) data gathered from the forelimbs of horses moving down an incline show an 8.4% increase in maximal vertical force and a 97.7% increase in maximal longitudinal breaking force (Chateau et al., 2014). This redistribution in force also neatly explains why, when visualised on an 6% inclined treadmill, horses trotting uphill have a significant increase in hindlimb fetlock extension (Sloet van Oldruitenborgh-Ooste et al., 1997). Again, data do not exist for horses trotting down a slope, but the inverse can be assumed to be true, further suggested by the decreased fetlock extension documented in the forelimbs of the same horses.

When a horse is worked on an incline there needs to be an increase in vertical force generation to achieve the increases in gravitational potential energy. This has been demonstrated with the application of exercising electromyography to horses trotting up and down an incline of 10%. Horses trotting uphill have significant increases in gluteus medius activity and horses trotting downhill have significant decreases in gluteus medius activity when compared to trotting on a horizontal surface (Crook et al., 2010). The extra force generated by the hindlimb musculatures’ increased activity has been documented with
dynamometric horseshoes fitted to the hindlimbs of horses trotting up a 7% incline recording significant increases in propulsive forces and significant decreases in braking forces compared to a flat surface (Munoz-Nates et al., 2017).

In our study population the reduction in weight distribution and therefore vertical force experienced by the hindlimbs is associated with a significant reduction in asymmetry when trotting downhill. Without a clinical diagnosis it is difficult to postulate a pathological chain of events leading to this reduced asymmetry. The fact that the MinDiff is slightly increased in the uphill data set might also suggest that the severity lameness in this group is exacerbated by the need to produce or withstand more vertical force, however the lack of significant increase in UpD among groups would suggest the latter.

The changes in asymmetry in the forelimb lame group between conditions is less predictable, but some marked changes in asymmetry are seen in individual horses. There are clearly more variables to consider in the forelimb than simply changes in force distribution, although this would certainly have a profound effect on some differential diagnoses for forelimb lameness. Significant reductions in superficial digital flexor tendon (SDFT) strain have been documented in horses trotting up an incline of 8% (but not significantly different up an incline of 3% which is closer to this study) (Takahashi et al., 2006) which would suggest that there could be a lesion-specific response to uphill and downhill locomotion. Similar reductions in SDFT strain have been documented in horses fitted with toe wedges (Lawson et al., 2007), which is not surprising given that the position of the uphill hoof during the stance phase would mimic that of a horse fitted with a toe wedge.

Applying our understanding of the effects of heel and toe wedges to distal forelimb biomechanics, we might be able to predict which types of lameness would be exacerbated by which type of slope. Toe wedges (inducing similar changes to uphill locomotion) have also been shown to decrease peak strain in the suspensory ligament and increase peak strain in the deep digital flexor tendon (DDFT) (Lawson et al., 2007), increase peak strain in the accessory ligament of the DDFT (Riemersma et al., 1996) as well as increasing maximal extension and decreasing maximal flexion of the interphalangeal joints (Chateau et al., 2006). We could deduce from these findings that horses with pain associated with the DDFT and associated structures (accessory ligament, podotrochlear apparatus) along with horses with distal interphalangeal joint disease may be more painful when trotting up an incline. However, this is not in agreement with what is commonly observed in clinical cases likely because the exacerbation is negated by the overall redistribution of force.

Conversely to this, wedges fitted at the heel of forelimbs (with some similarities to downhill locomotion) have demonstrated an increase in peak strain of the suspensory ligament and decrease in DDFT peak strain (Lawson et al., 2007; Riemersma et al., 1996), increase in peak strain of the SDFT (Lawson et al., 2007) along with decreased maximal extension and increased maximal flexion of the distal interphalangeal joint (Chateau et al., 2006). With these findings, we can hypothesise that the lameness in horses with pathology affecting the suspensory ligament or SDFT might be exacerbated during downhill locomotion, further confounded by the increase in overall forelimb force.

Changes in angle of the solar surface of the distal phalanx on a computerised limb model have been shown to have no significant effect on angulation of the metacarpophalangeal joint (Lawson et al., 2007). With the most profound biomechanical changes happening in the distal limb, it might be understandable that naturally occurring forelimb lameness would be more susceptible to changes in solar surface angle given that forelimb lameness is most associated with distal limb pathology. Hoof conformation has also been shown to have a marked effect on the influence of graduated shoes; horses with longer toes experience larger changes in joint angles and cross-sectional areas of tendons compared with horses with shorter toes when fitted with a shoe of the same graduation (Hagen et al., 2018). This long toe conformation is a common finding in horses with forelimb foot pain and may be a confounding factor in this study, but data were not available to investigate foot conformation as a variable in this population.

In the context of horses which are fitted with steel shoes on both forelimbs but unshod on both hind limbs we must consider the hoof-surface interaction. With the significant changes in propulsive and breaking forces discussed earlier, the interaction with the sloping ground will be similarly different between conditions. Horses trotting down a 7% incline demonstrated a 450% increase in longitudinal sliding during early stance phase (Chateau et al., 2014). This will act to dampen the impact of the limb (Barstow et al., 2019) but will also likely increase the vibrational power and frequency experienced by the hoof, although the clinical significance of this is yet to be revealed.

Limitations in this study include the relatively small sample size. Investigations of larger numbers of horses with known pathologies would elucidate the cause of the large individual variation (particularly in the forelimb group). A further complicating factor is the inability to distinguish horses with unilateral lameness from those with bilateral lameness in this study population. The surface used in this study would be the typical surface used for lameness evaluation (asphalt), but we must also consider that this is not the surface where horses are often worked. The influence of the influence of the hoof-surface interaction could be investigated by incorporating different surfaces.

5 CONCLUSIONS

This study demonstrates that significant changes in hindlimb asymmetry can be induced by using a slope which is markedly less steep than in most studies discussed here. Regardless of the mechanism, the fact that these changes have been documented could support the use of slopes to exacerbate mild asymmetries for diagnostic purposes as well as suggest the need to observe a horse both from the top of an incline as well as from the bottom before drawing conclusions on soundness (or lack thereof).

The results from the forelimb are more variable but still of interest to the clinician due to the magnitude of change seen in some cases. Further work to link changes in asymmetry to pathological conditions would be necessary if the specific responses to moving up or down a slope are to become a useful finding to the diagnostician.
AUTHOR CONTRIBUTIONS
Data collection was undertaken by Adam Redpath and James Bailey. Gayle Hallowell and Mark Bowen were responsible for the statistical analysis. The paper was prepared by James Bailey.

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DATA AVAILABILITY STATEMENT
Data availability is available from the corresponding author.

ETHICS STATEMENT
This study has been approved by the ethics committee of the School of Veterinary Medicine and Science, University of Nottingham.

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