Final report

Hind limb lameness in horses- why it is so difficult and how do we improve detection?

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Part 1: Detailed summary

Att korrekt bedöma bakbenshältor på hästar är svårt, även för erfarna veterinärer. Det leder till utbredda problem med felaktiga diagnoser och misslyckade behandlingar. Detta i sin tur skapar onödigt lidande för hästarna och dyra utredningskostnader för djurägare och försäkringsbolag. I det här projektet ville vi undersöka hästens rörelsemönster i detalj för att kunna öka kunskapen subjektiva visuella bedömningen och objektiva mätmetoder för att detektera bakbenshältor och förfina diagnostiken. Projektet är utfört i samverkan mellan SLU och Universitetsdjursjukhuset i Uppsala och NMBU i Oslo, Royal Veterinary College i London och Utrech Universitet. Vårt mål har varit att ta fram information som kan ge klinisk hjälp för subjektiv och objektiv hältanalys och utbildningsmaterial som ska leda till en nödvändig förbättring av diagnostiken och hjälpa hästsektorns aktiva att upptäcka hälta i ett tidigt stadium.

Projektet har fokuserat på det kroppssegment som är viktigast för att bedöma hälta, nämligen hästens bäcken.

Vi har gjort studier inom tre övergripande teman

1. Normalvariationen i bäckenets rörelse hos olika hästar mellan och inom raser och hastigheter.
2. Hur bäckenets rörelse förändras vid hälta.
3. Visuell inlärning av hältdetektion.

Vi har registrerat bäckenets rotationsrörelser hos 100 varmblodsridhästar, 30 shetlandsponnyer, 28 varmblodstravare och 24 kallblodstravare i trav på rakt spår. Vi kunde se att det fanns vissa grundläggande likheter men stora individskillnader i bäckenrörelserna. Individskillnaderna var tydliga även inom olika raser. För varmblodsridhästarna och shetlandsponnyerna hittade vi tre tydliga ”mönstertyper”. Travhästarnas rörelser är fortsatt under analys.

För att studera hur bäckenrotationerna förändras när hästen blir halt utförde vi en studie på kliniskt halta hästar. Från 350 fall av kliniskt halta hästar valde vi ut 20 hästar men en lindrig till måttlig bakbenshälta som kom från smärta i ett bakben enligt förutbestämda kriterier. Genom att jämföra detaljerade mätningar av bäckenets rörelse före och efter en bedövning som bort smärtan vilken skapade hältan kunde vi se att bäckenrotationen påverkades på ett systematiskt sätt av hälta. Efter bedövningen var bäckenet mer symmetriskt i sin rotationsrörelse. Vi försökte också att undersöka bäckenrörelse från hästar med smärta från två olika anatomiska platser i benet; hov jämfört med den

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stora hasleden, men hältorna var för varierande i grad för att jämförelsen skulle vara värdefull för vidare analys.

Att veterinären blir bättre på att mäta och detektera bakbenshälta hos hästar är förstås av största vikt. Men studier visar att många hästar som tränas faktiskt kan ha oupptäckt hälta (Rhodin et al. 2017, Greve & Dyson 2014). För att dessa hästar ens ska komma till veterinären för en undersökning måste tränaren /ryttaren/ kusken upptäcka tecken på hälta. Därför skapade vi ett digitalt utbildningsmaterial för att ge tränare chansen att förbättra sin förmåga att upptäcka bakbenshälta. Vi utvärderade också vilken metod för feedback som gav bäst inlärningsresultat. I en studie av 87 ridlärare / tränare kunde vi se att förbättring av hältbedömning var störst om man fick se videor med rörelsen i slowmotion som feedback. Studien pågick i 14 dagar. Vidare forskning bör göras för att utvärdera den mer långsiktiga effekten av inlärningen.

Projektet har resulterat i en ökad förståelse för det grundläggande rörelsemönstret med en kartläggning av variation och individmönster. Vi ser att bäckenets rotation har ett individuellt ”fingeravtryck”. Det ger indikationer om att det finns mycket att vinna på att följa samma individs rörelsemönster över tid.

Våra resultat visar att rotationen av bäckenet ändras hos hästar med hälta. Det fyndet är viktigt att föra ut till veterinärer via utbildning och integreras delvis redan idag flera i existerande mätverktyg för hältaanalys. Vi ser förhoppningsvis förbättrad hältdiagnostik för hästar framöver.

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Part 2: Main report *(max. 10 pages)*

Introduction

Background and objective.

Orthopaedic diseases is a pressing equine health and welfare issue, being the number one cause of both veterinary intervention and decreased survival. The main sign of orthopaedic diseases is lameness. The starting point, and the most important building block of the clinical investigation of the lame horse, is the veterinarian's visual appraisal of abnormalities in the equine movement pattern. Veterinarians' subjective visual assessments of hindlimb lameness has been shown to be inconsistent, with low to moderate agreement between observers.

The bouncing movement of the body created from the impact and push-off of the two limb diagonals lead to an upward-downward movement of the pelvis two times in each stride. Decreased impact and push-off of a lame hindlimb will lead to a decreased height of the pelvis during push-off and a decreased descent of the pelvis during impact which creates an asymmetry in the vertical displacement when compared to the movement associated to the other limb. The pelvic segment also rotates around three axes during each stride. The rotation that leads to a tilt of the pelvis seen from rear view is called "roll", or axial rotation. The tubera coxae in the "rolled" pelvis are at different heights. Changes to this rotation are also described indicators of hindlimb lameness, often called hip hike and hip drop off or hip drop. The other two types of rotations of the pelvis (yaw and pitch) are to our knowledge almost completely undescribed in both lame and non-lame horses.

When veterinary orthopaedic textbooks are reviewed for description of pelvic movement patterns that indicate hindlimb lameness the different rotational movements are not correctly described and confusion exists between books.

In fact, hindquarter movement in both textbooks and scientific literature do not describe the true variations in movements of horses' hindquarters at the trot.

In summary, before the project started we identified a number of scientific gaps :

- Hindquarter movements in sound and lame horses, with the pelvic movements being of specific interest, are not fully understood.
- There seem to be variations in the pelvic movement pattern that do not agree with published experimental and model data. This causes problems in the objective assessment of lameness for systems that rely on specific pelvic rotation patterns for step split.
- The changes in 3D movement of the pelvis in response to lameness is not fully described. We hypothesise that these movements can provide a more specific lameness identification, relating the alterations to more detailed event of the stride and thus opening the possibility to identify specific pain locations from movement data (objective techniques) and visual assessment.
- We do not know why human performance in visual assessment of lameness is so poor in spite of our well documented ability for advanced visual pattern recognition. Maybe increased conceptual understanding of the functional movement pattern and its variation can improve this performance. Also addressing temporal limitations to the visual

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perception can be of help, i.e. training lameness detection in slow motion.

The objectives

The overall aim of the project was to provide a new methodology that substantially improves our ability to correctly identify hindlimb lameness by focusing on the variation in movement patterns of the hindquarters (e.g. pelvic movement) and the subsequent changes introduced by lameness. As such we aimed for improvement of *both* human visual assessment as well as technical systems for lameness detection.

We had three more specific objectives:

- First we wanted to explore the three-dimensional movement pattern of the hindquarters of sound trotting horses, and to describe the normal variation in these patterns in different horses.
- Then we aimed to identify the most significant and/or visible movement pattern changes presented by hindlimb lameness.
- Lastly, we wanted to produce and validate an online interactive learning tool that should use our earlier findings to teach veterinarians and other equine stakeholders such as horse owners and trainers to better detect hindlimb lameness.

Material and methods

Exploring variations in the normal movement of the hind quarters of horses

Part 1: Prospective cross sectional study. The pelvic movement pattern of 100 European Warmblood riding horses and 30 Shetland ponies were analysed at trot in hand using a wireless body mounted multiple sensor system (Equigait or EquiMoves) or a 3D motion capture video system (Qualisys, Oqus 700+a, at 100Hz).) to detect 3D movement of the pelvis, limb, head and thoraco-abdominal segment. At their own preferred speed, horses were trotted on the soft straight-line (30 m x 2, back and forth) and lunged on soft surface, capturing 25 s per direction. 3D coordinate data for the above-described systems were exported to Matlab (R2019b, Mathworks Inc., USA) and analysed using custom-made scripts. Timeseries data were split into strides based on vertical maxima for the tubera sacrale marker (approximately corresponding to hind limb hoof-on), and pelvis roll was used to determine left vs right hind limb stance (Wegener et al. 2011). Single strides were excluded if stride duration or sacrum vertical range of motion (ROM) differed more than 20% from measurement median, or if head vertical ROM differed more than 40%. When the pelvic roll curve was modelled as a linear combination of sine and cosine curves, a sine curve with a period of one per stride and a cosine curve with a period of three per stride showed the clearly largest estimates. While the sine curve appears to describe the global rocking of the pelvis related to alternating left and right hind limb stance and protraction, the cosine curve marks a bump in the curve during the first half of each hind limb stance. Further exploring variation in these features across the group of 100 warmblood horses, using finite mixture models, it was found that the horses could be separated in three clusters. Compared to models with one or two clusters, the model with three had the lowest AIC value, and a model with four converged with duplicate clusters (equivalent to non-conversion).

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Part 2: Prospective cross sectional study. Twenty-eight Standardbred and twenty-four Coldblood trotters were measured with a 9-sensor IMU system (Bosch et al 2018) at low speed (jog) and high speed trot, adjusted to the speed suitable for each breed. High speed video footage was simultaneously captured from a camera placed on the driver's helmet. Data analysis principles from study part 1 were used with the addition of evaluating speed as an explanatory factor (not a random factor). The final data processing is still ongoing.

Hind quarter movement pattern changes in horses in response to hindlimb lameness

Optical motion capture data from 20 horses with unilateral hindlimb lameness, successfully blocked by local analgesia (assessed visually and objectively) were retrospectively retrieved. Pelvic rotation variables (e.g. range of motion, minima, maxima, angular velocities) were calculated. Lame and blocked conditions were compared using mixed models ($p<0.05$) with horse as random effect. From a total of 350 recorded lameness cases in the clinical database, 68 horses were initially selected based pelvic vertical asymmetry and response to block. From these, 20 cases remained in the study after exclusion of horses based on details in the clinical records. Pelvic roll, pitch and yaw were calculated as projection angles in the frontal, sagittal and dorsal planes, respectively, using data from markers at the tuber sacrale and the two tubera coxarum. In total 18 motion variables were selected for statistical analysis describing, at stride level the vertical symmetry and ROM for mid-pelvis and hips, pelvic rotations ROM for full and half strides, angular velocity of the roll and pitch as well as speed (see Table 2 for full list of variables). Mixed models were constructed to study differences in these variables, describing pelvic rotations and vertical motion symmetry, before and after blocks. In each model, horse was used as a random effect and lameness condition (lame or blocked) as fixed effect. The p-value limit was 0.05 in all analyses. R packages used included: lme4, lmerTest and emmeans.

We also collected data in a collaboration with a study in Utrecht looking at motion patterns in horses with induced lameness. Two induction methods were used, a sole pressure model and a LPS induction model with injection to the tibiotarsal joint. We tried to find motion pattern differences between these two anatomical locations on the hindlimb, but since the degree of lameness was not at a comparable level in many of the horses and some horses were lost to the study due to problems with infectious disease this study part was not successful due to low power. Inclusion of more horses was not possible due to ethical reasons with the invasive study design. Lessons were learned about the struggles with induction methods for lameness, the data was luckily usable for other research questions focusing on pain behaviour and asymmetry comparisons.

Exploration of efficacy of tools for learning in lameness evaluation and creation of a web based pedagogical training system for lameness detection

We performed a cross-sectional and prospective study to evaluate the ability of riding teachers and trainers to correctly assess hind limb lameness, and to evaluate feed-back methods intended for improvement of lameness detection. For the cross-sectional part, 64 riding teachers and trainers of varying level, and 23 high-level trainers, were subjected to a video test consisting of 13 different videos of horses trotting in a straight line (test 1). The participants could classify the horses as sound, left hind limb lame, or right hind limb lame. For the cross-sectional part, the riding teachers and trainers of varying levels (n=64) were also subjected to 14 days of feedback-based computer aided training to identify hindlimb lameness, where they assessed 13 videos (of which three were repeated from the video test) of horses trotting in a straight line. The participants were randomly allocated to three different groups (A, B, and C), where each group received different types of feedback after each

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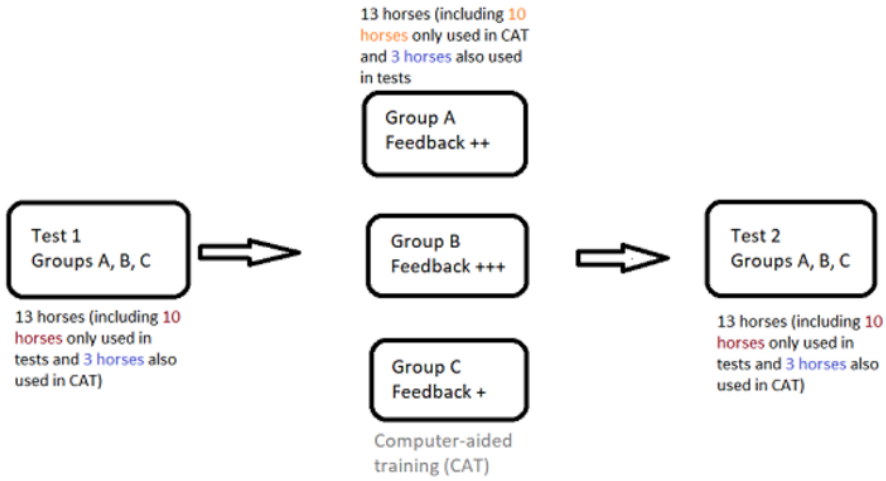
video (group A: correct answer and review of video in full speed and 65% speed, group B: correct answer, review of video in full speed and 65% speed and narrating voice providing explanations, group C: correct answer and review of video in full speed). After computer-aided training, the participants were again subjected to the video test (test 2, identical to test 1). In both study parts, participants answered background questions regarding their education and previous experience of lameness assessment.

The prospective study part set-up is described in the figure below.



Results and discussion

Exploring variations in the normal movement of the hind quarters of horses

This study uses a novel approach to describing the motion pattern of the horse's pelvis in trot in warmblood and , using time series analysis. The method allowed us to define three subcategories of the general motion pattern, based on the time series signal over the stride. We suggest that this is a usable approach to study categories or types of normal and abnormal motion patterns of body segments undergoing cyclic motion in horses, but also in other animals during steady state locomotion. Significant individual variation was identified within breed groups. Between breeds there were surprisingly no significant differences. The horses could be grouped into clusers of motion pattern types as described in the figure below.

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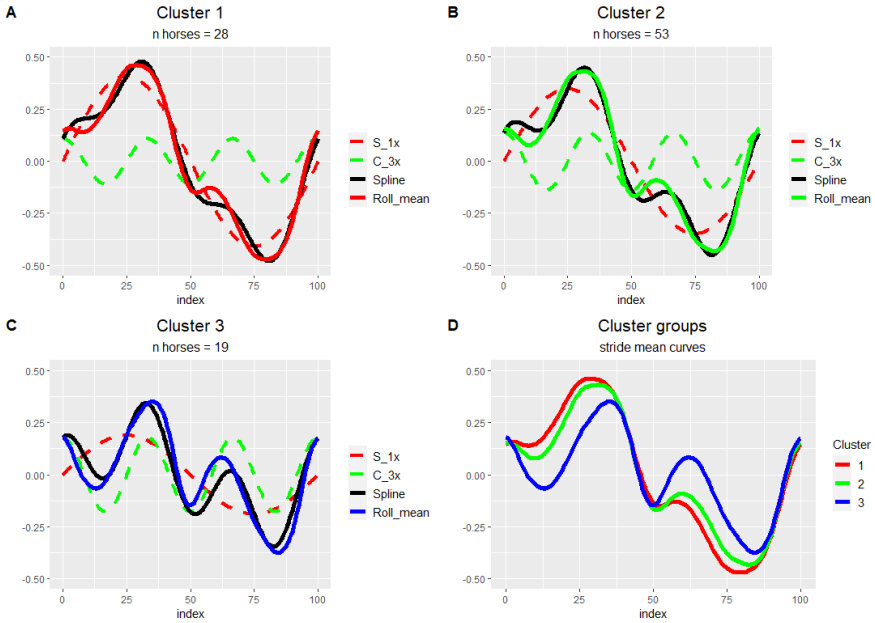
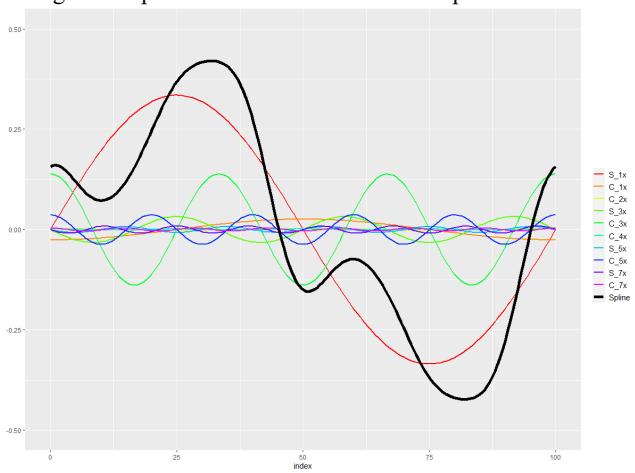
The cluster groups in the pelvic roll patterns of the horses and ponies studied in part 1 are presented in the figure below.



The signal components of the axial rotation are presented below.



The trotter (Part 2) study analysis is ongoing.

Hind quarter movement pattern changes in horses in response to hindlimb lameness

After block there was a significant reduction in differences between midpelvis vertical minima and vertical maxima (PDmin and PDmax), respectively, comparing left and right hindlimb steps. Estimates indicate about 20% residual lameness. There was no significant difference in trotting speed or stride frequency before and after blocks, at group level. There was a reduction in sacrum vertical ROM, 2.6 mm (p-value 0.043). Looking at the heat map, this variable was highly sensitive and specific in differing between strides from measurements before and after block, in five of the 20 horses.

Pelvis roll ROM over the whole stride did not change significantly. The stride average value for pelvis roll had a sensitivity of around 75% and specificity of around 80-90% in two horses, and was highly specific, close to 100% in two other horses, suggesting that this variable can be very useful, but only in some horses (Figure 2). At group level, stride mean pelvis roll was estimated to change from 1° tilt towards the lame side to 0.5° tilt towards the same side, suggesting that the pelvis became likely more level after block.

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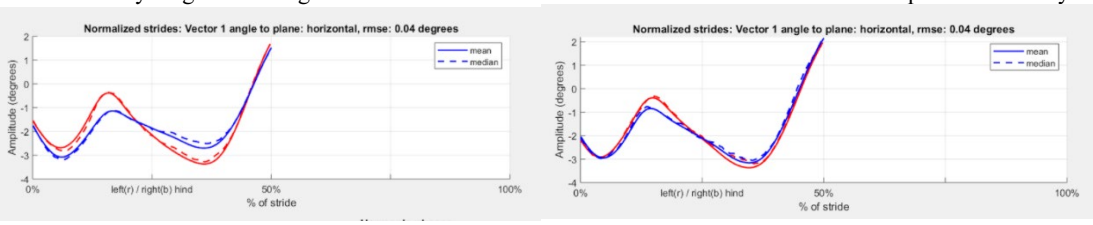
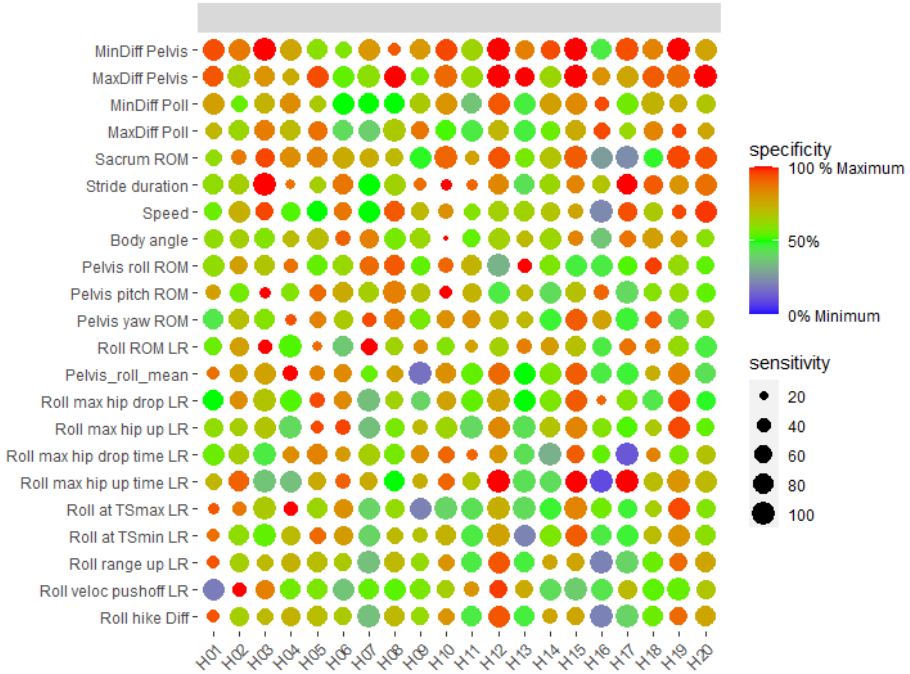
The left pane shows the roll curve for each half stride in red and blue before lameness was blocked. To the right the lameness is decreased by diagnostic analgesia and the curves have become more similar. The roll of the pelvis is more symmetrical.



Sensitivity and specificity for distinguishing lame from blocked horses are presented.



In summary we found that pelvis roll ROM over the whole stride did not change significantly, instead roll rotation was altered during specific sections of the lame step. After diagnostic analgesia these roll variables showed more similar values between lame and non-lame limbs. These results show that pelvic roll may indeed change as a consequence of hindlimb lameness and return towards symmetry in response to diagnostic analgesia.

Exploration of efficacy of tools for learning in lameness evaluation and creation of a web based pedagogical training system for lameness detection

In the cross-sectional part, 46% (riding teachers and trainers of varying levels) and 47% (high level trainers) of horses were correctly classified in test 1. Effect of participants' backgrounds on results were analysed using analysis of variance, and effect of the different feedback methods were evaluated using generalized estimation equations. Group A significantly improved their test score, both with (OR=0.48, $p<0.0001$) and without (OR=0.57, $p=0.009$) inclusion of repeated questions. In group C, significant improvement was seen with inclusion of repeated questions (OR=0.72, $p=0.041$). In group B, no significant improvement was seen. Overall, self-rated ability to assess lameness positively affected scores on test 1.

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Conclusions

Exploring variations in the normal movement of the hind quarters of horses

Our study of the normal variation in pelvic motion patterns in Warmbloods and Shetlandponies, two very different breeds in terms of conformation, show that there is substantial individual variation within the two breed groups, but also an underlying common patterns which could be divided into three main "pattern types". We expect that an even larger span of patterns would have been found if a number of different breeds were represented (cf. Barrey et al.2002). In contrast to the indications from a previous study (Starke et al 2015), our findings indicate that it cannot be generally assumed that pelvic motion patterns are consistent across horses. We also provide a new signal processing method to study clusters of motion patterns. The data from the trotters are still under investigation.

Hind quarter movement pattern changes in horses in response to hindlimb lameness

Pelvic roll changed when clinical lameness was improved by local analgesia. Roll differences can contribute to changes in hip-hike symmetry and to the visual perception of restored gait symmetry including a more active push from the blocked limb. The findings suggest that evaluation of pelvic roll can add substantial information to both visual and objective lameness assessment.

Exploration of efficacy of tools for learning in lameness evaluation and creation of a web based pedagogical training system for lameness detection

Our study including riding teachers and trainers shows that lameness detection skills need to be improved in order to secure early detection of lame horses in training. Less than half of the presented horses were correctly classified in the initial test. Luckily, improved lameness classification skills can be obtained with limited training through a digital learning platform. We found slow motion feedback to be most efficient for improvement.

Relevance for the practical horse sector incl. recommendations

We now know more about how lame horses move
The results from this project have provided new information to veterinary science about how horses alter their gait pattern in response to a painful process in a hind limb. We have found that the pelvic axial rotation (the roll of the pelvis) as well as the pitch are important factors to consider when lameness is assessed both visually and through objective diagnostic gait analysis. This means veterinarians can provide a better clinical investigation to help horses with hindlimb lameness.

Changes are implemented into clinical gait analysis tools
Our findings have already led to changes in how three available clinical gait analysis products make it possible to record, process and present data to the veterinarian during lameness assessment. The rotations of the pelvis can be measured and presented to the clinician in order to provide additional information. This provides a better and more complete image of the lameness associated gait pattern in the equine patient, and hence opens up for a more sensitive clinical assessment.

Lameness detection is difficult also for riding instructors and trainers
We have identified the need to provide learning opportunities to riders and trainers in order to detect lameness at an early stage. We found that the current level of detection capacity does not ensure that horses with lameness are identified in time and sent to the vet. We believe that awareness is an important point for the equine industry to continue to address in the future. Both awareness of the

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extent of lameness in the horse population as well as of the difficult for the human visual system to detect it.

Lameness detection in students and trainers can improve through training
We have discovered that it is possible to improve visual lameness assessment capacity in equestrian trainers and riding instructors and that **slow motion video is the most efficient feed-back method** in the learning setting we have tested.

Following horses' individual gait patterns over time seems important
Since we have found that the pelvic motion pattern is of importance in the detection of lameness and that the pelvic pattern has a strong individual "finger print" in each horse (also within breed), this has led us to conclude that gait monitoring over time should include analysis of the pelvic rotations. With this new knowledge we believe that a better distinction between what is a relevant change in the motion pattern and not.

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Part 3: Result dissemination

State all result dissemination from the financed project into the appropriate section, including information as indicated in each section. Additional rows can be added to the table.

Scientific publications, *published*	*Author(s), year, title, journal, Vol, No, pp. (doi/link if applicable)*
	Leclercq, A., Bystrom, A., Söderlind, M., Persson, E., Rhodin, M., Engell, M.T., Hernlund, E., (2022). Evaluation of feedback methods for improved detection of hindlimb lameness in horses among riding instructors and trainers. Front. Vet. Sci. 9, 1–11. https://doi.org/10.3389/fvets.2022.992954
	E. Hernlund, M.T. Engell, E. Persson-Sjodin, M. Rhodin, P. Haubro-Andersen, F.M. Serra-Braganca, N.I. Dolvik and A. Bystrom, 2022. Changes in pelvic axial rotation following diagnostic analgesia in hindlimb lame horses, Comparative Exercise Physiology, ISSN 1755-2540 print, ISSN 1755-2559 online, DOI 10.3920/CEP2022.S1
	A. Leclercq, M.T. Engell, M. Rhodin, E. Persson-Sjodin, A. Bystrom and E. Hernlund, 2022, Trainer detection of hindlimb lameness in horses-evaluation of feed back during web based training, Comparative Exercise Physiology, ISSN 1755-2540 print, ISSN 1755-2559 online, DOI 10.3920/CEP2022.S1
	A. Bystrom, A.H. Hardeman, M.T. Engell, J.H. Swagemakers, M.H.W. Koene, M. Rhodin and E. Hernlund, 2022, Normal variation in pelvic roll pattern in straight line trot in Warmblood horses, Comparative Exercise Physiology, ISSN 1755-2540 print, ISSN 1755-2559 online, DOI 10.3920/CEP2022.S1
Scientific publications, *manuscript*	*Author(s), title*
	A. Byström, A.M. Hardeman, M.T. Engell , J.H. Swagemakers, M.H.W. Koene, E. Hernlund. Normal variation in pelvic roll pattern and symmetry in straight line trot in Warmblood horses and Shetland ponies
	E. Hernlund, M.T. Engell, M. Rhodin, F.M. Serra-Bragança, T. Pfau, E. Persson-Sjodin, P. Haubro-Andersen, N.I. Dolvik, and A. Byström Pelvic axial rotation changes in hindlimb lame horses after local diagnostic analgesia.
	R. Arts, A Selven-Kallerud, F.M. Serra-Braganca, A. Bystrom, M. Rhodin, E. Hernlund, M.T. Engell, Hindquarter movement in harness racehorses.
Conference publications/ presentations	*Author(s), year, title, conference name, location and date, (link if applicable)*
	HVF höstkurs Oslo, Biomekanik och hälta, November 2019
	Svenska Veterinärkongressen, Pelvisrotationer hos halta hästar, October 2020
	Svenska Veterinärkongressen, Objektiv rörelseanalys vid besiktning, October 2021
	HVF höstkurs , Visuell bedömning av bakbenshälta, November 2021
	High performance seminar, Hind limb lameness –why is it so difficult to detect? Portland, April 2019

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Other publications, *media etc.*	*Title, year/date, place of publication (link if applicable)*
	Tutorial video on how to detect hindlimb lameness, over 11000 views. https://www.youtube.com/watch?v=hq0nmZ4bKyY
Oral communication, *to horse sector, students etc.*	*Title, year/date, group presented to (link if applicable)*
	ATG hopp och talang, att upptäcka hälta, yearly lectures 2019-2022.
	Stig H dagen, Januari 2022, nya metoder för hältanalys
	Veterinary student extra curriculum digital course, hindlimb lameness assessment autumn term 2019, 2020, 2021.
	Professional continuous education course for veterinarians specialized in orthopaedics, Visual assessment of hindlimb lameness, Mälaren hästklinik, June 2021.
	Professional continuous education course for veterinarians specialized in orthopaedics, Visual assessment of hindlimb lameness, Evidensia, May 2021.
	Professional continuous education course for veterinarians specialized in orthopaedics, Visual assessment of hindlimb lameness, Jordbruksverket, March 2022.
	International webinar in equine biomechanics for veterinarians, Biomechanics of lameness, UK, March 2021.
	Veterinary student, 3 Lectures in hindlimb lameness assessment, UC Davis USA, May 2019.
Student theses	*Author/Student, co-authors/supervisors, year, title, type of thesis (doi/link if applicable)*
	Lii Leo, Main supervisor Elin Hernlund, 2019, En studie av bäckenrotation hos hästar med bakbenshälta. https://stud.epsilon.slu.se/15441/7/leo_l_190218.pdf
	Marika Erkkilä, Main supervisor Elin Hernlund, 2021, Master thesis Veterinary program. Perceptuell inlärning av bedömning av bakbenshältor hos häst – en jämförande studie av två digitala inlärningsverktyg. https://stud.epsilon.slu.se/16493/1/erkkila_m_210119.pdf
Other	

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