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Final report

Objective gait and lameness detection in Icelandic horses

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Part 1: Detailed summary

Bakgrund

Islandshästar blir allt mer populära i Skandinavien. Deras unika gångarter gör dem mycket framgångsrika men gångarterna är också en svaghet, om de blir halta. Att utvärdera hälta och var hältan kommer ifrån är mycket svårt i andra gångarter än trav. Idag saknar vi den mest grundläggande kunskapen om hur islandshästar rör sig i de olika gångarterna och hur de förändrar sitt rörelsemönster när de blir halta. Den biomekaniska forskningen har kommit långt med att mäta hälta och automatisera dataanalysen för kliniskt bruk men dessa analyser förutsätter dock att hästen travar. Syftet med det här projektet var att studera hur islandshästar rör sig i de olika gångarterna, utveckla nya algoritmer för automatisk klassificering av gångarter samt identifiera känsliga symmetrivariabler för att detektera om hästen är halt samt var hältan kommer ifrån i de olika gångarterna. Kunskapen kan även användas för att kvantifiera gångartsegenskaper i genetiska studier samt i avelsarbetet.

Metod

Studie 1

Del 1 genomfördes i Utrecht där algoritmer utvecklades för identifiering av hov-isättning och hov-upplyft med IMU-sensorer genom validering mot en kraftmätningsplatta.

Del 2 genomfördes på Island, Hólar Universitet, där 44 Islandshästar utrustades med 13 IMU-sensorer. Hästarnas rörelser registrerades i skritt och trav för hand samt under ridning i skritt, trav, tölt, galopp och för vissa av hästarna även i pass. Data analyserades med hjälp av algoritmer som utvecklades för att detektera isättning och upplyft av hovarna. Därefter kunde

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avancerade dataanalyser göras med hjälp av AI och forskare vid KTH för att få fram en automatiserad gångartsklassificering.

Av de 44 hästarna som deltog i studien valdes 24 friska hästar ut med ett symmetriskt rörelsemönster. Huvudet, korsets och mankes rörelse i relation till benisättningen studerades.

S*tudie 2*

Studien genomfördes på Island och en mild-måttlig fram eller bakbenshälta inducerades på 21 hästar och hästarnas rörelsemönster registrerades med IMU-sensorer när de skrittade och travade för hand samt reds i skritt, trav och tölt.

Därefter testades de utvecklade algoritmerna för gångartsklassificering och symmetrimätningar på 80 friska samt halta Islandshästar i Sverige med avseende på gångartklassificering samt hältbedömning.

Resultat

Studie 1 Vinkelhastighet och accelerationsdata från IMU-sensorerna användes för att identifiera isättning respektive upplyft av hovarna. Med 98,9% säkerhet kunde sedan gångarterna hos Islandshästarna klassificeras med hjälp av data från IMU-sensorerna och avancerade AI-analyser.

Huvudet och korset rör sig upp och ned två gånger under varje stegcykel i alla gångarterna. Huvudets och korsets lägsta position inträffade vid mitten av belastningsfasen för alla gångarter förutom för korsets rörelse i skritt.

Studie 2 I skritt och trav kunde huvudets vertikala rörelseasymmetri användas för att detektera en frambenshälta men inte i tölt. Korsets vertikala rörelse kunde användas för att detektera bakbenshälta i trav men inte i tölt och skritt.

Algoritmerna för gångartsklassificering samt symmetrimätningar i de olika gångarterna fungerade utmärkt och kunde klassificera gångarterna hos 80 Islandshästar och detektera rörelseasymmetrier/hälta hos majoriteten av hästarna. Det är dock oklart när en asymmetri är kopplad till smärta vilket kräver ytterligare studier. På en liten andel av hästarna genomfördes en hältutredning och rörelseanalyserna fungerade utmärkt.

Konklusion

Gångartsklassificering kan göras automatiskt hos hästar som rör sig i skritt, trav, galopp, tölt och pass. Huvudets och korsets lägsta position infaller mitt under belastningsfasen, där fram- respektive bakbenet bär som mest vikt i trav, tölt, pass men ej i skritt för korset. Det innebär att asymmetrier för huvudet eller korsets lägsta positioner är ett bra mått på en belastningshälta. När Islandshästen blir frambenshalt kan man titta på asymmetri i huvudets lägsta position för att detektera hälta i skritt och trav men inte i tölt. Vid bakbenshälta kan man se asymmetri i korsets vertikala rörelse i trav men inte i skritt och tölt.

Rekommendation

Vi har nu skapat grunderna för att göra objektiv gångartsklassificering av islandshästar som rör sig i andra gångarter än trav. Vi har också identifierat att de variabler som används för subjektiv och objektiv hältbedöming i trav inte kan appliceras i tölt. Då hältbedömning av Islandshästar är mycket svår kan objektiva hjälpmedel förbättra diagnostiken av ortopediska skador hos våra Islandshästar. Ytterligare bearbetning av data krävs för att hitta variabler som kan upptäcka fram- och bakbenshälta i tölt.

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Part 2: Main report

Background

The diversity in footfall patterns and the fast stride frequency make subjective lameness evaluation of the five-gaited Icelandic horse extremely challenging. The rapid increase of this breed in Scandinavia and the rest of Europe signifies increased demand for veterinary expertise in this field. Objective tools for lameness evaluations are available, but are currently limited to assessment of lameness only during trot.
The overall goal for this three year multicentre study between the Swedish University of Agricultural Sciences, the Norwegian University of Life Sciences and Utrecht University in The Netherlands is to produce an objective kinematic method for gait analysis and lameness detection of the Icelandic horse in all of its five gaits.

Aim and objectives.

The overall aim of this study is to develop an objective sensor-based method for gait classification of the five gaits performed by Icelandic horses and to identify symmetry measures sensitive for lameness detection in the different gaits.

The objectives of the study are to

1) Develop algorithms for gait detection (walk, trot, canter, pace and tölt) by using data from hoof mounted sensors and also validate limb mounted sensors for gait classification.
2) Describe the normal movement pattern of the head, withers and pelvis in relation to stance phases of the limbs during the five different gaits performed by Icelandic horses.
3) Identify changes in movement symmetry of the head, withers and pelvis, sensitive for lameness detection in five-gaited Icelandic horses.

Material and methods

WP1:

Objectives:
1) To classify each of the five gaits from hoof mounted sensors and then validate limb mounted (cannon bones) sensors for gait detection.
2) To describe the normal motion patterns of the head, withers and pelvis in relation to the loading of the limbs in the five different gaits in sound Icelandic horses.

Study design:

Part 1 For gait classification, hoof-on and hoof-off events are fundamental locomotion characteristics of interest. These events can be measured with inertial measurement units (IMUs) which measure the acceleration and angular velocity in three directions. In an experimental study in Utrecht two algorithms for automatic detection of hoof-events from the acceleration and angular velocity signals measured by hoof-mounted IMUs in walk and trot on a hard surface was performed. Seven horses were walked and trotted in hand over a force plate for internal validation. The agreement between the algorithms for the acceleration and

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angular velocity signals with the force plate was evaluated by Bland Altman analysis and linear mixed model analysis.

Part 2 Prospective cross-sectional study. Healthy five-gaited privately owned Icelandic horses (N= 44), of mixed age and gender, without any history of lameness within 6 months were recruited for the study in Iceland and evaluated while ridden at the walk, trot, tölt, canter and pace. The gaits that could be shown at hand (walk and trot) was also evaluated in hand. The novel sensor technique developed for the EquiMoves system was used to measure both low and high accelerations and rotations of the segments they are attached to. Video recordings from each measurements as well as high-speed video recordings from the faster gaits were collected for visual assessments of the gaits. Algorithms for identification of hoof-events developed in part 1 was used (1,2).

Advanced data analysis with the use of AI-technique was performed in collaboration with computer scientists at KTH (Royal Institute of Technology) to classify gaits.

Part 3 From the data set 24 horses with symmetrical movements at trot were selected to further analyse the upper body movement in relation to the limb timing. Vertical displacement minima and maxima were calculated for in hand and ridden walk and trot and for ridden walk, trot, tölt, pace and canter. Stance and swing phase for each limb and the lowest/highest vertical position of the head (Hmin/Hmax) withers (Wmin/Wmax) and pelvis (Pmin/Pmax) were calculated. Data was compared to data from warmblood riding horses.

WP2

Objectives: To describe changes in movement symmetry of the head, withers and pelvis in relation to induced lameness in fore- and hindlimbs of Icelandic horses performing different gaits.

Study design: Prospective, interventional experimental study: Healthy five-gaited privately owned Icelandic horses (N= 21), of mixed age and gender, without any history of lameness within the last 6 months was recruited for the study in Iceland. A subtle lameness 1-2 degrees (AAEP scale) was induced by a fully reversible sole pressure model in a forelimb in 10 horses and in a hindlimb in 11 horses. The horses were evaluated in hand during walk and trot and while ridden at the walk, trot and tölt. No measurements in pace and canter were performed to reduce the risk of the horses at higher speed gaits with induced lameness. These gaits are not relevant to asses during lameness examinations.

The IMU-sensors and software for gait detection (developed in WP1) was used to identify gait (3) and to relate changes in movement symmetry of the head, withers and pelvis to the stance phases of the limbs.

Part 2 To test the general performance of the system, gait analysis was performed in 80 sound and lame Icelandic horses in order to verify that the algorithms and symmetry-variables are working correctly.

Ethical permission
Ethical permission has been obtained from the Iceland National Animal Research Committee to perform gait analysis in 24 Icelandic horses, induce a reversible lameness as well as obtain blood samples of all included horses for genetic testing. Informed consent for data collection were obtained from all the horse owners prior to the study.

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Results and discussion

WP1-Gait classification

Part 1

Development of algorithms for hoof events

For the hoof-on detection, the angular velocity algorithm was the most accurate with an accuracy between 2.39 and 12.22 ms and a precision of around 13.80 ms, depending on gait and hoof. For hoof-off detection, the acceleration algorithm was the most accurate with an accuracy of 3.20 ms and precision of 6.39 ms, independent of gait and hoof.

Part 2

Gait classification (GC) based on feature extracted models.

For all the different methods applied, the highest accuracy for classification was obtained when all variables were used, achieving a classification accuracy of 98.6% using a fully connected (FC) artificial neural network followed by 96.3% using the support vector machine model. If gait classification was based only on stride variables (e.g., stride duration and duty factor), poor classification accuracy was achieved. With the classification based on the two variables of Hildebrand (duty factor and lateral advanced placement), GC achieved a slightly higher accuracy, peaking at 78.7% using a decision tree. The highest confusion between classes was observed between pace and tölt.

Gait classification based on raw IMU data and LSTMs.

Classification using LSTMs on the raw normalized sensor data achieved a high classification accuracy, peaking at 95.5%. Gait classification based on a single sensor yielded poor accuracies, peaking at 79.9% only. Training based on sensors mounted on the upper body of horses, mainly head, withers and pelvis, yielded significantly higher accuracies (92.3%) and adding one limb sensor, pushed the accuracies only slightly higher (93.3%), achieving similar accuracies as the models relying solely on all four limbs (92.7%). The highest accuracy was observed using and training the network with the data from all available IMUs, this is, head withers, pelvis and all four limbs (98.9%).

Part 3

Upper body movement in relation to limb movements

Hmin/Pmin occurred at 55.0%/17.9% (walk), 46.5%/ 65.9% (trot), 44.4%/66.7% (pace) and 52.1% /60.3% (tölt) of the stance phase of the forelimb/hindlimb. All Hmax/Pmax occured within the last 10% of the stance, during suspension phase or the first 10% of next limb stance phase, except for Pmax at walk (75.7% of stance phase), see figure 1.

Manuscript is in preparation.

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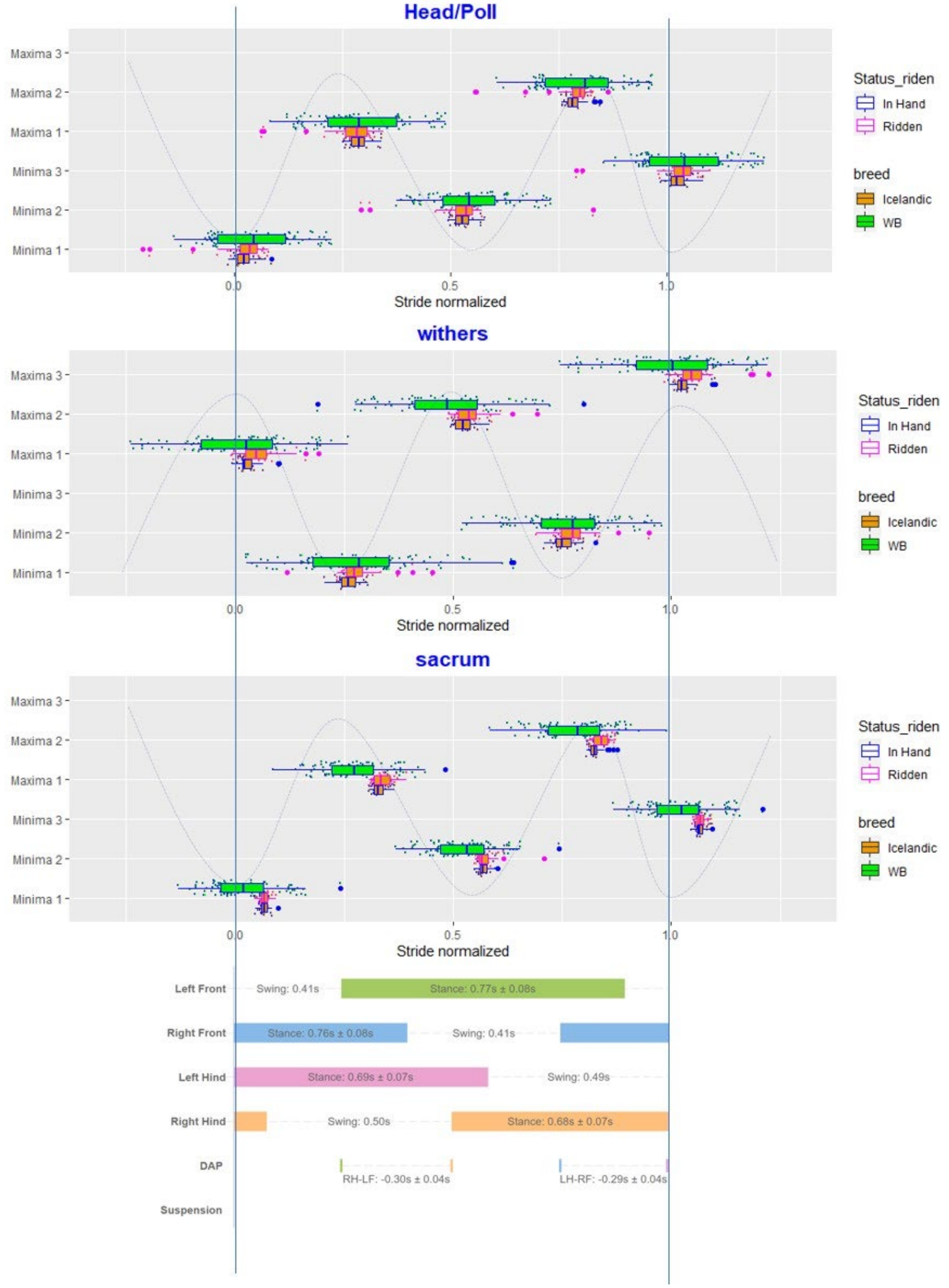

Figure 1 Illustration of the minima and maxima of head, withers and sacrum in relation to the stance phase of each limb during walk for Icelandic horses compared to warmbloods ridden and in hand.

WP2

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Identification of changes in movement symmetry of the head, withers and pelvis, sensitive for lameness detection in different gaits.

Differences in lowest position of the head (HDmin) identified forelimb lameness at walk and trot but not in tölt. Differences in lowest position of the withers (WDmin) identified lameness at trot in hand but not when ridden (figure 2).

Differences in lowest position of pelvis (PDmin) identified hindlimb lameness at trot, both in hand and when ridden but not in walk and tölt. Differences in lowest position of the withers (WDmin) identified lameness at trot when ridden but not in hand (figure 1).

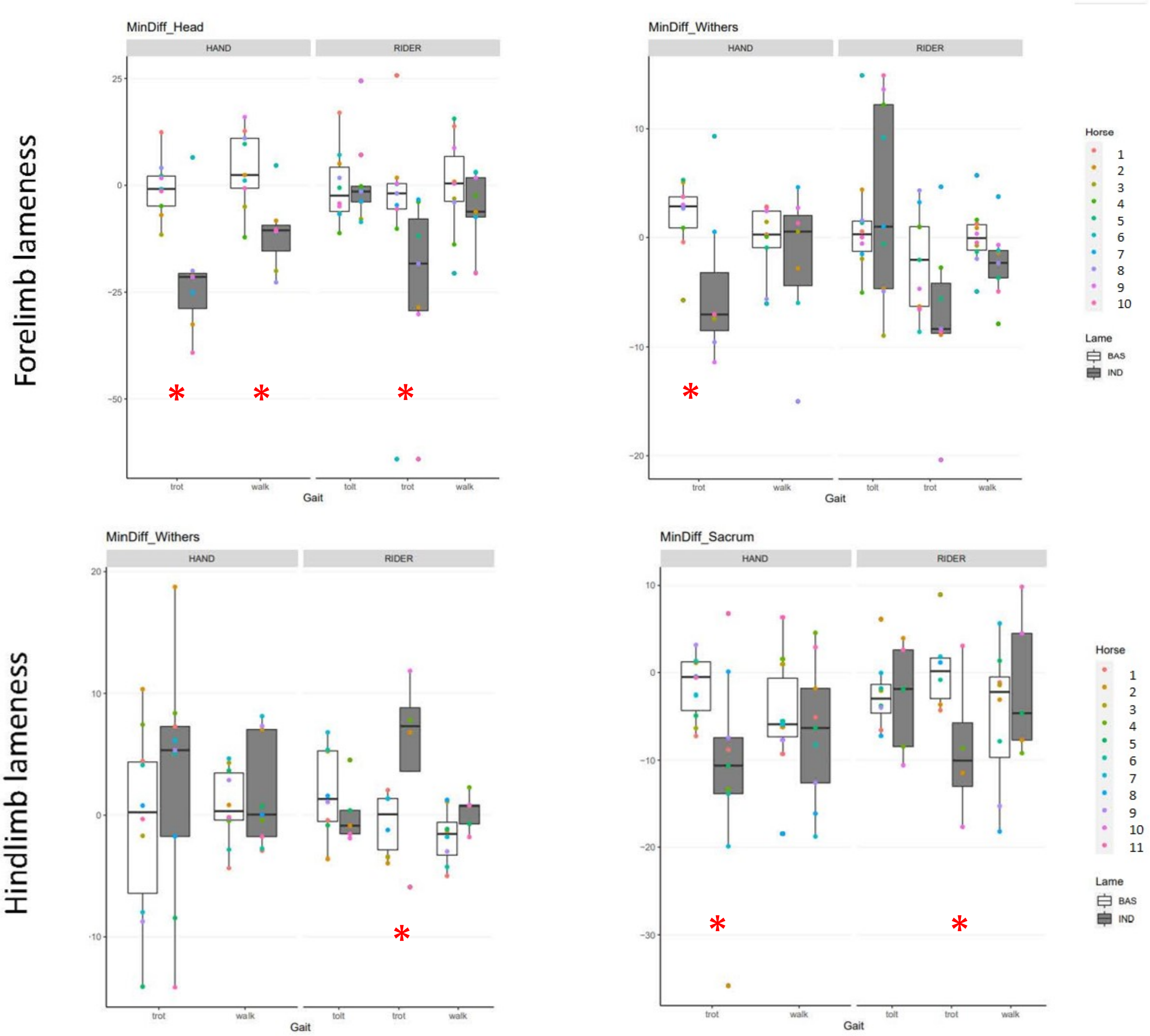

Figure 2 Differences in lowest vertical displacement of head, wither and pelvis are illustrated in horses with fore- and hindlimb lameness induction, performing different gaits either in

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*hand or when ridden. * Indicate for which variables and gaits a significant differences are seen after lameness induction.*

Further analysis of the data are in progress to identify other kinematic variables sensitive for lameness detection at toelt.

Finally the sensor system were tested in 80 Icelandic horses performing walk, trot and toelt without any technical problems and the analysis manage to measure movement symmetry of head, withers and pelvis in all gaits.

Conclusions

The angular velocity and acceleration algorithms look highly promising for identification of hoof-on and hoof-off events and can be used for gait classification purposes.

The algorithms developed for gait classification facilitated accurate gait classification that enables in-depth biomechanical studies and allows for highly accurate phenotyping of gait for evaluation of lameness, performance and genetic research and breeding.

Lowest position of the head (Hmin) and pelvis (Pmin) were closely related to midstance of the fore- and hindlimb respectively in all gaits, except for the Pmin at walk. Therefore, changes in vertical movement symmetry for Hmin/Pmin are probably good indicators of weight bearing lameness. Pmax is probably a good indicator of a push-off lameness, except for the walk.

Differences in lowest position of the head (HDmin) and pelvis (PDmin) are commonly used to quantifiy of forelimb and hindlimb lameness during trot (4). Also withers movement symmetry can be useful to detect lameness (5). For the Icelandic horses HDmin can be used to detect forelimb lameness at walk and trot but not for toelt.
Differences in lowest position of pelvis (PDmin) identified hindlimb lameness at trot, both in hand and when ridden but not in walk and toelt.
Therefore the commonly used symmetry variables used for subjective and objective lameness detection at trot are not valid during toelt and other variables need to be developed for lameness detection during toelt.

The performance of IMU-sensors with fully automatic gait classification and symmetry measures were tested in 80 Icelandic horses equipped with 9 sensors while they performed walk, trot and toelt with excellent performance.

Relevance for the practical horse sector incl. recommendations

The gaits, the temperament and the easy keeping of the Icelandic horse make it ideal as a pleasure horse, for tour-riding and for competitions where the gaits toelt and pace are shown. Sweden counts approximately 1000 licensed competition riders. The Icelandic horse has during the last 20 years become a very popular breed in Scandinavia, with approximately 13.000 registered horses in Norway, 31.000 in Sweden and 39.000 in Denmark. The breed is now the third largest breed in Sweden, and the largest in Denmark

However, the relatively few tools available to diagnose, manage and prevent orthopaedic diseases of Icelandic horses present an obvious weakness in the welfare management of this otherwise healthy breed. Early detection of lameness and increased ability to make a precise diagnosis will contribute to decreased suffering and even longer lives of these magnificent horses.

In the current project we have developed methods for identification of hoof-on and hoof off and methods for objective gait classification from IMU-sensors that can be used for field measurements. Objectively classified gaits is useful for objective lameness assessment but also to evaluate performance and to objectively phenotype gaited horses for genetic studies.

We have also investigated the normal upper body movement in relation to the limb events which is a prerequisite to understand compensatory lameness strategies in different gaits.

Finally we investigated specific compensatory lameness strategies in Icelandic horses performing walk, trot and tölt. The lameness measures used at walk and trot (vertical movement asymmetry of head and pelvis) cannot be used in toelt which is important knowledge when evaluating lameness in Icelandic horses. Further data analysis is needed to understand the compensatory strategies and to identify lameness measures during toelt.

The algorithms evaluated for gait classification and lameness has been tested in 80 Icelandic horses with an excellent performance.

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Part 3: Result dissemination

Scientific publications, *published*	Serra Bragança F.M., Broomé S., Rhodin M., Björnsdóttir S., Gunnarsson V., Voskamp J.,Persson-Sjodin E.P, Back W., Lindgren G., Novoa-Bravo M., Roepstorff C., Van der Zwaag B.J., Van Weeren P.R. and Hernlund E. (2020) Improving gait classification in horses by using inertial measurement unit (IMU) generated data and machine learning. Nature Sci Rep 10, 17785 (2020). https://doi.org/10.1038/s41598-020-73215-9
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	M. Tijssen, E. Hernlund, M. Rhodin, S. Bosch, J.P. Voskamp, M. Nielen, F.M. Serra Bragança (2020) A method for automatic hoof-event detection in horses based on hoof-mounted inertial measurement units. PlosOne https://doi.org/10.1371/journal.pone.0233266 https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0236138
Conference publications/ presentations	M. Tijssen, M. Rhodin, S. Bosch, J.P. Voskamp, M. Marin-Perianu, M. Nielen, W. Back, P.R. van Weeren, F.M. Bragança. (2018) Validation of gait event detection algorithm using hoof-mounted inertia measurement units (IMU) International Conference on Equine Exercise and Physiology, Australia, November 2018. https://www.wageningenacademic.com/doi/pdf/10.3920/cep2018.s1
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	Gunnarsson V., Tijssen M., Björnsdóttir S., Voskamp J.P., Van Weeren P.R., Back W., Rhodin M., Sjödin E.P., Serra Bragança F.M. (2018) Objective evaluation of stride parameters in the five-gaited Icelandic horse. International Conference on Equine Exercise and Physiology*, Australia, November 2018* https://www.wageningenacademic.com/doi/pdf/10.3920/cep2018.s1
Other publications, *media etc.*	Results from the three published papers have been disseminated in a popular manner through different media (SLU newsletter, HästSverige, Veterinärmagazinet, Facebook). https://www.slu.se/forskning/kunskapsbank/publicerat/sport--och-sallskapsdjur/hastnotiser/automatisk-klassificering-av-hastens-olika-gangarter/ https://www.slu.se/forskning/kunskapsbank/publicerat/sport--och-sallskapsdjur/hastnotiser/automatisk-analys-av-hasthovens-isattning/ https://www.facebook.com/djursjukhus/posts/4234453826582681/

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Oral communication, ***to horse sector, students etc.***	Veterinärkongressen November, Uppsala 2018, presentations Marie Rhodin and Elin Hernlund. Gait classification in the Icelandic horse and Upper body movement in the different gaits.

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