Sensor analysis and initial assessment of detectable first hoof contacts and last break-overs as unique signal fluctuations for equine gait analysis

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ABSTRACT: The objective of the control study was to assess 2 prominent fluctuations in a single optical signal as being either a true first hoof contact or a last break-over based on descriptive measures. The study builds on initial findings from a preliminary investigation of the embedded-optical-base system's (EOBS) capabilities in signal capturing and feasibility as potential alternative to existing gait technologies, such as piezoelectric (e.g., load cell) systems. Hoof contacts and break-overs were measured (0 to 1 au; arbitrary units) using a 2.4-m (length) × 0.9-m (width) platform containing 1 EOBS. Three mixed-breed horses (n = 3) were injected with saline or either 100 IU or 200 IU Botox (i.e., onabotulinumtoxinA) with a 2.5-mL final volume. Injections were made into the deep digital flexor muscle at the motor end plates, with electromyography and ultrasound guidance. Horses were observed for 3 time points (pre-, post-, and recovery test days) over the span of a 4-mo period. Signal fluctuations [i.e., amplitude of hoof impacts based on true first hoof contacts (ΔS_{TS}) and true last break-overs (ΔS_{TL})] and kinematics [i.e., complete gait pass (CGP) time duration (T)] were recorded from each horse. Visual observations and video analysis were used for determining gait pattern categories. Individual horse measurements were analyzed for each trial, compared with video data and classified. Comparison of primary signal fluctuations (i.e., ΔS_{TS} vs. ΔS_{TL}; forelimb vs. hindlimb) exhibited significant differences between hoof contacts and break-overs (P < 0.05). Right and left forelimb hoof contacts and hindlimb break-overs were not significantly different (P = 0.966; 0.063 ± 0.135; Estimate ± SE; P = 0.606; 0.176 ± 0.142; Estimate ± SE, respectively). Additionally, treatment vs. saline forelimbs did not exhibit significant difference (P = 0.7407; −0.098 ± 0.279; Estimate ± SE). Overall, data showed that the EOBS can collect repeatable and unique primary signal fluctuations as prominent and different gait measurements providing evidence to further development and research of the sensing system.

Key words: equine, gait analysis, optics, sensors

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INTRODUCTION

Animal stepping, tracking, and various gait behaviors are indicators used for assessing welfare

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problems, such as lameness (Krohn and Munksgaard, 1993; Haley et al., 2001). Lameness represents a welfare issue due to prolonged pain and discomfort that may occur and result in severe disorders such as colic and weight loss (Scott, 1989; Pluk et al., 2012). In horses, musculoskeletal problems also represent a significant economic impact on owners and the equine industry due to loss in sales and fees (USDA, 2001; Moorman et al., 2013b). Early detection could be an effective method to preventing lameness from developing into a chronic condition (Clarkson et al., 1996). Technologies developed for early detection of lameness require analysis of obtained signal readings so as to detect motion changes before visual lameness is observed. Studies have shown that stationary force platform kinetic and optical kinematic systems were sensitive to detecting changes in the walk when only slight lameness was visible at the trot (Moorman et al., 2013a, 2014). However, current systems can be lacking in dynamic range, limited in use outside of research, and require high input costs as suggested by Prankel et al. (2017). As such, the scope of the study was to evaluate a new optical sensor's signal readings and its capabilities to detect gait features as a potential alternative to existing lameness detecting technologies such as piezoelectric (i.e., load cells) and pressure mats. The main objective of this study was to identify 2 primary signal fluctuations as uniquely different within a single linear optical signal. Additionally, this study aimed to describe the signal fluctuations as either true (i.e., anomaly/noise free) first hoof contacts or last break-overs from descriptive statistical analysis. Video and signal data collected during animal walks over the EOBS were compared for validating signal fluctuations with respect to time.

MATERIALS AND METHODS

The research protocol for this study and all procedures involving animal handling were approved by the Colorado State University (CSU) Institutional Animal Care and Use Committee (IACUC; approval number 16-6611AA). Experiments were conducted over 3 time points; test 1 and 2 occurred in January 2017, and test 3 was completed in May 2017.

Animals and Housing

A total of 3 clinically normal, mixed-breed horses were used.[1] Horses were comprised of 1 mare and 2 geldings at 3, 4, and 5 yr of age with weights at 471.76, 351.53, and 476.27 kg, respectively. Horses were encoded as C, A, and B. Horses were housed individually and provided ad libitum water with feedings twice a day. Facilities and horses were inspected daily. Horses were visually sound at a walk. Horses did not have their feet trimmed and balanced prior to evaluation. All horses were acclimated to the Equine Orthopaedic Research Center (EORC) Gait Analysis Laboratory prior to data being collected.

Platform Design and Procedure

The EOBS platform was based on current commercial dimensions [0.914 m (width) × 2.438 m (length) × 0.051 m (height)] found in standard livestock scales. An adjustment feature of an additional 1.219 m of 1¼ inches rubber matting at the start and end of the platform was implemented. The EOBS platform was constructed of 1 optical sensor attached and protected within a metal case.

The EOBS platform had an approximate holding capacity of 1361 kg. A protective rubber matting was placed underneath to eliminate noise in signal readings. A signal-base-unit (SBU) logged hoof contact as signal fluctuation and time with a rate greater than ~50 average samples per second (s). A laptop with commercial software was used to graph and analyze readings. Data was saved offsite using custom code. A single standard camera system was used to record the position of the horses' limbs during walks over the EOBS platform. Videos were synchronized with the signal readings. Signal observations were initiated when a horse placed its first forelimb on the EOBS platform and ended once the final hindlimb lifted off the platform.

Experimental Design

An experimental, repeated-measures design was used to compare multiple horse signal readings for 3 d over a 124-d period. Horses were acclimated to the EORC facility, tools, and handling for approximately 1 wk prior to commencement of the study. Individual horses were evaluated by the research veterinarian before gait analysis. Horses were compared with themselves before and after intramuscular injection. The testing of the optical system was done in conjunction with a study investigating the effects of 2 doses of Botox on muscle function and limb kinetics and kinematics for veterinary usage. The experimental design was a 3 (days) × 3 (horses) × 3 (treatments) factorial arrangement, and horse was the experimental unit.

[1]Four horses were initially enrolled. However, prior to the start of the study 1 horse was removed due to complications that led to its inability to properly complete the tests for data collection.

Experimental design allowed for control of intra- and interanimal and day variations in signal readings. Both forelimbs were injected. One randomly assigned forelimb of each horse had a saline injection and the contralateral limb had Botox injected (100 or 200 IU). Limbs were retreated 4 mo after the study with opposite forelimb having saline or Botox dose in contralateral limb. Injections were made in the deep digital flexor muscle at the motor end plates of the forelimb. Electromyography (EMG) was used to determine end plate locations. The study was not balanced due to 1 animal removed prior to testing leaving only 3 animals to be tested. Three test days were compared: D−4 (sound/baseline, defined as 4-d pretreatment), D+3 (peak treatment, defined as 3-d post-treatment), and D+124 (recovery period, defined as 124-d post-treatment). Days were compared along with fore- and hindlimb primary signal fluctuations (true first hoof contact or last break-over). Days D−4, D+3, and D+124 were based on previous treatment models validated by Carter and Renfroe (2013), Wijnberg et al. (2013), and Hardeman et al. (2013).

Data Processing

Data were collected from all 3 horses walking over the embedded-optical-base system (EOBS). Video observations were analyzed to detect and determine both valid and invalid periods of recorded hoof impacts. Hoof contacts which were made within the sensor's detection zone (i.e., detectable 3 (column) × 4 (row) gridded sector and 1-in. dead zone border; Figure 1) were identified and considered valid as they corresponded to either a hoof contact or a break-over reading. Video observations allowed for removal of inaccurate hoof readings during the recording periods (e.g., hoof placement half off the platform). Analysis was performed using varying methods from Pastell et al. (2006), Chapinal et al. (2010), and Conte et al. (2014).

Data measured were first hoof contact (i.e., when a hoof impacted the platform prior to a second hoof's impact; ΔS_{TS}) and last break-over (i.e., when the last hoof lifted from the platform; ΔS_{TL}). Signal amplitude (i.e., peak-to-peak curves) was measured from signal fluctuations. Limb placement on the EOBS platform was also evaluated. Stance time (i.e., when a hoof was in contact with the platform prior to being lifted) was recorded for future analysis. Additionally, swing time (i.e., when a limb was in movement from the platform to its next impact) was not analyzed with initial analysis due to time constraints though it is an influencing factor on hoof contact and break-over. First hoof contacts and last break-overs were considered true (i.e., valid anomaly/noise free) signal fluctuations and analyzed for any significant trends as to their difference. Horses walked at a steady pace on the platform (Figure 2) with additional detailed

R4 | C3	R3 | C3	R2 | C3	R1 | C3
R4 | C2	R3 | C2	R2 | C2	R1 | C2
R4 | C1	R3 | C1	R2 | C1	R1 | C1

Figure 1. Example of EOBS platform grid rows (P_R) and columns (P_C). White border represents platform's signal dead zone. Shaded areas represent signal detection zone.

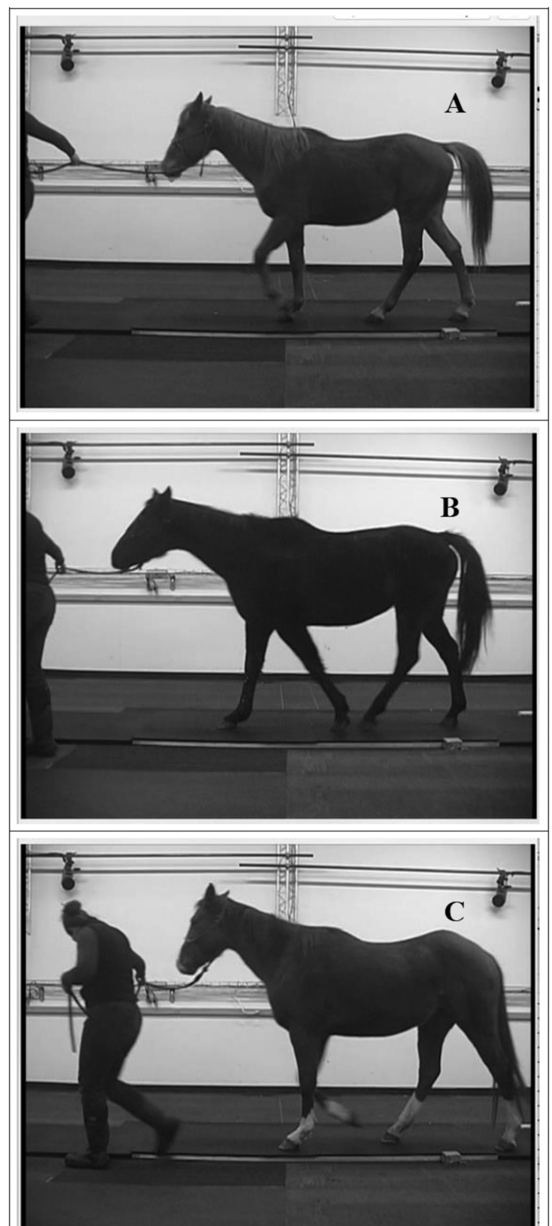

Figure 2. Images of horses walking across EOBS for 1 test day.

descriptions of the gait recorded by a trained observer. Specific criteria were utilized to determine signal data for each horse. Horse signals for each pass were classified either valid or nonvalid. Valid signals (e.g., signals without interruptions from missteps out of the grid or extended pauses on the platform) were analyzed.

Statistical Analysis

Primary signal fluctuation data [i.e., true first hoof contact (ΔS_{TS}) and true last break-over (ΔS_{TL})] were tested for normality using the *pearson.test* function from the *nortest* package in Gross and Ligges (2015). Due to random occurrences during walks over the EOBS, data were not normally distributed; thus, data were log transformed. Signal readings were continuous and fit to a linear mixed model to assess differences between primary signal fluctuations. Left and right fore- and hindlimbs were not reported separately but categorized together due to separate limb samples being largely skewed and limited in providing reasonable comparisons. Initial correlation tests were measured between time (T), platform grid (P_R = row; P_C = column) and primary signal fluctuations (ΔS_{TS} and ΔS_{TL}). The *lme4* package was used for Welch-Satterthwaite's *t*-tests to look at the difference between ΔS_{TS} and ΔS_{TL} to assess their usability as signal markers for walks over the EOBS (Bates et al., 2015). The model (1) was fitted and expressed as

$$Y_{pjk} = a + T_i + C_p + Hj_k + e_{pjk} \quad (1)$$

where Y_{pjk} represents primary signal fluctuation (ΔS; log transformed) observed in day k, in animal j, and by ΔS classification p (ΔS_{TS} or ΔS_{TL}); a is the intercept; T_i is the fixed effect of time i (T); C_p is the fixed effect of pth ΔS classification (ΔS_{TS} or ΔS_{TL}); H_{jk} is the repeated-measures term for jth horse within day k due to horses performing multiple walks over the EOBS platform within a test day; e_{pjk} is the residual term. Estimates, standard errors and P-values for fixed effects of primary signal fluctuations (ΔS_{TS} or ΔS_{TL}) and time (T) were reported for the model (1). Proportion of variance (R^2) for fixed and random effects for the model (1) was determined using the *MuMIn* package in R (Barton, 2018; R Core Team, 2018; RStudio Team, 2018). A secondary linear mixed model was constructed to assess limb (left or right; forelimb or hindlimb) and treatment (Botox or saline injection) differences. Treatments of 100 and 200 IU were combined (i.e., Botox group) for analysis. The model (2) was fitted and expressed as

$$Y_{pjk} = a + T_i + L_t + R_p + H_{jk} + e_{pjk} \quad (2)$$

where Y_{pjk} represents primary signal fluctuation (ΔS; log transformed absolute value) observed in day k, in animal j, and by treatment method p (Botox or saline); a is the intercept; T_i represents the fixed effect of time i (T); L_t represents the fixed effect of limb t (left or right; forelimb or hindlimb); R_p represents the fixed effect of treatment method p (Botox or saline); H_{jk} is the repeated-measures term for jth horse within day k; e_{pjk} is the residual term. Estimates, standard errors, and P-values for fixed effects of limb, treatment, and T were also reported for the model (1.2). Pairwise comparisons using the *lsmeans* package compared differences between primary fluctuations (ΔS_{TS} or ΔS_{TL}), limbs and treatments (Lenth, 2016). A P-value of ≤0.05 was considered significant. A single model should have been utilized during analysis however, due to related variables found in the first model the study required analysis of multiple models.

RESULTS AND DISCUSSIONS

Repeatability Study

Prior to injection, all 3 horses were found clinically sound. Soundness was defined as the ability to move freely using 4 limbs and showing no evidence of abnormal weight-shifting, non-weight-bearing behavior, and/or reluctance to walk on any limb (Pairis-Garcia et al., 2015). Horses demonstrated no additional signs of systemic disease during the testing period. Peak treatment effects were assumed to be exhibited on D+3 based on previous studies (Carter and Renfroe, 2013; Hardeman et al., 2013; Wijnberg et al., 2013). No visual signs of lameness were observed between treatments and no horses became non-weight-bearing during the testing period. Horse limbs for all treatments exhibited minute differences in signal fluctuation strength. It was also noted that due to the location of the treatments in each limb and the EOBS's sampling threshold at the time of study, noticeable gait fluctuations in the signal may have been reduced. Thus, sensor fluctuations between saline and treated limbs were not reported separately in the initial analysis but utilized as a factor within horse and day to explain deviations within the model. However, inflictions or stress on a limb (proximal or distal) may change how an animal places it, resulting in noticeable deviations. Observed variables were then calibrated on the basis of animal's gait characteristics to eliminate horse effects as suggested by Zhao et al. (2018).

Distribution of Signals

A total of 53 normal ΔS_{TS} (n = 53; Table 1) and 53 normal ΔS_{TL} (n = 53; Table 1) for horses A, B, and C were collected and used for analysis (Figures 3 and 4). A Savitzky-Golay low-pass filtering was used for adjusting the signal baseline. Mean hoof contacts and break-overs were calculated ($\Delta S_{TS} = -0.426$; $\Delta S_{TL} = -0.045$). Ratio means (±SD) were used to standardize values and determine variation between ΔS_{TS} and ΔS_{TL} (Table 2). Horse C's ΔS_{TL} exhibited greater variability (0.132 ± 0.084; ratio mean ± SD). Due to Horse C's small number of recorded passes over the EOBS, extremes in deviations and/or variability may be noticeable as inflated differences. Individual horses crossed the EOBS at a consistent speed during each walk with an average hoof impact time (ST_{avg}) of 0.67 s and an average break-over time (LT_{avg}) of 0.79 s. Average hoof impact time (ST_{avg}) and LT_{avg} were based on ΔS_{TS} and ΔS_{TL} variables as an assumption that animals will maintain a symmetrical pattern for each secondary hoof contact and break-over while walking across the EOBS. Sound animals exhibit left-right symmetry of limb placement and motion during a walking gait while asymmetry is expressed by differences in stride duration, stride length, and number of spacing frames (Maertens et al., 2011; Zhao et al., 2018). Thus, a single horse was used as its own control for determining soundness. Any noticeable asymmetries would allow for the assumption that the animal was lame as studies on horses with induced lameness have reported within-animal changes for various gait variables (Buchner et al., 1996; Keegan et al., 2001; Pluk et al., 2012). Observable differences between horses were found across the 3 d. For ΔS_{TS}, horses A and C's signal amplitudes increased over the testing period while horse B's amplitude decreased during D+3 and increased again for D+124 in signal amplitude (Figure 5). For ΔS_{TL}, horses A and C's signal amplitudes decreased over the testing period while horse B decreased during D+3 and increased again for D+124 in signal amplitude (Figure 6). As seen by Figures 5 and 6, ΔS_{TL} and ΔS_{TS} are closely associated to each other. From these observable trends, horses A and C may have incurred slight functional changes in muscle activity due to treatments causing deviations in variability found in ΔS_{TS} and ΔS_{TL}. Alterations in muscle activity may modify limb motion resulting in perceived changes in the signal. However, additional factors such as velocity, hoof impact location, and limb (i.e., right vs. left) may have also influenced deviations in signal fluctuation variability.

Evaluation of Signal Correlations

Simple correlations were examined based on time to cross the platform (T), primary signals (ΔS_{TS} and ΔS_{TL}), and platform grid (P_R = row; P_C = column) to examine initial relationship trends in the data. Weak positive correlation (r = 0.085) between T and ΔS_{TS} was observed. Additionally, a weak negative correlation ($r = -0.148$) was observed between T and ΔS_{TL}. Both observations indicated that T does not have a linear relationship with ΔS_{TS} and ΔS_{TL} allowing for their use without noticeable interference. However, time and velocity are traditionally related with faster velocities having been shown to influence stance, swing, hoof contact, and break-over (Moorman et al., 2013b). Thus, lacking relationship along with exclusion of velocity may have reduced any noticeable differences for T with ΔS_{TS} and ΔS_{TL} (Goodwin and Leech, 2006). Platform row (P_R) had a moderately positive correlation (r = 0.5142) to ΔS_{TS} and moderately correlated (r = 0.457) to ΔS_{TL}. Both ΔS_{TS} (r = 0.336) and ΔS_{TL} ($r = -0.507$) were moderately correlated to platform column (P_C). Last break-over

Table 1. Observations (i.e., visual counts) of total true first hoof contacts (ΔS_{TS}; forelimb) and true last break-overs (ΔS_{TL}; hindlimb) along with left and right limb counts for individual horses (n = 3) at a walking gait for 3 d (pre-, post-, and recovery) over a 4-mo period

	First hoof contact (ΔS_{TS}; forelimb)			Last break-over (ΔS_{TL}; hindlimb)		
Animal	Normal[1]	Left[2]	Right[3]	Normal[1]	Left[2]	Right[3]
Horse A	16	8	8	16	5	11
Horse B	22	5	17	22	5	17
Horse C	15	9	6	15	5	10
Total	53	19	34	53	15	38

[1]Total normal hoof contact (fore- or hindlimb) with EOBS. Normal was considered an impact or break-over that did not show signs of deviation or error during its contact with the EOBS.

[2]Left hoof contact (fore- or hindlimb) with EOBS.

[3]Right hoof contact (fore- or hindlimb) with EOBS.

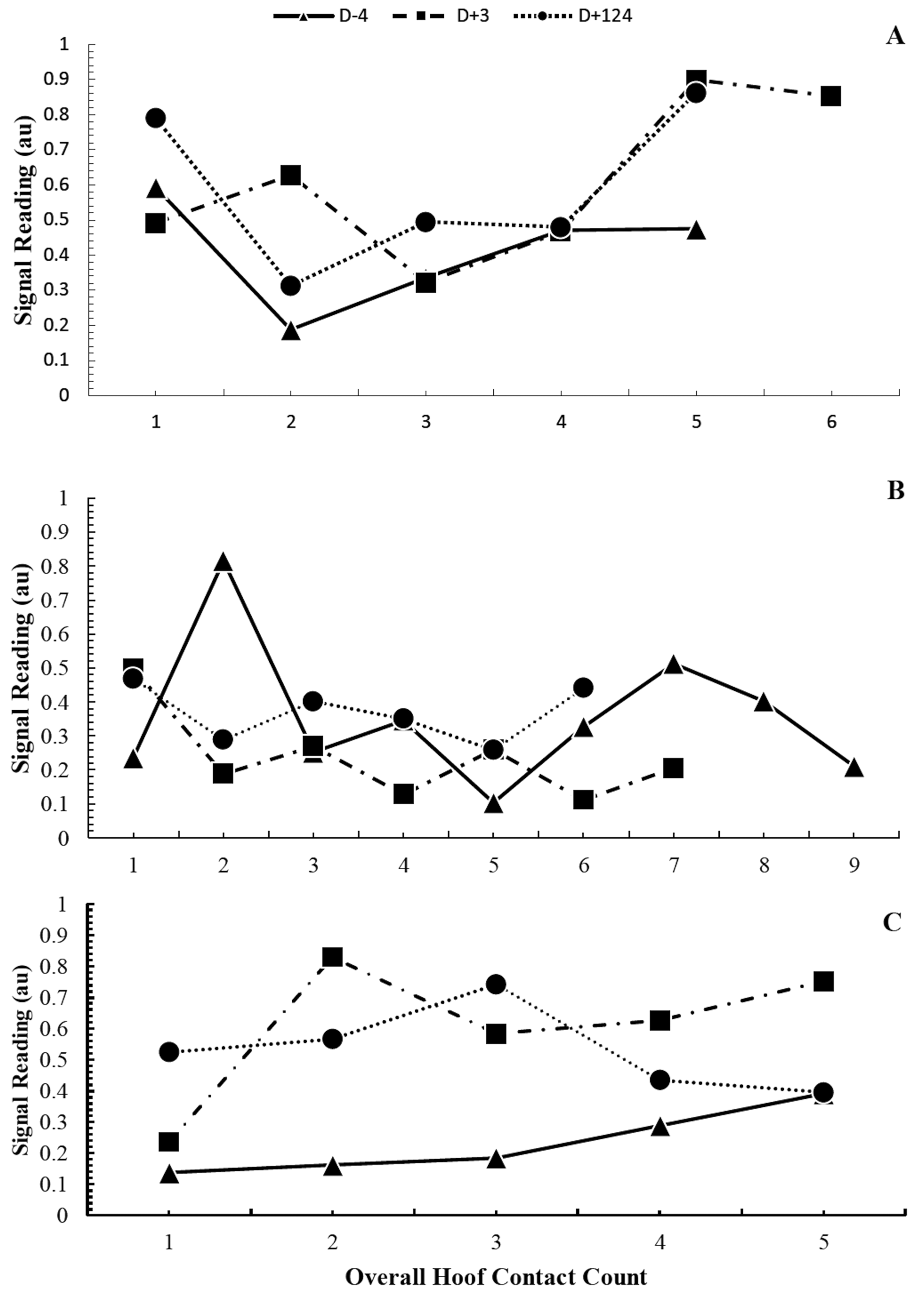

Figure 3. Plots of true first hoof contact signal amplitudes (ΔS_{TS}; au) for visual trend analysis between pretreatment (D−4; solid line), peak treatment (D+3; dashed line), and post-treatment (D+124; dotted line) days per horse (A, B, and C) reported over a 4-mo period.

(ΔS_{TL}) was stronger in correlation to P_C related to sensor position and mechanical flex. However, ΔS_{TS} was strongly correlated to P_R due to proximity within the sensor's detection zone. Both moderate correlations between signal strength for ΔS_{TS} and ΔS_{TL} with P_R and P_C are expected trends based on the EOBS platform construction.

Analysis of First Hoof Contact and Last Break-over Signals

Primary signal fluctuations were significant ($P < 0.05$; −3.434 ± 0.382, ΔS_{TS}; 2.209 ± 0.102, ΔS_{TL}; Estimate ± SE, Figure 7), whereas T was not significant ($P = 0.441$; 0.368 ± 0.475; Estimate ± SE) within the model (1). True ΔS_{TS} exhibited moderate negative estimated correlation with ΔS_{TL} (r = −0.595). Time (T) exhibited negative estimated correlation with ΔS_{TL} (r = −0.966). Moderate positive estimated correlation between ΔS_{TS} and T was observed (r = 0.514). Roughly 84% of variability (R^2 = 0.836; Fixed) in the model (1) is explained by ΔS_{TS}, ΔS_{TL}, and T. Additionally, ~2% of variability (R^2 = 0.858; Fixed + Random) in the model (1) was accounted for due to horse within day and horse. By including the effects of horse and day, primary fluctuations

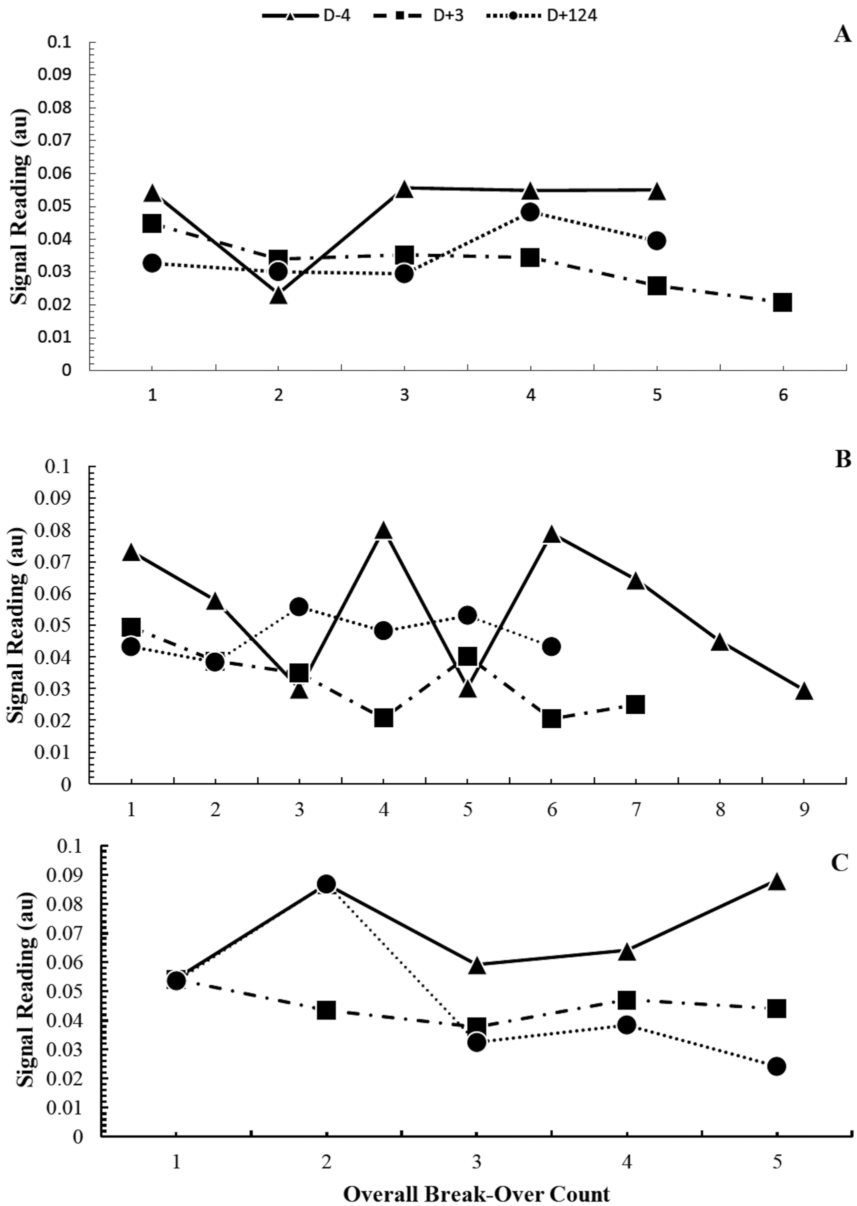

Figure 4. Plots of true last break-over signal amplitudes (ΔS_{TL}; au) for visual trend analysis between pretreatment (D−4; solid line), peak treatment (D+3; dashed line), and post-treatment (D+124; dotted line) days per horse (A, B, and C) reported over a 4-mo period.

Table 2. Overall descriptive statistics of true first hoof contacts (ΔS_{TS}; forelimb) and true last break-overs (ΔS_{TL}; hindlimb) for individual horses (n = 3) at a walking gait for 3 d (pre-, post, and recovery) over a 4-mo period

Animal	Min	Max	Range	Median	Ratio mean (±SD)
First hoof contact[1]					
Horse A	−0.899	−0.187	0.711	−0.485	0.924 ± 0.033
Horse B	−0.815	−0.103	0.712	−0.278	0.865 ± 0.046
Horse C	−0.829	−0.137	0.692	−0.435	0.868 ± 0.084
Last break-over[2]					
Horse A	−0.056	−0.021	0.035	−0.035	0.076 ± 0.033
Horse B	−0.080	−0.020	0.060	−0.043	0.135 ± 0.046
Horse C	−0.088	−0.024	0.064	−0.043	0.132 ± 0.084

Max, min, range, median, and ratio mean (±SD) based on signal output (S_O) in arbitrary units (au) from a corrected baseline.

[1]True first hoof contact (ΔS_{TS}) recorded during animal hoof impact on EOBS.

[2]True last break-over (ΔS_{TL}) recorded during animal toe-off from EOBS.

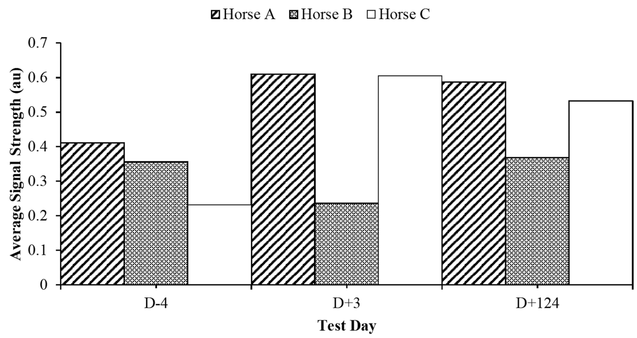

Figure 5. Histogram of average true first hoof contact signal amplitude (measured in arbitrary units) between horses relative to 3 d (pre-, peak, and post-treatment) over a 4-mo period. Horses A and C increased in signal amplitude over the study period while horse B dipped during D+3 and increased again for D+124 in signal amplitude. Horse B followed an inverted trend compared to horses A and C.

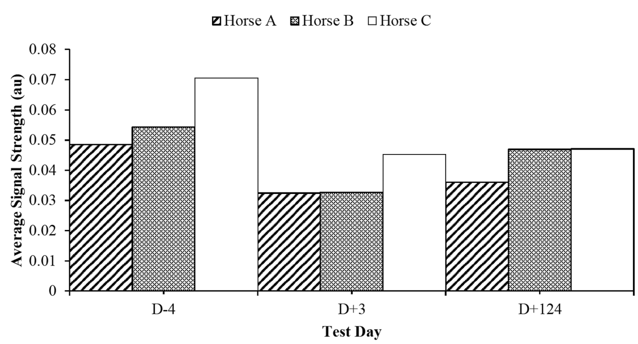

Figure 6. Histogram of average true last break-over signal amplitude (measured in arbitrary units) between horses relative to 3 d (pre-, peak, and post-treatment) over a 4-mo period. Horses A and C decreased in signal amplitude over the study period while horse B dipped during D+3 and increased again for D+124 in signal amplitude. Horse B followed an inverted trend compared to horses A and C.

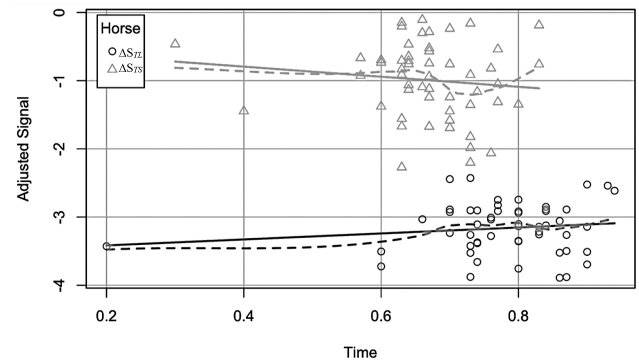

Figure 7. Scatter plot comparison between adjusted signal amplitude (y-axis) for horse break-overs (ΔS_{TL}) and hoof contacts (ΔS_{TS}) and time duration (*T*; x-axis). Solid lines represent linear trends and dashed lines represent moving mean trends. Open circles represent break-overs (ΔS_{TL}) and open triangles represent hoof contacts (ΔS_{TS}) per horse. True break-overs and hoof contacts exhibit clear separation indicating difference between primary signal fluctuations.

with respect to animal influence were considered more accurate. True first hoof contact (ΔS_{TS}) and last break-over (ΔS_{TL}) values may have differed due to asymmetry (i.e., unevenness) in weight bearing (i.e., limb shifting). The center of gravity is closer to a quadruped's forelimbs (i.e., 60% to 65% of body weight) and could result in larger fluctuations (Baxter et al., 2011). Limb placement on the platform relative to the embedded sensor's location or outside of the sensor's detection zone also influenced signal strength. Signal fluctuation strength was shown to be associated with contact location in previous studies and may result in greater deviations between passes. Slight animal hesitation, observed during video analysis of passes over the EOBS, may have also contributed to small horse deviations. However, comparison between right and left limb hoof contacts and break-overs from model 2 were not significantly different for fore- or hindlimbs ($P = 0.966$; 0.063 ± 0.135; Estimate ± SE; $P = 0.606$; -0.176 ± 0.142; Estimate ± SE, respectively). Additionally, treatment (i.e., Botox) vs. saline forelimbs did not exhibit significant difference ($P = 0.7407$; -0.098 ± 0.279; Estimate ± SE). It was noted that limb stance phase while in contact with the EOBS and secondary limb's swing phase contributed to weight shifting causing first hoof contact signals to deviate on the tail-end of a signal fluctuation. As such, implementing animal body weights to attributed shifting could allow understanding the relative quality of primary fluctuations. Minimizing the number of nonvalid signals (e.g., signals with interruptions from missteps out of the grid or extended pauses on the platform) can be addressed by adjusting the platform design while integrating observed secondary fluctuations to better assess signals. The authors recognize that the small sample size reduces statistical robustness of the study. However, despite the small sample size, differences were found that a follow-up study with a greater sample size could possibly allow for smaller statistical differences to show. Although there are limited significant results, existing patterns could result in true significance from a larger sample size and be useful for future second-phase research (Tsang et al., 2009). Additionally, within a larger study, left and right fore- and hindlimbs will be observed separately so as to analyze limb signals both combined and separately as fluctuations may vary depending on the set of limbs.

Conclusions

The use of sensor-oriented techniques is a growing field for lameness detection. High-speed cameras to investigate locomotion and hoof contact (Herlin and Drevemo, 1997; Meyer et al., 2007) and systems for ground reaction force detection (Tasch and Rajkondawar, 2004) coupled with motion analysis software (Flower et al., 2005) have provided sensitive indicators for limb assessment (Pluk et al., 2012). The studied EOBS proved a reliable source for continuous automatic recording of unique signal fluctuations and showed potential to be a new addition to this group of technologies. The EOBS was found to be able to detect the 2 primary signal fluctuations as being uniquely different within the linear optical signal. Video and signal data collected during complete gait passes (CGP) over the EOBS platform were compared for validating signal fluctuations with respect to time (*T*). As such, the 2 primary signal fluctuations were described as either true (i.e., anomaly free) hoof contacts (ΔS_{TS}) or break-overs (ΔS_{TL}). Additionally, the 2 observed gait variables (ΔS_{TS} and ΔS_{TL}) provided segmentation between animal passes. Horses' estimated velocities ($\sim v$) were not calculated due to further research needed to determine the accuracy of the estimate from observed segmentation. Lastly, differences between ΔS_{TS} and ΔS_{TL} resulted in mechanical thresholds between CGP that provided individual horse evaluation.

Further research should be conducted to evaluate the signal's detection and representation of multiple secondary hoof contacts and break-overs within an animal's CGP over the EOBS. Also, evaluating animals' pain sensitivity (i.e., pain threshold before gait deviations are exhibited) during CGP over the EOBS is needed to understand various degrees of lameness such as transient lameness (i.e., short-lived gait issue; pain not exhibited as a long-term gait deviation). Further research should be conducted with a broader set of different types of livestock and should be based on blind assessment of lame vs. sound animals of the same species. Larger datasets of animals should be assessed with a species-specific numerical lameness scale by an experienced scorer. For example, in cattle lameness studies the Step-Up Beef Cattle Locomotion Scoring System (Zinpro Corporation, https://www.zinpro.com) can be utilized. Animals would also be tested on the optical sensor by an assessor who is blind to the numerical scoring system.

This study provided information on the potential use of optics for gait analysis and future lameness detection. By analyzing prominent signal fluctuations such as first hoof contacts (ΔS_{TS}) and last break-overs (ΔS_{TL}), observed signal fluctuations in the linear optical signal proved reliable discriminant measures. Continued research and development could provide a robust new sensing technology for detecting subclinical lameness.

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Conflict of interest statement. None declared.

LITERATURE CITED

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