To do

Widen

Finish address comments as best as I can

Jess limb events definition.

Start R.

Motion index – just sum of activity – divide by observation period ? or proxy of behavior? They have minutes also.

Standard deviation of which subset of data.

Remove Pactivity change – same as standing counter

Plot typical activity

Make it so Swing dur doesn’t break it when implementing the other variables?

Typical Swing Phase diagram – typical step diagram

Then - Redo speed

Hourly variables

Novel Features – Section

Send Laurence revised first section with all the analysis presentable?

Email Maher

Interpretive summary

**Generalizability of indicators of impaired locomotion**

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**Abstract - 214**

Automated lameness detection research using pedometers has to date been primarily based on cow behavior, changes in behavior over time and comparisons to healthy herd mates. These approaches have been the basis of several studies which have reported reasonable levels of accuracy (up to 91%) in one off and generally small studies. However, no independent replication of any of these studies have been reported. Widespread adoption of automated lameness detection has thus not been supported by a robust evidence basis of a high efficacy broadly generaliseable automated lameness detection system. This paper examines several behavior and gait features previously identified as being associated with lameness from several papers from mostly indoor herds and are assessed in four pasture based trials (Ireland) and one indoor controlled experiment (Germany). Five cohorts consisting of 75 unique cows are studied using 10 Hz and 100 Hz accelerometers in Ireland and Germany respectively. The mean and variance of variables such as lying time, lying bouts, swing phase duration of a step and speed are examined in relation to locomotion score and changes in locomotion. In general, the associations with lameness reported in past studies were not supported in this study. The raw data and analysis script for the reported analyses are made freely available to support further development of automated lameness detection.

Acknowledgments: the authors would like to thank the locomotion scorer in Teagasc Moorepark, Noel Byrne, and the authors of (Haladjian et al., 2018) for sharing their data for inclusion in this study.

# Introduction

Lameness is considered to be one of the biggest welfare issues associated with dairy farms given its endemic nature and the severity of the associated pain (Dolecheck and Bewley, 2018). Automated detection of lameness is seen as a potentially important tool that would aid in addressing lameness similar to how milk-recording or pre-stripping is currently used to manage mastitis (Alsaaod et al., 2019). Various approaches for automated lameness detection are in development including pressure plate based systems which cows walk over and various computer vision based approaches (Van Nuffel et al., 2015). However, commercially available systems are still rare (IceRobotics, 2017). Accelerometers are becoming increasingly prevalent on dairy farms. This is primarily for heat detection purposes and general behavior measurement (standing, lying, rumination, walking, etc). This study focuses on using these or similar accelerometers. We examine how well previous findings a recent review by several of the present authors (in preparation) generalize to cows at grass.

Lameness detection using these behavior measures has been attempted and been modestly successful (Kamphuis et al., 2013; Thorup et al., 2015). A review paper by some of the authors (in preparation) concluded that gait measures are likely required to complement these behavior measures to increase the accuracy of lameness detection in a binary lame/non lame system and to facilitate the development of automated locomotion scoring on a scale to quantify lameness severity. Gait variables have the potential advantage of providing a lameness ‘signature’ which would be independent of cow management variables. For example, walking and rumination are likely to be influenced by management (REF) and estrus while lying time is influenced by precipitation when cows are grazing (Thompson, 2018). Gait measures associated with lameness may thus be more robust variables and may generalize better across contexts when implementing automated lameness detection.

In the review it was found that the key behavior variables identified were:

1. Activity/walking duration (Thorup et al., 2015) and step count (Byabazaire et al., 2019);
2. The ratio of day to night time activity (Van Hertem et al., 2013);
3. Standing & lying bouts and swaps (changes in behavior) (de Mol et al., 2013; Kokin et al., 2014; Beer et al., 2016; Byabazaire et al., 2019); and,
4. Rumination time (Van Hertem et al., 2013; Beer et al., 2016).

The key gait variables measurable by accelerometers were:

1. Asymmetry in variance (requires two pedometers) of the forward acceleration (Pastell et al., 2009) and swing phase (Alsaaod et al., 2017);
2. Step phase % and swing phase % (Alsaaod et al., 2017) – proxies of asymmetry with one pedometer;
3. Walking speed (Chapinal et al., 2010; Alsaaod et al., 2015; Beer et al., 2016);
4. Stride distance (Beer et al., 2016; Alsaaod et al., 2017);
5. Weight shifting while standing (Chapinal et al., 2011; Thorup et al., 2015); and,
6. Average individual step cycle duration (s) (Flower et al., 2005)

Some of these studies reported good automated lameness detection accuracy in relatively controlled experimental conditions. We present an analysis of five trials. Four of these were where accelerometers were attached to cows legs collected x,y,z at 10 Hz using the prominent research tool RumiWatch pedometer. Three of these trials were at DairyGold research farm and the fourth at a nearby commercial farm. In the fifth trial, yaw, pitch, and roll data (i.e., gyroscopic data) in addition to x,y,z data at 100 Hz resolution were collected using a custom device (Haladjian et al., 2018).

We present methods of collecting the data and calculating relevant variables in the materials and methods. How these variables are associated with the locomotion score of the relative to expected findings based on past research are then presented. Then we discuss the implications of the findings before concluding remarks.

# Materials and methods

### Data collection

Data was collected from five trials. The sample size of individual trials was limited by the number of pedometers available at any given time – hence multiple smaller trials. Trials 1-4 were carried out by the authors in Ireland. Trial 5 is a secondary analysis of the data collected by (Haladjian et al., 2018).

### Trials 1-4

For four of the trials – those in Ireland – the cows studied were lactating grazing cows milked twice a day with minimal supplementation. As the cows were grazing, they so walked to and from the paddock twice a day and accelerometer data was recorded for several days varying with the duration of each trial varying depending on operational requirements at the time (Table 1).

For three of the trials (1, 3 & 4), the cows were locomotion scored twice to assess changes in locomotion (Table 1). Three of the trials (1, 2 & 3) were at DairyGold research farm and one at a nearby commercial farm (4). Trial 5 was collected by a separate team of researchers in Germany.

Trials 1-4 employed one experienced locomotion scorer based at Teagasc Moorepark. The DairyCo 0 to 3 scale was used to assess the cows, with 0 being healthy gait, 1 mild, 2 moderate and 3 severe gait abnormalities on a scale used by (Schlageter-Tello et al., 2014). Very few score 3 cows were present on the study farms so approximately equal numbers of score 0’s, 1’s and 2’s were selected in each trial creating a stratified sample of cows with healthy, mildly and moderately impaired locomotion. Cows were allocated to each group on a first observed basis until the group was full (number of pedometers available divided by 3).

The change in values observed between locomotion scoring trials 1, 3 and 4 was calculated to ascertain effects associated with changes in locomotion scores after 11, 4 and 4 days, respectively.

The pedometers used for trials 1-4 was the Rumi Watch 10 Hz pedometer attached to a rear leg at the metatarsus position. This is a research-focused tool that outputs data at various levels of aggregation. In this study, the 24 hour daily summaries of variables were calculated using the Rumi Watch converter 7.3.36, algorithm V00\_56. In addition, the 10Hz x,y,x data is analyzed to generate gait characteristics data during a time frame close to the locomotion scoring event. At the end of each trial, data was transferred to a tablet using a USB cable. Technical issues with the Rumi Watch resulted in reducing numbers of available units being attached to cows and increasing numbers of data sets being discarded upon inspection. The sample size was thus limited by the number of pedometers available which varied from trial to trial depending on pedometer downtime for maintenance and some pedometers failing to record data. From 21 data sets in the first trial, this reduced to 10 usable data sets in the final trial.

Table 1. Sample information about cows included in the study.

|  |  |  |  |
| --- | --- | --- | --- |
| **Event, location & date** | **N** | **Breed** | **Analysis period relative to when cows were scored.** |
| 1. A Dairygold (01/06/2017) | 20 | Jersey | Scored morning. Pedometers attached in the evening. Next morning walk to parlor (xyz data) and day (24-hour summary) analyzed. 16–40 hour gap to locomotion scoring. |
| 1.B Dairygold (15/06/2017) | 21 | Jersey | Pedometers removed day before scoring (14th) – xyz data used on way to parlor 24-hour gap from locomotion scoring. 24-hour summary from 2 days before (32-56 hour gap). |
| 2 Dairygold Holstein Friesian (16/06/2017) | 16 | Holstein Friesian | Scored pedometers attached morning of 16th. Next morning walk to parlor (xyz data) and day (24-hour summary) analyzed. 16–40 hour gap to locomotion scoring. |
| 3.A Dairygold  (08/08/2018) | 16 | Holstein Friesian | Scored morning. Pedometers attached in the evening**.** Next morning (xyz data) and day (24-hour summary) analyzed. 16-40 hour gap to locomotion scoring. |
| 3.B Dairygold  (13/08/2018) | 16 | Holstein Friesian | Pedometers were on for 4 days– xyz data used from morning they were scored 2nd time (exiting parlor). 24 hour summary from the same day used. Pedometers removed day after. |
| 4.A Commercial farm  (16/08/2018) | 10 | Holstein Friesian | Scored and pedometers attached in the morning. Next morning walk to parlor (xyz data) used and day (24-hour summary) analyzed. 16-40 hour gap to locomotion scoring. |
| 4.B Commercial farm  (20/08/2018) | 10 | Holstein Friesian | Scored in the morning. Data used from the walk to the parlor that morning (0–3 hour gap to scoring). 24 hour summary on the day of scoring. |
| 5. TUM (Haladjian et al., 2018) | 10 | Holstein, Flechvieh, crosses. | Healthy locomotion compared to when block attached to the same cow’s left and right leg. 30 data sets from 10 cows. |

### Trial 5

The analysis of trial 5 is the secondary analysis of collected at the indoor stable of the Ludwig Maximilian University (LMU) Munich, Germany described in (Haladjian et al., 2018). 10 cows’ activity was recorded for approximately 35 minutes each in an experimental design. There was no locomotion scoring per se for these cows, but the locomotion of healthy cows was impaired by the intervention of attaching a rubber block. Though not assessed, the impact on locomotion was reported by the researchers to be modest and barely noticeable to a trained locomotion scorer. The intervention thus simulated only mild locomotion impairment (J. Haladjian, Technical University Munich, Germany, personal communication). The pedometer used a resolution of 100Hz, and cows were observed for approximately 21 minutes while ‘healthy’ and 7 minutes when a block was attached to each leg (14 minutes of induced mildly impaired locomotion). A similar approach to simulating lameness has been reported in sheep where one leg was taped up in such a way to restrict locomotion (Barwick et al., 2018).

## Data preparation

The two r scripts created for this study are available for inspection at Github.com/nialloleary/Lameness. One was the LSE events 1-4 with RumiWatch data and for the Haladchen et al. (2018) data.

The Trial 1- 4 script first loads the required packages and creates a table with the data sets metadata relating to each locomotion scoring event which includes specifications for which data was to be imported into R and various parameters for the analysis that varied from each locomotion scoring event. For example, the number of rows to be skipped until the chosen period and if any cows were to be excluded from the analysis are included here. The directory containing all the RumiWatch 10Hz x,y,z accelerometer data is scanned for file names with each pedometers serial number and a results table created with a row associated with each cow in the particular study. This will hold variables calculated from the raw accelerometer data such as swing duration and later the RumiWatch generated behavior summary data. Then a for-loop reads in a selected portion of each file for x,y,z data analysis (1 cow locomotion score = 1 row in the results table). It is upon the results table that analysis (such as correlation) is performed. Various variables for each cow were calculated and used to populate the results table. The loop then proceeds to the next cow and repeats the process calculating the gait variables for each cow.

Once this x,y,x data was aggregated it was combined with their locomotion score and the Rumi Watch software (algorithm version 56) calculated 24 hour summary variables using a SQL join. The latter included validated behavior measures such as lying time and activity index previously associated with lameness (REFERENCE JESS). For the day and night ratios for activity, the hourly summaries were also imported and the ratio of day to night time activity calculated. The variables stride distance appeared to be calculated incorrectly in the 24 hour summaries but appeared reasonable in the hourly summaries. A secondary 24 hour average of these variables were thus also calculated via the hourly records. The program for reading in the raw data and generating the results is X lines long takes approximately 15 minutes to run (R 3.5.2, RStudio - 1.1.456, laptop, Intel i5 processor).

The R script for analysing the Haladchen et al (2017) data was structured as follows:

The initial setup section includes the loading of packages, scanning of the data folder for file names. Several tables are initialised to be subsequently populated with results. A loop then begins pulling in each file and analyses it, populating tables with results for each of the 30 files (10 cows \* 3 treatments). Analysis consisted of some pre-processing, (e.g. creation of vector with squared root of acceleration), detection of time when cow was likely to be walking consistently (based on averaged activity over a rolling 20 second window), identifying troughs in acceleration corresponding to the measured foot striking the ground, calculating step cycle duration (trough to trough), widening the data around these strike points with 0.3 to 0.7 seconds data prior when the swing phase was likely to start (Figure 1) and detecting when it started, calculating the swing phase %.The means and variance of each variable is then calculated and t-tests performed to compare, normal, block attached to measured leg and block attached to opposite leg. The script is Y lines long, takes approximately X minutes to run (R 3.5.2, RStudio - 1.1.456, laptop, Intel i5 processor) and can be inspected on the project github repository.

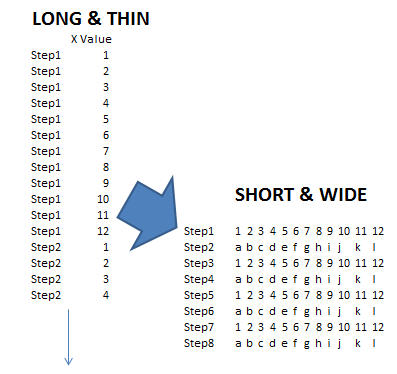


Figure 1. Illustration of data widening to a per step resolution.

### Night time to day time activity

Several papers have reported that the cow behavior during specific periods during the day relative to other periods (and herd maters) is indicative of lameness (Table 1).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Reference | Variables predictive of lameness | Sample and context | Accuracy | Summary stats nonlame & lame (lying time hours / day) | Time split |
| (Blackie et al., 2011) | Chronically lame react slower to feeding, particularly in the evening. Stand in more at night, maybe to avoid conflict. | 59 cows on one UK farm. | N/A | Nonlame 10.9 Chronically lame cows lay for 13. |  |
| (Garcia et al., 2014) | Lame cows more active in the morning, more variable rest of the day. Production impacted in a robotic milking system. | 150 Holstein, Danish Red & crosses. On AMS system | Lame / non lame. 77% & 79% parity 1 & 2. | N/A | Activity for 05.00, 13.00 and 16.00. |
| (Nechanitzky et al., 2016) | More lying, less standing over 12 hours at night (P< 0.05). Bouts are similar. | Holstein. 10 nonlame, 32 lame. | Area Under the Curve 0.71. | Night time lying 5.5 hours, 6.48. | 17.00 – 5 a.m. = Night time. |
| (Weigele et al., 2018) | Lame lay longer, longer bouts, greater asymmetry in preferred lying side. Lower activity 1 hour after feed pushed up. | 17 farms, 142 non lame and 66 moderately lame. | Summary of moderately lame and nonlame | Lying-bout duration 81 for nonlame, 89 minutes for lame, |  |
| (Yunta et al., 2012) | Lames cows rose 13 minutes later after ration was delivered and lay down 19 minutes earlier after. Severely lame cows were excluded. | 10 farms, 10 – 15 cows each farm | Not significant. | Bout duration longer in lame cows. Average Lying time 11.9. |  |
| (Van Hertem et al., 2013) | The ratio of night time to day time activity positively associated with lameness. Rumination. Neck collar sensor (SCR Engineers Ltd., Netanya, Israel). | 118 Holsteins (44 lame) | Sensitivity 89%, specificity 86%. Cross validation 77%, 84%. |  | 20.00 – 04.00 = Night time. |

### Table 1. Studies which discuss relation of night time to daytime activity (mostly lying and feeding) as an indicator of lameness measured by accelerometer. Adapted from REVIEW with additional column about definition of night and day and excluding feeding only focused studies.

### Consistent walking

As lameness was judged likely to be most discernible when a cow was walking consistently, periods when cows were walking consistently were identified. The RumiWatch system includes a lying, standing and walking classification down to the 10th of a second. Using this as a basis, periods when cows were classed as walking consistently for 1,000 records (500 records prior and after the point, 1 minute 40 seconds in total) were classed as periods of consisten walking. The forward – backward axis was the primary data assessed subsequently, in this study labelled X. X values were standardised (but not centred).

In the Haladjian et al (2017) data, classification of lying/standing or walking was not already present so a rolling mean of acceleration on the forward – backward (relative to cow) axis of over 2000 records (20 seconds) was assigned to each record. Those records with a rolling mean acceleration greater than the 40th percentile (within that cow and treatment) was judged highly likely to be walking consistently and so used for subsequent analysis.

### Step identification

The next step was to detect and delineate steps. This was achieved by detecting when the leg wearing the pedometer struck the ground which is associated with, though not exactly in sync with significant negative acceleration on the forward – backward axis (Alsaaod et al., 2017; Haladjian et al., 2018). The literature reported that a step cycle lasts approximately 1.2 to 1.3 seconds. As the 12hz data was in 10 Hz resolution – this corresponds to 12 records per step. The 12th percentile of forward – backwards acceleration was thus chosen as the threshold to mark records as potentially marking this forward – backward acceleration trough, and was used to delineate the end of one gait cycle and the beginning of another. These records were then checked to see if neighboring records had greater deceleration with the greatest deceleration being identified as the anchor point of the step.

For the 100Hz data the identification of the greatest deceleration was achieved by creating a vector with the rolling minimum forward- backward acceleration of 180 records (0.9 seconds before and after). The matching record was then identified as the strike point. That data set is at this point in the analysis long (many rows).

For individual step analysis, the data set was first ‘widened’ - records were transposed for the previous values into additional columns on the same row (long and narrow to long and wide data frame, Figure 1). Each row thus contained the acceleration record for that moment in time and the preceding and following 10 records. Only the records (rows) classed as recording the strike were then selected for the next section of analysis – step analysis (short and wide data frame). Variables such as step duration and swing phase were then calculated using this wide data set.

### Swing phase identification

In this study we look to see if swing phase estimated using 10 and 100 Hz accelerometers (one accelerometer per cow) is indicative of lameness. A manual delineation of swing and stance phase using slow motion video analysis was reported by Alsaaod et al., (2017). An algorithmic approach is required for this variable to be of practical use in lameness detection. The present study presents such an algorithmic approach for automatic detection of swing and stance phase.

The point of greatest deceleration on the forward – backward axis is closely associated with, though does not exactly correspond to when the foot strikes the ground (Alsaaod et al., 2017) is, the anchor point of the step analysis - the start and end of each step. This moment of greatest deceleration is henceforth referred to as the step trough. As the only negative trough in a typical step cycle, it is unambiguous.

Typically, relatively low gross acceleration values were observed associated with the stance phase of the step on the forward – backward axis (x-axis). During the stance phase, the claw is stationary on the ground and the meta tarsus to which the accelerometer is attached is pivoting forward propelling the animal. During the swing phase, a more rapid movement, a generally high forward acceleration is detected. The threshold value for large was chosen as 0.5 of a standard deviation of acceleration in the 10 Hz RW data. In the 100hz Haladjian data, 0.35 of a standard deviation of the animal’s acceleration was the chosen threshold. The 10x difference in resolution likely explains why the differing thresholds seemed to work better in each context. From step-trough minus 7 tenths of a second, any large acceleration value is taken to indicate the start of the swing phase. As swing phase is thought to last between 2 and 5 tenths of a seconds – this range appeared appropriate Table X. Alternatively, the last value below the threshold closest to the step trough was classed as the start of the swing phase. The duration of the swing phase is then calculated until the trough, and the swing% using the step duration as the denominator of the swing duration.

### Define every variable

(Barwick et al., 2018) Table 2 a potential format to emulate. Do I need the math? Would be good to understand it and how it is done. Also good overview of sensitivity, specificity, accuracy and precision.

### Correlation analysis

The first step for the analysis was to perform summary and exploratory analysis to assess if the associations reported in past studies existed in the examined data. Then, for those associations which were found, prediction analysis would be carried out to ascertain their usefulness in automated lameness detection.

Given the large number of variables assessed in this paper – novel findings statistical importance should be considered in light of the expectation that with enough variables – some will be associated with lameness by chance. Therefore, stricter thresholds for significance should be considered or the results viewed with appropriate caution until they have been independently validated.

### Open source research

We publish all data collected by the authors and acknowledge the support of Haladjian et al., for providing their data set for secondary analysis. The RW watch data used for this analysis is available at … The data created by Haladjian et al (2018) can be requested from [haladjia@in.tum.de](mailto:haladjia@in.tum.de).

The two R scripts for using both datasets are also available on Github. We hope this is a valuable resource which may encourage more open source approaches to automated lameness detection and dairy cow welfare precision applications in general.

# Results and discussion

In this section, we first present analysis of the simplest measures from accelerometers – mean acceleration values and measures of variance of the same. As they have been previously developed (and for the most part validated – Jess References) by other researchers, behavior measures are for our purposes still relatively simple / readily understood. These behavior variables are derived exclusively from the RumiWatch converter software and so not available for the data set created by Haladjian et al. Then gait variables – attributes of the step’s such as step duration, stride distance, swing phase and walking speed are assessed. These were all investigations prompted by prior research findings. Finally, associations observed in the process of assessing the previous are presented which are novel to this paper.

### Acceleration measures

The ratio of nighttime activity to daytime activity as measured by a collar accelerometer has been reported as being indicative of lameness (Van Hertem et al., 2013) and Thorup et al., (2015) reported that (units of acceleration relative to that of just gravity (g) per day per activities – walking, standing & lying) differed between groups of differing locomotion scores.

In this study – the ratio of day time activity was assessed in two ways- one by comparing the hourly summaries for behavior generated by the Rumi Watch converter and second – by assessing the raw data and manually calculating the motion index for day time and night time, walking standing and lying.

The motion index was calculated for these behaviors and the RumiWatch created variable – activity index – “Activity” the averaged variance of acceleration (“Activity”) over a 24 hour (as calculated by the RumiWatch sensor) .

First we look at the Spearman correlations between locomotion scores, changes in locomotion score and the acceleration variables (table X). Here we see that correlations to absolute locomotion score were variable between locomotion scoring events and weak on average with a rho of 0.14 being the highest average Rho. This was for total x (backward – forward) acceleration during the 6 hour observation period – a proxy for walking behavior. For changes in locomotion score – the variance in total activity and mean Y acceleration during the whole 6 hour period (x\_mean cow) were associated with increases in locomotion score. So cows whose total activity variance increased and whose average Y acceleration (left – right when ing) increased were more likely to have a higher locomotion score. The strength of these associations also varied significantly between locomotion scoring events - these associations were not evident / much weaker for the Jersey trial. Activity inded was inconsistently associated with locomotion score within LSE events ranging in correlations from 0.43 in LSE 7 to -0.47 for LSE 3.

Motion index by behavior …

Table X Spearman’s Rho for measures of acceleration and locomotion score Add in ratio of day time to night time activity? Fix variable names. Only activity index and motion index by behaviour. x mean, y mean



\*TA = Total activity (sum of squared square root of x y and z acceleration per 10th of a second. These were not statistically significant.

x mean, y mean – Haladjian data.

Overall – it appears that the gross acceleration measures and indexs did not have consistent or reliable associations with locomotion score across a range of typical contexts observable on pasture based farms.

### Behavior

In the review it was found that the key behavior variables identified were:

1. Activity/walking duration (Thorup et al., 2015) and step count (Byabazaire et al., 2019);
2. The ratio of day to night time activity (Van Hertem et al., 2013);
3. Standing & lying bouts and swaps (changes in behavior) (de Mol et al., 2013; Kokin et al., 2014; Beer et al., 2016; Byabazaire et al., 2019); and,
4. Rumination time (Van Hertem et al., 2013; Beer et al., 2016).

Behavior measures were not available for the data set supplied by Haladjian et al., (2018) , so here we focus on the Rumi Watch converter, a software that generates validated and non-validated measures of animal behavior using the accelerometer data. Here we look at 24 hour summaries near to the point of locomotion score (time difference for each LSE in table 1). We also look at the change in behaviors observed with changes in locomotion score using spearman rank correlation (rho) analysis. So if the difference (if there was one) between locomotion score on 2 occasions and the difference in behavior was correlated.

Summary table? See format for step duration

Table x. Spearman’s Rho correlation between various measures of behavior for seven observation periods and locomotion score, and change in locomotion score for three periods with some change in locomotion score. Simple average of group correlations - not weighted for group size. Add N as a column at the top.



Here it can be seen that most behavior measures were also not consistently associated with locomotion score across each locomotion scoring events. STANDINGCOUNTER was found to be consistently associated with locomotion score – consistent with (de Mol et al., 2013; Kokin et al., 2014; Beer et al., 2016; Byabazaire et al., 2019). The higher the standing counter increased – the lower the locomotion score indicating the number of times a cow stands and sits was a robust indicator of both absolute locomotion score (relative to her cohort) and also change in locomotion score (within the cohort). Also of note was LIMBEVENTS though this was less consistent. Definitions of Limbevents and were not found in the manual. Jess?

We can thus conclude that the previous associations reported with Walking time (Thorup et al., 2015) were not consistently associated with lameness in these trials on pasture – both for absolute locomotion score and change in locomotion score. This may explained by the confounding effects of precipitation (Thompson, 2018).

The ratio of day time to nighttime activity

### Steps and step Duration

Table X. Previous and present findings relating to step duration.

|  |  |  |  |
| --- | --- | --- | --- |
| Study | Method | Breed | Step cycle duration |
| Alsaaod et al., (2017) | High Speed Video analysis | Holstein Friesian, Red Holstein, Swiss Fleckvieh and Rhaetisches Grauvieh | 1.22 or 1.29 |
| Beer et al., (2016) | Accelerometer | German Holstein | 1.58. Lame 1.98. Non lame 1.83. |
| (Flower et al., 2005) | Video analysis only | Holsteins | Stride duration for healthy cows 1.26 seconds, 1.48 for cows with sole ulcers (n=7). |
| Present study grazing | Accelerometer only | Jerseys | 1.20 – no major difference by locomotion score |
| Present study grazing | Accelerometer only | Irish Holstein Friesian | 1.30 seconds – no major difference by locomotion score |
| Present study short controlled observation. | Accelerometer only | German Holstein, Fleckvieh and crosses of both breeds | Pseudo Lame 1.29. Non lame 1.25. |

(Flower et al., 2005) reported that severely lame cows with sole ulcers had significantly different average step durations than healthy cows or cows with sole lesions but no so for other less severe forms of lameness. Alsaaod et al., (2017) reported no significant differences in step duration between a group of lame and healthy cows. The step duration was reported to last 1.22 seconds on average with an SEM of 0.05 (Table 2) or 1.29 (discussion section p1424).

Beer et al., (2016) reported using weighted average of hourly summaries of a variable “Stride Duration”, an output of the Rumi Watch pedometer, and found that lame cows step cycles were longer (1.98 seconds) than healthier cows (1.83) seconds (p=0.0002). In this study using the same hardware and algorithm looking at the 24 hour summaries of the stride duration variable – we found ... Redo to take out zero values which biased the numbers down. Divide by 1000 Read beer for variables.

Table X – To be redone with out 0 vales biasing the scores down.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Locomotion score** | **0** | **Locomotion score** | **1** | **Locomotion score** | **2** |
| 1 | 1531 | 1 | 1526 | 1 | 1522 |
| 2 | 1575 | 2 | 1605 | 2 | 1581 |
| 3 | 1490 | 3 | 1495 | 3 | 1498 |
| 4 | 1653 | 4 | 1564 | 4 | 1620 |
| 5 | 1678 | 5 | 1635 | 5 | 1658 |
| 6 | 1678 | 6 | 1687 | 6 | 1662 |
| 7 | 1559 | 7 | 1662 | 7 | 1587 |
| Average | 1595 | Average | 1596 | Average | 1590 |
| Jersey Mean | 1553 | Jersey Mean | 1565 | Jersey Mean | 1551 |
| Holstein Mean | 1595 | Holstein Mean | 1596 | Holstein Mean | 1590 |

In this study we also created another step duration algorithm as a requirement for calculating swing phase % (discussed later). This only assessed when the cow was walking consistently during a 6 hour window.

Table X Redo and change units to seconds.



The mean step cycle duration for all the cows in LSE 1:7 was 12.8 records (1.28 seconds) as measured by the RumiWatch and the Haladchen using the trough identification technique for both healthy and locomotion impaired cows.

For the novel algorithm for analyzing the RumiWatch data (cows in Ireland walking to and from the milking parlour), the mean step duration was slightly higher (1.29) for score 0, 1 and 2 cows together (105 observations of 64 cows). Score 0 & score 2 cows were both 1.3 second and score one cows were 1.27 seconds. The mean step duration also varied by observation period from 1.15 and 1.21 for the Jerseys in LSE1 & 2 to 1.45 seconds for LSE 5 - the second observation period for the Holstein Friesian cows at the research farm in 2018 (RW 478). It is of note that Jerseys appear to have a distinctly shorter gait cycle differing highly significantly (t test, p=<0.001) Jerseys = 1.18, Holstein Friesian 1.34 seconds). The Jersey’s also had greater variance in the duration of their steps (t- test p=0.0004, Jerseys = 0.4, Holstein Friesian = 0.28).

Also of note is that that number of strides, the ratio of strides to movement, and the number of steps within the 6 hour window were indicative of lameness. Stride move ratio was only indicative of absolute locomotion score, the number of steps only the change in locomotion score and number of strides was moderately indicative of both.



For the Haladjian data, the means for healthy and impaired locomotion differed but not to a statistically significant extent. Unimpaired, the mean was 1.25 and 1.29 for when a block was attached to either leg (t-test, p = 0.11).

Step duration and step duration variance was not indicative of locomotion score 0-2 using the RW derived variables or when a cow had impaired locomotion due to a block being attached one foot (Haladjian data) – means not significantly different. Overall – it appears that moderately lame cows were not significantly different as measured by step duration alone consistent with was reported by Flower et al (2005). There is however strong indications that breed of cattle significantly influences step duration. The cattle used in previous studies with longer reported step durations were Holstein Friesian generally, while those reported were smaller breeds and the Irish Holstein Friesian cows also tend to be smaller than their Holstein Friesian cousins elsewhere such as Germany (Flower et al., 2005; Beer et al., 2016; Alsaaod et al., 2017).

Whether or not cows were grazing or not is also a potential factor with cows being herded several hundreds of meters to and from pasture being a very different context than found in door systems which are generally more congested with cows walking at a slower pace – or having the option to walk slower – rather than grazing animals which would be herded at a relatively faster rate.

### Swing

Variance in recorded swing phase between both rear legs was identified by (Alsaaod et al., 2017) as effective for discerning lame from healthy cows using two 400Hz accelerometers. Alsaaod et al., 2017 found that a typical step lasts 1.29 (or 1.22) seconds and that the leg was on average swinging for 36.5% of that time using video analysis combined with accelerometer data. Lame cows were best distinguished by the difference in variance of swing phase recorded between left and right back legs (on the same cow) achieving 100% accuracy and sensitivity with a threshold of 17.94%. This was achieved using manual delineation of stance and swing phase using a high speed video reference. Alsaaod et al.’s (2017) study demonstrated the potential predictive value of swing and stance phase using a 400hz accelerometer. We hypothesized that one pedometer per cow may be able to detect when the proportion of swing phase differs from normal – which if true would be of interest in a commercial context.

### Results Swing % Rumi Watch

The mean duration of swing phase was 4.44 records (0.44 seconds) and the mean swing % was 35%, corresponding closely to the values reported by Alsaaod (36.51%,SEM = 0.68) for healthy cows. Some caution here, as some of the thresholds were adjusted / tuned to achieve a result closer to Alsaaod’s 36.5%, so this is not a corroboration of that finding (which used high speed videos as a gold standard), just that the algorithm approximated these values reasonably well.

It should also be noted that the average swing pc differed significantly between locomotion scoring events from 32% for the second scoring of the Holstein Friesian cows in 2018 (LSE 5) to 36.6% for the first scoring of Holstein Friesian cows on the commercial farms (LSE 6).

The variance in swing % was relatively consistent ranging from 0.003% to 0.005% with a mean of 0.004%.

For healthy cows (score zero), the swing% was slightly lower on average (34.7%).



A correlation analysis found no associations between mean swing %, variance in swing % and locomotion score. The RumiWatch data therefore did not support the hypothesis that swing % and measures of variability in swing % could differentiate lame from healthy cows. There does however appear to be an ability to indicate change in locomotion score within a cow for the two variance measures.

Table X. Spearman’s Rho Correlation for swing duration measures – REDO with fixed names.



Table X shows the results of a correlation analysis. It appears that mean values were not indicative of either absolute or change in locomotion score while variance appears to be indicative of change in locomotion score (though this was only support in 2 of the 3 trials - not found in the BW18 trial).

**100hz results (Halidjian et al., data)**

In this sample 10 unique cows were assessed. Each were healthy. To simulate lameness, a block was attached both to left leg only and right leg only with the accelerometer remaining on the left throughout. The foot which was causing a problem was thus known. Therefore the difference swing phase for the left leg can be compared for when the cow is healthy, the left leg has a block attached or the right leg has a block attached. This is thus slightly more similar to Alsaaod et al., (2017) paper. However, it was the variance of the swing PC that was important there.

**Table X – P values from T-tests between cows in different interventions, Norm (normal), Left ( block on left foot), right (block on right foot). Sensor was always on left leg. Using raw x values.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| rowname | NormLeft | NormRight | LeftRight | LameAverage |
| M\_SwingDur |  |  |  |  |
| **M\_swingPC** |  |  |  |  |
| V\_SwingDur |  |  |  |  |
| V\_swingPC |  |  |  |  |

Then the block was on the opposite leg, there was not a discernible difference in variance (paired t-test p =0.79) indicating a potential indicator of which leg is lame or a physical artifact of having the block attached. Comparing when the blocks were on left or right leg, (sensor always on the left), there was a marginally significant difference in variance (p=0.053).

Using these results it is appears that variance in swing% could only be used to discern if the leg the sensor was attached to was lame but does not give an indication if the opposite leg is lame.The swing % of the sound leg is not affected discernibly by the opposite leg being impaired. Therefore – if a method of detecting lameness on any leg (or just rear legs) was developed, this could be combined with the present finding to identify the likely leg of interest**.** When comparing when the block was on the left to the right leg, the average swing % and average swing duration were different (paired t-test p <0.05) – again providing a potential indication of which leg is lame though the effect is probably too weak to be of use for reliable prediction of which leg is of interest.

**Summary Swing duration & percentage and mean & variance**

Overall – the differences in variables between a cow’s two legs identified by Alsaood as being indicative of lameness, appear to have only marginal value when derived from only one leg at a time with lower resolution accelerometers.

indicating that application of Alsaaod’s et al., 2017 pedogram does require a pedometer on each leg, potentially of higher resolution.