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Technical note: Validation of a semi-automated software tool to determine gait-cycle variables in dairy cows

M. Alsaaod,*[1] R. Kredel,† B. Hofer,† and A. Steiner*
*Clinic for Ruminants, Vetsuisse-Faculty, and
†Institute of Sport Science, Faculty of Human Sciences, University of Bern, 3001, Switzerland

ABSTRACT

This paper presents the validation of a software tool called Cow-Gait-Analyzer (University of Bern, Switzerland) to determine gait-cycle variables in lame and non-lame dairy cows using features derived from low-cost, stand-alone 3-dimensional accelerometers (400 Hz). The Cow-Gait-Analyzer automatically extracts the relevant gait events of foot load and toe off, which characterize gait-cycle duration, stance phase, and swing phase during walking. A nonautomatic step is visual inspection of the pedograms. If the software does not automatically choose the right peaks according to pedogram definitions, peaks can be manually chosen. We validated the algorithms by comparing the accelerometer data (pedogram) with the synchronized video data, which we used as a gold standard. We carried out the measurements at the metatarsal level of paired hind limbs during walking. We included 12 non-lame cows and 5 lame cows and expressed overall differences between the Cow-Gait-Analyzer and the gold standard as relative measurement error (RME). We analyzed 34 hind limbs with a mean of 9 gait cycles. The median RME for gait-cycle duration and stance phases were 0 and 1.69%, respectively. The peaks of gait-cycle variables showed RME of 0.67 and 0.24% for foot load and toe off, respectively. The semi-automated Cow-Gait-Analyzer can accurately determine gait-cycle variables in both lame and non-lame cows, and could be used to assess gait patterns in routine clinical and research practice focusing on individual cows.
Key words: dairy cow, gait cycle, accelerometer, algorithms

Technical Note

Automated measures of behavioral-based animal welfare indicators in cattle are highly desirable as practical tools to support human observers (Rushen et al., 2012). One of the most beneficial aspects of automated measures is that they can help observers detect subtle changes in behavior (Van Nuffel et al., 2015). Behavior changes associated with foot pathologies can be quantified using (1) kinematic gait analysis (Flower et al., 2005), such as high-speed cinematography with the cow on a treadmill (Schmid et al., 2009) or image-processing techniques (Poursaberi et al., 2010; Viazzi et al., 2013); or (2) kinetic gait analysis using 1-dimensional or 3-dimensional ground reaction force systems (Rajkondawar et al., 2006; Walker et al., 2010; Thorup et al., 2014) or pressure-sensitive walkways (Van Nuffel et al., 2009; Maertens et al., 2011). For example, weight shifting among legs during standing indicates discomfort and pain associated with lameness (Pastell and Kujala, 2007; Chapinal et al., 2010; Nechanitzky et al., 2016). However, these methods may be expensive, time-consuming, or both, limiting their practical application. Increasing asymmetry in kinematic and kinetic measurements of gait events is a promising indicator for objective diagnostic tests when pathologies are present (Flower and Weary, 2006; Thorup et al., 2014; Alsaaod et al., 2017). Assessment of the stance phase is a promising approach for detecting lameness and foot pathologies in dairy cows using kinematic gait measurement (Flower et al., 2005) and in equines and cattle using accelerometers with a high sampling rate (Olsen et al., 2012; Alsaaod et al., 2017). Using a 3-dimensional accelerometer to detect extended locomotion behavior (Alsaaod et al., 2015) and identify slightly lame cows in dairy herds has been described recently (Beer et al., 2016). The objective of this study was to validate a semi-automated tool, the Cow-Gait-Analyzer, (University of Bern, Switzerland) to extract kinematic (temporal events: gait-cycle duration, stand phase duration, and swing phase duration) and kinetic (peaks: foot load and toe off) variables from the outputs of accelerometers with a high sampling rate at the metatarsal level during walking. We hypothesized that gait-cycle variables could be derived from the Cow-Gait-Analyzer that had a high correlation with results

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[1]Corresponding author: maher.alsaaod@vetsuisse.unibe.ch

from synchronized cinematographic pedograms (gold standard) in lame and non-lame cows.

Twelve dairy cows without any signs of lameness, that were not subjected to abdominal surgery, and that did not have clinical mastitis (non-lame), and 5 cows referred to the Clinic for Ruminants, Vetsuisse-Faculty, University of Bern, for evaluation of a lameness problem in the hind limbs (lame) were used in the study. We rated lameness using a numerical rating system of 1 to 5 (**NRS**; where 1 = sound, non-lame, and 5 = severely lame; Flower and Weary, 2006). The lame group (NRS ≥3) included cows with one of the following unilateral pathologies: bulb abscess, double sole, osteitis of P3, septic tendovaginitis of the common digital flexor tendon sheath, or septic arthritis of the tibiotarsal joint. Cows in the lame group had a mean [± standard deviation (SD)] lactation number of 1.2 (±0.45), a mean daily milk yield of 25.5 (±3.32) kg, and a mean BW of 546.75 (±77.95) kg. The breeds involved were Holstein Friesian (n = 2), Red Holstein (n = 1), Brown Swiss (n = 1), and Eringer (n = 1). Cows in the non-lame group (NRS <3) had a mean (± SD) lactation number of 2.58 (±1.31), a mean daily milk yield of 30.5 (±8.87) kg, and a mean BW of 632.36 (±94.01) kg. The breeds involved were Holstein Friesian (n = 2), Red Holstein (n = 4), Swiss Fleckvieh (n = 5), and Rhätisches Grauvieh (n = 1).

All cows were halter-broken when they arrived at the clinic. Cows were also individually guided to walk quietly for 10 to 20 min immediately before each measurement. They were then encouraged by an animal caretaker to walk in a straight line for >10 m on an asphalt floor, 3 times (3 walking phases), using 2 stand-alone accelerometers (400 Hz; USB Accelerometer X16-4; Gulf Coast Data Concept, Waveland, MS), each attached to 1 hind limb, synchronized with high-speed video camera (120 Hz) as described by Alsaaod et al. (2017). We selected a mean of 9 gait cycles using convenience sampling from 3 walking phases per limb pair, after excluding gait cycles that represented running or cycles with signal artifacts (as determined by visual inspection). We processed the raw data from the accelerometers using the software tool Cow-Gait-Analyzer (http://www.wiederkaeuerklinik.unibe.ch), developed by the Institute of Sport Science, Faculty of Human Sciences, University of Bern, Switzerland (Figure 1). This MATLAB-based software tool simplifies analysis by automating most of the steps necessary to extract relevant gait-cycle variables. After the raw data file or folder has been selected, the Cow-Gait-Analyzer automatically filters the raw data with a zero-lag, second-order, low-pass Butterworth filter using an optimal estimate of the cutoff frequency (Winter, 2009), and then graphically displays the 3-dimensional vector magnitude pedogram (as described by Robert et al., 2009; Chapinal et al., 2011; Alsaaod et al., 2017). If selected, the unfiltered vector magnitude pedogram and the unfiltered accelerations in X, Y, and Z dimensions are also displayed. Using graphical sliders, the temporal region of interest can be selected, and calculation of a defined gait-cycle event can be repeated. This is particularly helpful when the sensors' raw data include steps before or after the experimental trial.

Based on the filtered vector magnitude pedogram data, the software tool automatically estimates the gait-cycle events of peak foot load and peak toe off

Table 1. Definitions of the kinematic (temporal) and kinetic (peak) pedogram variables of cows' gait at the level of the metatarsus, including gait phases/complexes, temporal events, and peaks as described by Alsaaod et al. (2017)

Variable	Definition
Phases/complexes	Gait initiation phase includes the end of the swing and the beginning of the stance phase; complex of pedogram that includes the foot-load peak
	Gait termination phase includes the end of the stance and the beginning of the swing phase; complex of pedogram that includes the toe-off peak
Kinematic (temporal)	
Gait-cycle duration (s)	Interval between 2 consecutive foot-load peaks
Stance phase (%)	Interval between foot-load peak and toe-off peak of the same gait cycle of the same limb, expressed as percentage proportion of the total gait-cycle duration of that limb
Swing phase (%)	Interval between toe-off peak and consecutive foot-load peak of the same gait cycle of the same limb, expressed as percentage proportion of the total gait-cycle duration of that limb
Kinetic (peak)	
Foot load (g)	Maximum peak of the gait initiation complex exerted by a simultaneous peak of the x- and y-axis (+ or − value) of the accelerogram, corresponding to the initial ground contact of the claw
Toe off (g)	Maximum peak of the gait termination complex exerted by a simultaneous peak of the y-axis (+ or − value) of the accelerogram, corresponding to the termination of the ground contact of the tip of the claw