Dairy Cattle Linear and Angular Kinematics during the Stance Phase

V. Carvalho,[1], R. A. Bucklin[2], J. K. Shearer[3], L. Shearer[3], I. A. Naas[4] , Mollo Neto, M. [5], S.R.L. Souza, [5] and V. Massafera Jr.[6]

[1]Ph.D., Agricultural and Biological Engineering- State University of Campinas –UNICAMP, Rua Pedro Vieira da Silva, 144 – Building D – 01, Jd. Sta. Genebra – Campinas, SP - Brazil.
victor.ciaco@gmail.com
[2] Prof. Chair, Agricultural and Biological Engineering- University of Florida
[3] Prof., Veterinary Medicine College, Large Animal Clinical Sciences-University of Florida
[4]Prof. Chair, Agricultural and Biological Engineering- University of Campinas –UNICAMP
[5] Ph.D. Candidate, Agricultural and Biological Engineering- University of Campinas –UNICAMP
[6]Undergraduate student, Agricultural Engineering College -University of Campinas (UNICAMP)

ABSTRACT

Claw lameness can be associated to biomechanical factors caused by imbalances of the pressure distribution under the hooves when cows are confined in modern dairy operations with hard concrete flooring. In order to assess gait parameters of un-trimmed cows housed on concrete floors and how these parameters are affected by trimming the foot, linear and angular kinematics data were obtained from video recordings of two group of cow's walking stride: un-trimmed and trimmed groups. Linear (spatial and temporal) and angular (fetlock joint range of motion) kinematics were obtained using a biomechanical software developed for humans gait analysis (eHuman®). Stride time showed a close to significance trend for the main factors group (G) and leg (L) ($p < 0.0857$ and $p < 0.0708$), trimmed group showed a slight shorter stride time (1.29 s) than un-trimmed (1.45 s). Stride length and stride velocity were not significant ($p < 0.72$ and $p < 0.17$ respectively between groups). However, stride velocity tended to be faster for the trimmed group as compared to un-trimmed (1.29 m/s vs. 1.17 m/s). Angular kinematics of fetlock joint motion presented significant differences between the two groups at midstance ($p < 0.0045$) and presented extensions of 157° for un-trimmed as compared to trimmed cows 162°. The small changes resulted from the study implies that trimming the foot affects gait in a positive way by providing more confidence and stability during walk.

Keywords: Gait, lameness, biomechanical analysis, dairy cattle

1. INTRODUCTION

Lameness is among the most prevalent and costly of clinical disease conditions in dairy cattle. Causes include rations and/or feeding conditions that encourage rumen acidosis; confinement of cows to harder, wetter, more abrasive floors; or un-grooved floors that are smooth (and thus slippery, etc.). Flooring is of particular importance, because of pressure distribution and redistribution on claws. Uneven weight-bearing of hoof walls of cows managed on hard floors (i.e. concrete) lead to pressure redistribution on claws, due to excessive overgrown hoof tissues, and thus causes greater pressure concentration and stress on claws (Raven, 1989). The typical sole lesion spot is considered to be the region where the highest pressures concentrate under the foot and occurs usually associated under conditions of confinement on concrete and poor or absent trimming practices and is the site, on the lateral claws of the rear foot, where sole ulcers usually develop (Shearer & Van Amstel, 2000; Raven, 1989).

The economic loss incurred as a result of disease (i.e., sole ulcers) arises primarily from the consequences of the disease and not the cost of treatment. Walking impairment imposed by hoof lesions causes decreases in feed and water intake, resulting in marked losses in body weight and milk production and also poor reproductive performance (Shearer, 2003). The resulting pathological gait of large animals caused by lameness can, over an extend period of time, favor upper limb lameness as joints and ligaments becomes compromised. A moving horse is expected to compensate for lameness through changes in limb weight-bearing, propulsion and deceleration forces. This abnormal gait maybe detected by lack of symmetry between limbs, reduced or non-uniform rates of loading and unloading, reduced maximal and minimal forces and changed duration of force application (Leach, 1987). The most current approaches used to evaluate abnormal gait in human and animal patients involve video analysis of kinematic and kinetic parameters either quantitatively through biomechanical analysis or qualitatively through observational analysis (Pedersen et al., 2003, Zonderland et al., 2003, Nääs et al., 2005 and Perissinoto et al., 2006).

The objective of this study was to evaluate linear and angular kinematic changes between two groups of cows: Untrimmed (unbalanced claw) and trimmed (balanced claw) using quantitative video analysis and associate these changes, if any, to lameness etiologies of biomechanical origin.

2. METHODS

The experiment consisted of 32 Holsteins cows divided into two groups: A – Balanced/Trimmed claws (Control) with 14 cows, and B – Unbalanced claws with 17 cows. All cows were from the Dairy Research Unit (DRU) dried herd at the University of Florida-Gainesville, FL. USA and had an average of 3^{rd} to 4^{th} parturitions. Data were collected during one month from June 5^{th} to July 3^{rd} of 2003. Un-trimmed group (17 cows) data collection started on 5^{th} of June 2003 and lasted until the 26^{th} of June 2003. The 14 cows belonging to the trimmed group were trimmed before starting the experiment, every other day, from 26 of June 2003 to 03 of July 2003. The temperature ranged between 24°C to 35°C and relative humidity around 80%. From trimming the cows, it was observed that their hooves were about 0.6cm overgrown in height at the heel and about 1.27cm to 1.9cm overgrown in length at the toe. Concrete floor properties from DRU Facilities were not assessed. The average weight of the cows accounting for both groups was 644 Kg. The cows were fed corn silage mixed with soy protein based mix during the experiment.

A motion analysis system consisting of a digital video camera (JVC GDR-120U – 30 Hz. 520 lines vertical resolution) placed at a distance of approximately at 6.7 m away from the plane of motion (wooden platform with a force/pressure system section used for plantar pressure data collection in an associated study, Carvalho et al., (2005) was used for acquisition of 2D (two dimensional) video kinematics data. The camera was aligned on its vertical and horizontal axis and at a 90° angle from the plane of motion to record sagital plane kinematics of single stride during walking trips over a custom built wooden platform. The kinematics data provided spatial and temporal parameters of the cow's stride, angular range of motion of joints, displacement and velocities of limbs. Figure 1 diagram shows the complete setup of the data acquisition system used for the experiment.

To analyze kinematics of gait during the stance phase of a cow's walking stride, a wooden platform was built. The wooden platform was designed with dimensions of 6,8 mts x 0,91 mts x 0,089 mts to fit inside a restraint corridor located in the feed animal barn. The length of the platform was chosen according to the length of an average large Holstein cow (approximately 2.17 m) and to assure at least two complete strides before stepping onto the force/pressure system. The video data was collected with each passage of a cow, recorded on the camera and captured afterwards into a PC using video editing software (Adobe® Premiere 6.5; Adobe Corporation®). The gait kinematics data were calculated using the Human Movement Analysis Software (Hu-m-an™) developed by the HMA Technology Inc. – Ontario –Canada.

The videos of the cows' strides were loaded into the software and landmarks of the fetlock joint, pastern joint and foot were manually digitized in order to calculate fetlock joint flexion and extension ranges of samples of the two different groups (trimmed and untrimmed).

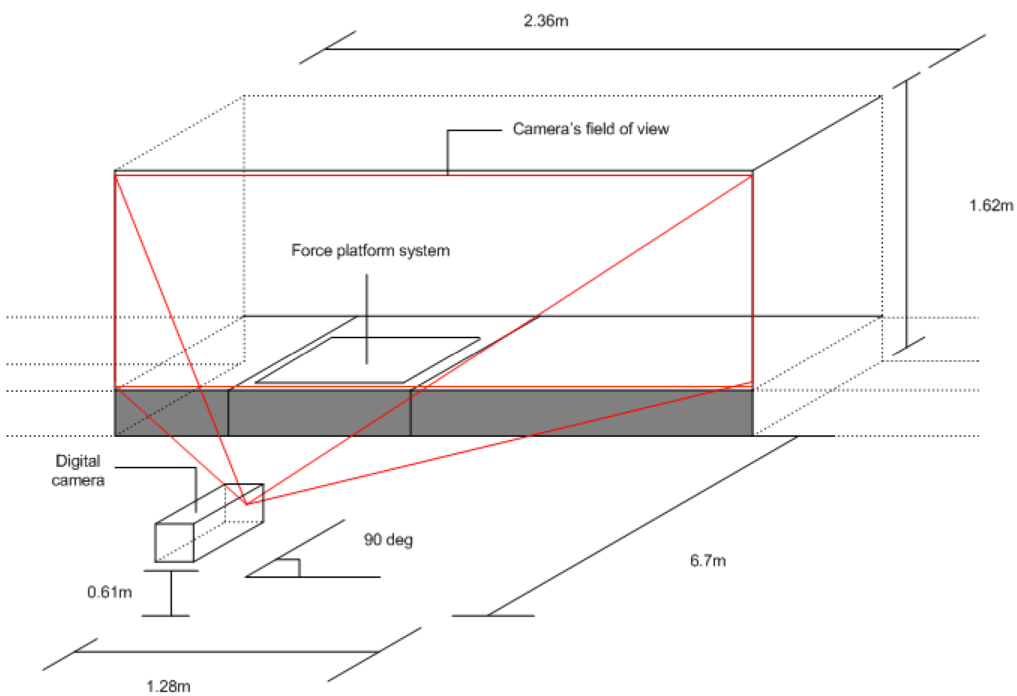

Figure 1. Diagram of the camera's field of view and platform setup.

The amount of frames recorded (± 30) and the displacements of the front and rear feet for a single stride in the clips of the cows were used to calculate spatial and temporal characteristics of each cow such as stride length, and stride times, respectively. In addition, velocities were calculated from the position of the feet landmarks and by applying a differentiation method. For simplicity and due to the large amount of data processing involved, only stride velocities were obtained by simple calculation of spatial and temporal characteristics of stride:

$$\text{Stride velocity} = \text{Stride length } (p_f - p_i) \,/\, \text{Stride time } (\Delta t) \qquad (1)$$

Where,

p_f is the final position of the digitized midpoint of the foot at the beginning of the cycle (m);

p_i is the initial position of the digitized midpoint of the foot at the beginning of the gait cycle (m);

Δt is the time elapsed during the gait cycle (s).

The SAS® V.8.2 was used for the statistical analysis, and the statistical design was carried out using PROC MIXED at a default 95% confidence interval. The statistical design consisted of two groups: A – Balanced claws (control) and B – Unbalanced claws. The arrangement used was 2 x 4. This represents two groups of cows: 17 cows in group A and 12 cows in group B totaling 29 cows, and at least 2 legs (front and rear) per cow yielding 69 observations for the temporal and spatial (linear kinematics). The procedure tested the main fixed effects: Group (G), Leg (L) and the 2-way interaction G*L. Ten cows of each group were selected for the angular kinematic analysis (fetlock joint flexion/extension range of motion) using the same statistical design described for the linear kinematics.

3. RESULTS AND DISCUSSION

Some of the cows did not have either a two consecutive heel strike or a two consecutive toe-off to allow calculation of spatial and temporal kinematics (linear kinematics). Usually that happened because the stride was too long and the second heel strike fell outside the camera's field of view, thus preventing the digitizing of the foot landmark.

The analysis for stride time presented the main factors G and L close to significance ($p < 0.0857$ and $p < 0.0708$) according to PROC MIXED (SAS®). The interaction term group*leg (G*L) was not significant ($p < 0.4687$). Stride time LSMeans for groups are presented in the Figure 2.

Values for stride time ranges are presented in Table 1. Stride time was slightly longer for the un-trimmed (G1) group (not significant) and may have indicated that cows walked slowly compared to the trimmed (G2) group (1.29 s vs. 1.45 s for trimmed and un-trimmed respectively). Orthogonal contrasts for stride time main effect Leg (L) were tested for differences across the 4 legs.

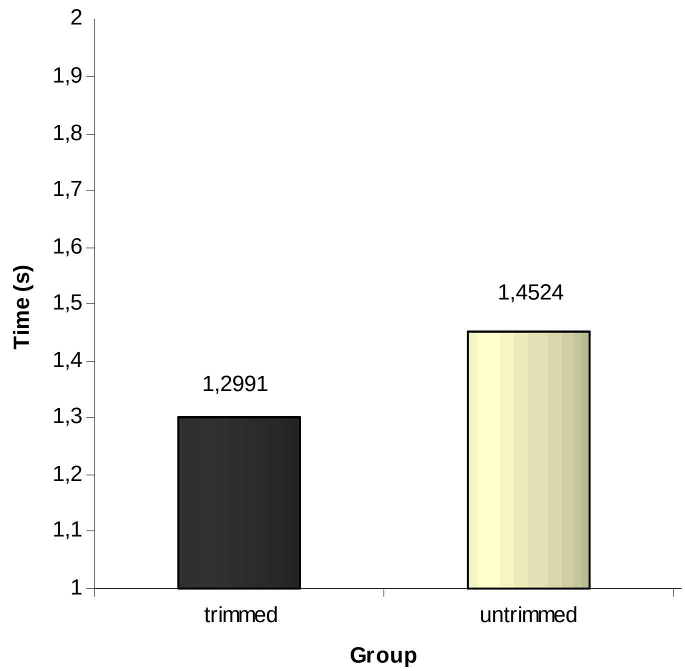

Figure 2. Stride time LSMeans for the two groups

Table 1. Stride time range values (sec.) for the two groups

Group	Min. (sec)	Max. (sec)
Un-trimmed	1.03	2.36
Trimmed	1	1.56

The significant differences across legs (Table 2) suggested that there are asymmetries between left and right side and small variations between front and rear legs, according to the analysis. These differences are emphasized in Tables 3 and 4, which shows that right side had shorter stride times and faster gait (1.27s versus 1.48s for right and left side respectively accounting for both groups).

Table 2. Stride time orthogonal contrasts for leg (L) main effects.

Contrast	Estimate	SE	DF	T value	Pr > |t|
Leg (L)					
1 *vs*. 2, 3, 4	0.376	0.169	31	2.22	0.033
2 *vs* 3, 4	-0.218	0.087	31	-2.5	0.017
3 *vs* 4	0.203	0.077	31	2.64	0.012

Table 3. Stride time for front and rear legs accounting for both groups (s)

Leg	Time (s)	SE
Front left	1.469	0.069
Front Right	1.271	0.046
Rear Left	1.482	0.069
Rear right	1.279	0.046

The analysis for stride length was not significant for either of the main effects (G or L) ($p < 0.721$ and $p < 0.649$ respectively). The stride length LSMeans values for the untrimmed and trimmed groups were 1.64 m and 1.66 m respectively. Stride length range of values are presented in Table 5.

Table 4. Stride time for front and rear legs within groups (s)

Group	Leg	Time (s)	SE
Untrimmed	Front left	1.595	0.060
	Front Right	1.335	0.057
	Rear Left	1.542	0.058
	Rear right	1.335	0.057
Trimmed	Front left	1.344	0.125
	Front Right	1.207	0.072
	Rear Left	1.422	0.125
	Rear right	1.222	0.072

Table 5. Stride length range values (m) for the two groups

Group	Min. (m)	Max. (m)
Un-trimmed	1.28	2.29
Trimmed	1.4	1.92

The analysis for stride velocity was not significant for main effects group (G) and leg (L) or the interaction term (G*L) ($p < 0.177$, $p < 0.161$ and $p < 0.265$ respectively). However, stride velocity tended to be faster for trimmed group. The LSMeans for un-trimmed vs. trimmed groups were 1.17 m/s and 1.29 m/s respectively. Figure 3 shows a representation of the velocity pattern of the two groups using the original calculated velocities. Although no significant differences were detected in kinematics of spatial and temporal data between the two groups, it was expected that differences would exist for velocities between the two groups since untrimmed cows tended to have a longer time spent during stride and would indicate that trimmed cows should have had faster stride.

The videos of 20 cows' stride were used for analyzing angular kinematics (10 trimmed cows and 10 un-trimmed cows). Five body landmarks on each lower portion of the front legs and rear legs of each cow were digitized frame by frame for each movie. Frames corresponding to the three phases used for the pressure analysis (midstance, loading response and push-off phases) were selected according to its position in the movie, as seen in Figure 4.

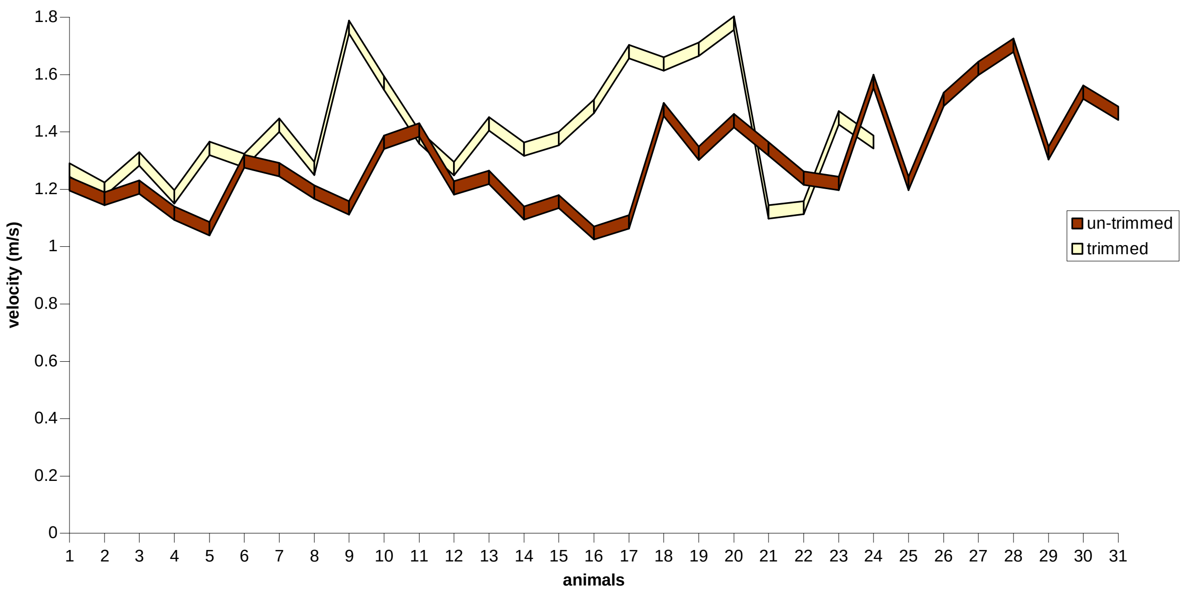

Figure 3. Calculated velocity data set for the two groups

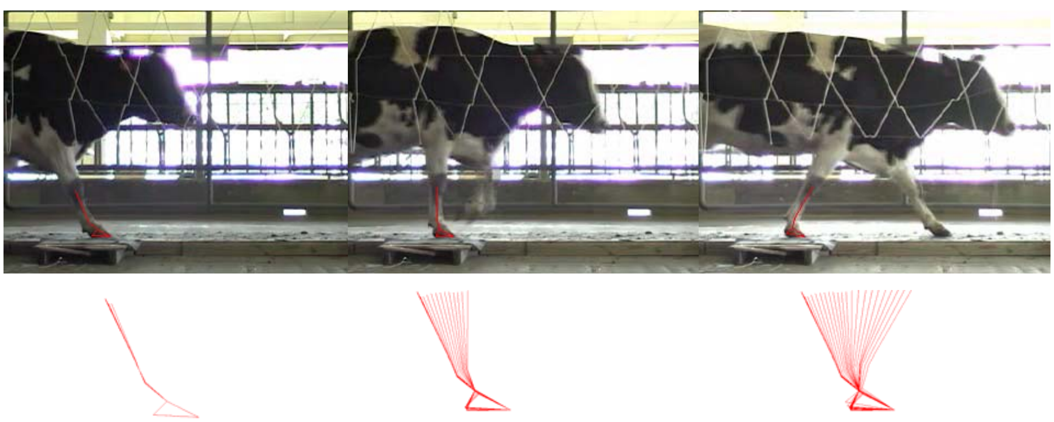

Figure 4. Video digitizing and lower limb digitized model

The analyses were performed for the three different phases individually (Loading response, midstance and push-off). The only significant analysis was midstance phase. Midstance fetlock relative angle analysis was statistically significant for the main factor group (G) ($p < 0.0045$) according to PROC MIXED (SAS®). Fetlock relative angle LSMeans obtained for untrimmed cows presented significant smaller joint angle (157±1.05° SE) compared to trimmed cows (162±1.05° SE). This difference implies a reduced amount of extension of the two body segments that form this joint presented by the untrimmed group. The increased extension angle at the fetlock joint shown by the trimmed cows may be due to the fact that trimming the foot brings the sole more parallel (level) with regard to the pavement, thus extending these two segments. Differences between front and rear legs for trimmed and untrimmed groups are presented in Table 6, average differences between groups were approximately 5°. Figure 5 shows a diagram, which simulates a hypothesis of the changes in the relative fetlock joint extension angle obtained by trimming the claws.

Table 6. Maximum extension angles for both groups (deg)

Group	Leg	Angle (deg)	SE
Untrimmed	Front	158.33	1.49
	Rear	156.16	1.49
Trimmed	Front	162.92	1.49
	Rear	161.27	1.49

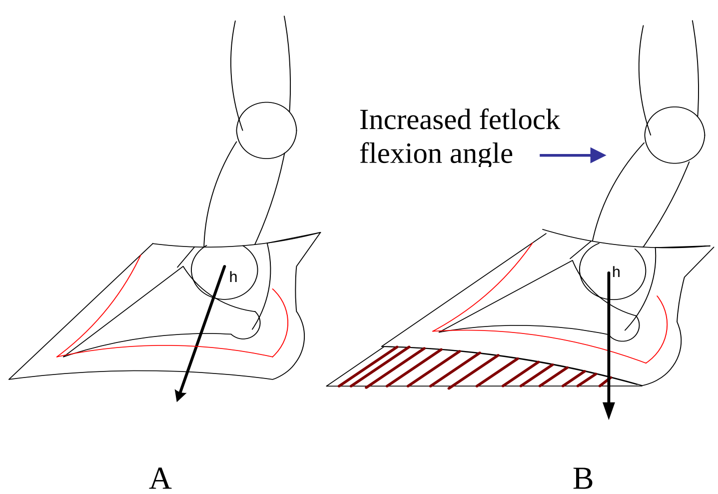

Figure 5. Fetlock relative extension angle changes. A) trimmed. B) un-trimmed

Data on kinematics presented here agree with previous studies for stride duration (Rajkondawar et al., 2001, Flower et al., 2003) and stride velocity (Flower et al., 2003). It can be speculated from these values that claw trimming could have provided a slightly more comfortable gait for cows, mostly during push off where the hind limbs are more involved in propulsion of the body forward (Scott, 1988).

Gait analysis has been done in a preliminary basis using video capturing and editing technology within requirements for this type of analysis. The results are supported by trends reported in previous study for spatial and temporal analysis (Flower et al., 2003). The increased velocity and greater extension of the fetlock joint at midstance are results that may affect gait of trimmed cows. The data obtained in this study suggested that, claw trimming may affect gait positively by allowing a more vertical posture of the fetlock joint at midstance favoring increased velocity and hence, showing more confidence during walk. In addition, concomitant results of pressure analysis showed that there is a decrease of the pressure concentrations at the heel bulb and that these pressure concentrations become slightly better redistributed to other portions of the sole (Carvalho, 2005). The redistribution of pressures occurred to the frontal portion of the sole which were, in average, absent of surface contact pressures on untrimmed claws but, on the other hand, also increased the concentration of pressures to the typical sole lesion spot which may or may not cause overburdening and predisposing this region to hemorrhages and ulcers over time.

Using quantitative video analysis it was possible to evaluate the positive effect of hoof trimming in dairy cows locomotion. Gait linear kinematics analysis showed that un-trimmed cows tended to have a significantly longer stride time ($p < 0.0857$) than trimmed (1.45s *versus* 1.299s for untrimmed *versus* trimmed respectively). Trimmed cows presented a higher degree of fetlock joint angle extension as compared to untrimmed cows. The increased extension angle at the fetlock joint shown by the trimmed cows may be due to the effects of trimming. This result leads to the assumption that trimming the claw brings the sole more parallel (level) with regard to the floor, thus extending the two leg segments, anterior and posterior to the fetlock joint. The range of fetlock joint relative angle values obtained for trimmed cows had overall higher maximum extension angles in all three phases of stance.

4. CONCLUSIONS

It was concluded that the assessment of animal kinematics and behavior observations through the use of image tools, such as video recordings associated to biomechanical analysis software, can be used to identify gait abnormalities and animal welfare on lame cows as a consequence of lower and upper limbs pathologies.

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