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SmartCow: an integrated infrastructure for increased research capability and innovation in the European cattle sector

SmartCow

an integrated infrastructure for increased research capability and innovation in the European cattle sector

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EXECUTIVE SUMMARY

Background	The behaviour of an animal is highly sensitive to its internal state. A sick animal is usually less active, resting for more time and eating less, and interacting less with its environment whereas a stressed animal is usually hyperactive and reactive. Some behaviours may in turn favour the occurrence of welfare problems.
Objectives	We address two issues: - the potential of behavioural metrics to detect a welfare problem at a very early stage, that is before overt clinical signs - the extent to which certain behavioural profiles predispose animals to diseases
Methods	In D7.3, we proposed quantitative metrics to describe cow activity from data provided by sensors. These metrics were applied to study the relation between drinking behaviour and mastitis, between the circadian rhythm of activity and diseases - whatever they are - or stress, and between activity before calving and postpartum health.
Results & implications	Cows behaviour, health and welfare status are interconnected: - Infectious diseases and stress alter the activity of a cow. This was observed through a transient decrease in water consumption in case of mastitis and in alterations in the daily rhythm of activity (less marked in more than 90% health disorders). Such changes occur before appearance of clinical signs of a disease. - The behavioural phenotype of a cow during the dry period (especially the periodicity of activity) seems to determine its health robustness after calving. The drinking profile of a cow may predict the susceptibility to mastitis (cows with a more fragmented drinking behaviour are more susceptible). The data from sensors automatically recording activities have the potential to be used to better monitor or predict animal health, welfare and production. Such opportunities can in turn help farm management at operational (refinement of the daily interventions) and strategic (e.g. use of behavioural criteria for selection) levels. Nevertheless, there is still a long way from the identification of the links between behaviour and health (or welfare and production) as done in this deliverable, to Precision Livestock Farming tools ready for farmers. We need to better characterise behavioural modifications in relation to the various disorders (e.g. distinction between diseases) and to determine the sensitivity and the specificity of the methods to detect disorders or characterise the sensitivity of an animal. Some of these issues are currently addressed by SmartCow partners and will be reported in D7.5.

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SmartCow
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1 Introduction

The behaviour of an animal is highly sensitive to its internal state. A sick animal is usually less active, resting for more time and eating less, and interacting less with its environment (especially with congeners) (Hart, 1988)(Dantzer and Kelley, 2007)(Byrd and Lay, 2018). Stressed animals on the contrary are often more active and more reactive to their environment, at least during the acute phase of stress. Sickness behaviour can start before actual clinical symptoms of disease. For instance, during an episode of mastitis, cows are less reactive to their environment and change activity less often before hyperthermia occurs (De Boyer Des Roches et al., 2017). Therefore, the monitoring of animal behaviour can help detecting welfare problems at a very early stage, allowing to take corrective actions before the problem fully develops. Some behaviours may in turn favour the occurrence of welfare problems. For instance, the rapid ingestion of concentrates in large quantity may lead to ruminal acidosis, and a reduction in the time spent lying over a longer period of time may enhance the likelihood of lameness.

In the previous deliverable (D7.3), we proposed quantitative metrics to describe cow activity from data provided by activity meters. These metrics include: time spent in each activity, activity level, regularity and cyclicity of the activity (incl. circadian rhythm), and synchrony between animals. In the present deliverable, we explore whether these metrics can be used to study changes in behaviour due to disease or stress. We more specially addressed two issues:

- the potential of behavioural metrics to detect a welfare problem as a very early stage, that is before overt clinical signs

- the extent to which certain behavioural profiles predispose animals to diseases

We investigated these issues in three settings: We studied drinking behaviour in relation to mastitis, modification of the circadian rhythm of activity under diseases - whatever they are - and stress, and we attempted to predict postpartum health of cows based on their behaviour before calving.

We are currently investigating the links between animal behaviour – especially feeding behaviour – and efficiency. The analyses are not yet completed. The results will be reported in Deliverable D7.5.

2 Results

2.1 Drinking behaviour and health

We evaluated the association of 43 mastitis events with drinking behaviour traits and resting time in 31 cows. Clinical mastitis events were considered independent if they occurred more than 7 days apart. They were detected by farm staff according to the presence of abnormal milk, or high conductivity obtained using milking parlour sensors (Afimilk system).

At IRTA experimental facility (EVAM), cows were housed in free-stall pens with twenty cows per pens. They were milked twice daily in a parallel milking parlour using electronic milk meters (AfiMilk, Afikim Ltd., Kibbutz Afikim, Israel) and an on-line analysis of milk components (AfiLab system, Afikim Ltd., Kibbutz Afikim, Israel). After each milking, all cows were weighed using AfiMilk SortWeight system (Afikim Ltd., Kibbutz, Israel). Pens were equipped with 20 cubicles bedded with a mixture of compost and sawdust, four electronic water troughs (MooFeeder, MooSystems, Cortes, Spain) to record

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individual water intake, and fifteen electronic bins (MooFeeder, MooSystems, Cortes, Spain) to record individual feed intake. Every time a cow put the head in a water bin, she was identified, and the door was opened. Once the animal removed its head from the water bin, the door was closed. The system recorded the time and the water bin weight when the animal went in and out. These data were summarized as water intake (kg/d), time spent drinking (min/d), drinking rate (kg/min), and duration (s) and number of drinking bouts (/d). Drink criterion was calculated by fitting a combination of two normal distributions to the distributions of log-transformed hit intervals. The drink criterion was determined as the point at which the distribution curve of interdrink intervals intersected the distribution curve of the intradrink intervals (DeVries et al., 2003). The drink criteria were used to calculate drinking frequency (number of drinking bouts) and duration per bout (drinking size).

The activity of the cows was recorded thanks to a leg sensor (AfiAct II, Afimilk, Israel).

For each event of mastitis events, we considered the week prior mastitis (7 days), the clinical mastitis period (4 days), and the following 6 days after the event. Furthermore, two categories of mastitis were created based on if a single quarter was affected and *Escherichia coli* was not involved (mild; n = 24) or if more quarters were affected or *Escherichia coli* was the cause of the mastitis (severe; n = 19). Data were analysed with a mixed-effects model including the fixed effects of type of mastitis, the period related to mastitis, and their 2-way interaction, and the random effect of cow. Period entered the model as a repeated measure using the unstructured, compound symmetry, and autoregressive order 1 covariate-variance matrix and the one with the lowest Bayesian criterion was selected. Data were analysed using daily data or summarized data by period.

Results on summarised data per periods

This section sums up the parameters studied relative to mastitis events by period (before, during, after).

Drinking and resting time were affected during a mastitis event. In general, cows with mastitis spent less time at the drinker and resting.

Table 2. Drinking and resting behaviour in dairy cows before, during and after having a mastitis event (least square means).

	Period effect				P-values		
	Before	During	After	SEM[1]	Mastitis severity	Period[2]	Mastitis x Period
Water intake, L /d	95	94	99	2.9	0.009	0.12	0.71
Time drinking, min/d	13^{ab}	12^{b}	13.5^{a}	64.7	0.46	0.03	0.7
Drinking rate, L/min	10.9	10.3	9.4	0.95	0.82	0.28	0.99
Drink bout duration, s	107^{a}	98^{b}	106^{a}	5.9	0.04	0.006	0.88
Drink bouts, /d	7.4	7.3	7.7	0.41	0.41	0.31	0.15
Resting time, h/d	13.1^{a}	12.6^{b}	12.8^{ab}	0.37	0.16	0.03	0.22
Resting bouts duration, min	74	73	74	3.9	0.15	0.76	0.56

[1] Standard error of the mean

[2] 3 periods: 7 days before the mastitis event, 4 days during the event, the 6 following days

Results on daily data

This section sums up daily evolution of drinking behaviour and resting time relative to mastitis and its severity.

Water intake was lower in cows with severe than with mild mastitis throughout the entire studied days (P<0.05, Table 1, Figure 1). Water intake tended to decrease from Day -2 to Day -1 ($P = 0.09$). Time spent drinking slowly decreased from Day -7 to Day 1, and slowly increased afterwards ($P = 0.05$), independently of mastitis severity (Figure 2). Drinking rate did not vary with the evolution of a mastitis event or with mastitis severity. Drinking size was lower ($P < 0.05$) in cows with severe than with mild mastitis throughout the entire studied days (Table 1). Drink size increased from Day -3 to Day -2 then decreased from Day 0 to Day 1 ($P < 0.05$, Figure 3). Drinking bouts were more numerous in cows suffering from severe mastitis compared to those suffering from mild mastitis on Day -7, and similar between the two types of cows afterwards (Figure 4). Resting time slowly decreased from Day -2 to Day 1 and increased from Day 1 to Day 2 ($P = 0.05$), independently of mastitis severity (Figure 5).

Table 1. Drinking and resting behaviour in dairy cows that suffered from mastitis (least square means).

	Mastitis severity			P-values[1]		
	Mild	Severe	SEM[1]	Mastitis severity	Day	Severity x day
Water intake, L/d	101	90	3.6	0.02	0.09	0.95
Time drinking, min/d	13.8	11.9	1.42	0.34	0.05	0.90
Drinking rate, L/min	9.9	10.8	1.31	0.59	0.75	0.70
Drink bouts duration, s	115	92	7.9	0.04	0.06	0.78
Drink bouts per day	7.2	7.8	0.52	0.44	0.06	0.05
Resting time, h	12.6	13.3	0.46	0.21	0.03	0.17
Resting bouts duration, min	77	70	3.9	0.20	0.61	0.63

[1] Standard error of the mean

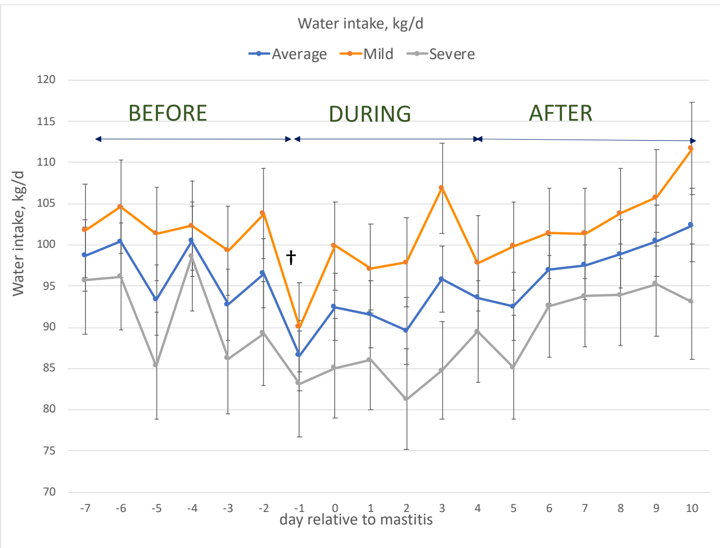

Figure 1. Evolution of water intake before, during and after a mastitis event.

† denotes a tendency between consecutives days

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Figure 2. Evolution of drinking time before, during and after a mastitis event.

† denotes a tendency between consecutives days

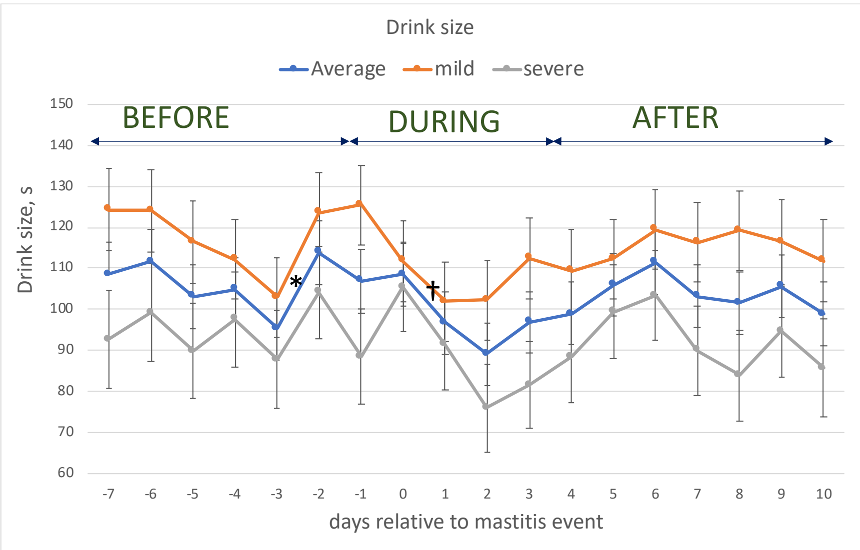

Figure 3. Evolution of drinking size before, during and after a mastitis event.

† denotes a tendency between consecutives days

* denotes a significant difference between consecutives days

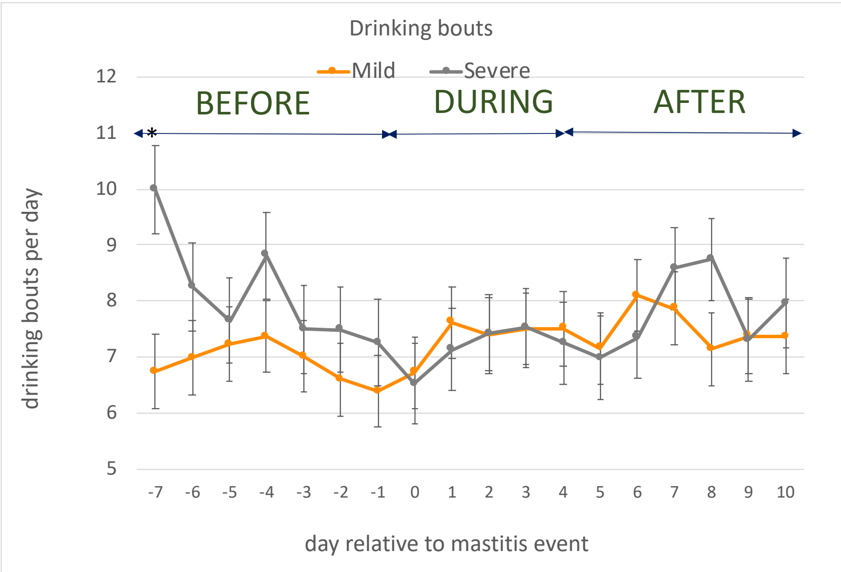

Figure 4. Evolution of drinking bouts before, during and after a mastitis event.

* denotes a significant difference between treatments at that point

Figure 5. Evolution of resting time before, during and after a mastitis event.

Conclusion

Just before mastitis, cows spend less time drinking – in relation to shorter drinking bouts – while keeping the same drinking rate, resulting in a decrease in water consumption. From Day 2 of a mastitis event, time spent drinking, duration of drinking bouts and water consumption progressively increase again so that cows resume their initial behaviour in few days. Resting follows a similar pattern with a decrease on the days before the mastitis and a slight increase thereafter. The behaviour of cows is thus affected by mastitis and the change seem to start before clinical mastitis is detected.

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Cows affected by severe mastitis differ from those affected by a mild mastitis, already before the mastitis event occurs: their drinking bouts are shorter and more frequent.

Drinking behaviour and mastitis seem thus interconnected: the time spent drinking is affected by mastitis and the way a cows organises its drinking activity (with more or less fractioning) may reveal its sensitivity to mastitis.

2.2 Activity rhythm and health

The rhythm of activity of animals (including humans) is altered in case of stress or disease. For instance, in earlier studies we observed a less marked circadian rhythm of activity in heifers suffering from pneumonia (Veissier et al., 1989) and in calves submitted to repeated mixing (Veissier et al., 2001). The changes in rhythm seem part of the sickness behaviour or more generally poor welfare behaviour, reflecting how the animal feels about the situation rather than being linked directly to the causal factors.

In Deliverable D7.3 we described the FBAT method that detects changes in the circadian rhythm of activity from one day to the next. Briefly, FBAT uses the level of activity of animals per hour of the day, calculated as a weighted sum of the time spent in each basic activity (resting, feeding…). FBAT models the circadian variations of the level of activity by a Fourier transform. It uses Harmonic 0 that gives the average level of activity and Harmonic 1 that summarises the variations between day and night. It calculates the distance between models obtained on two consecutive 24 h time series. If the distance is above a definite threshold, the rhythm is considered to have changed.

The detection of changes in the circadian rhythm of activity by the FBAT method was compared to the occurrence of disorders, be they diseases, specific physiological states or other potentially stressful events. The work was carried out with the Real Time Locating System 'CowView' that allows estimating the cow activity (described in D7.3). Three activities were distinguished and attributed the following weights: resting, −0.15; in alleys (standing or walking), +0.12; eating, +0.34. We used four datasets with about 120 000 cow*days. The disorders tagged were: diseases (categorised into ruminal acidosis, lameness, mastitis, and other infectious diseases), accidents (including injuries, retained placenta, or vaginal laceration), oestrus, calving, and external stimuli such as handling (for vaccination, oestrus synchronization, anthelmintic treatment, claw trimming…) and relocation (with mixing). The disorders were extracted from the farm logbook except acidosis that was detected thanks to ruminal pH sensors in one dataset.

With FBAT we were able to detect changes in the circadian rhythm in 100% of accidents, 95% of disease or reproductive events (calving or oestrus), and 60-70% of handling and relocation events. The change in rhythm was often detected before the caretakers detected the signs of a disease, calving or oestrus: 1.5 day before in case of calving, lameness, and infectious diseases other than mastitis, 1 day before in case of mastitis. Besides, no changes in the rhythm was detected in 80% of the days where no disorders had been noted in the farm logbook. The 20% apparently false positives could be partly due to the lack of detection of problems by caretakers (e.g. silent oestrus, no overt sign of stress, subclinical acidosis…). The exact proportion of false positives may therefore be lower than 20%.

The FBAT method seems appropriate to detect welfare disorders occurring on a farm. The number of rhythm anomalies obtained in a given context (a farm or a treatment in an experiment) likely reflects the occurrence of disorders – whatever their origin – and could provide an overall index of welfare.

This work was part of Nicolas Wagner thesis funded by INRAE and University Clermont Auvergne. It has been published (Wagner et al., 2020, Wagner et al., 2021). We are now investigating ways to better describe rhythm changes and to relate them to diseases, physiological states, or stress due to handling or relocation. This would help the diagnosis of problems. We also investigate ways to reduce the number of false positives (detection of a change when no disorder has been noticed). The results of current investigations will be reported in D7.5.

2.3 Prediction of health risks after calving

We examined the relationship between cow activity before calving and its health after calving.

A total of 180 Dutch Holstein-Friesian dairy cows of various ages (37 primiparous, 43 parity 2, 38 parity 3 and 55 parity 4 and older) from 4 dairy farms situated in the Netherlands enrolled in this study. Cows were selected based on the expected day of parturition. Experimental period per cow lasted from 2 weeks prior to expected parturition until 6 weeks after parturition. Only cows scored healthy prior to parturition and with a complete clinical dataset were used, resulting in a final dataset with 173 cows.

All dry cows were kept in one separate pen on each farm. When the cows showed signs of parturition, they were moved to an individual straw-bedded maternity pen in the same building. After calving, they were introduced into pens with lactating cows. Group size and group composition were dynamic, as animals were moved between pens before and after the dry period, but cows remained in the same group after calving until the next dry period. Number of cows per group was kept as steady as possible. The cows were fed twice daily a TMR consisting of corn silage, hay silage, with concentrates added (protein and mineral supplement) adjusted to the production level of the group. Dry cows were fed dry cow diet consisting of TMR. Water was available ad libitum. For the duration of the experimental period, feed composition was kept constant.

Clinical examination, blood parameters and total deficit scores

Each cow was examined by a bovine vet practitioner twice per week. Three practitioners were enrolled. They measured heart rate (beats per minute), breathing rate (per minute), rectal temperature (°C), rumination (chews per minute), udder condition, uterus condition and excretion, and manure consistency and they estimated the cow overall condition according to these measurements as described by (Hajer et al., 1988). Blood samples were collected from the coccygeal vein once before parturition, once in the first week after calving and once in the fifth week after calving. Blood values indicative and related to peri-parturient problems were determined to evaluate our clinical assessment: calcium, magnesium, inorganic phosphorus, albumin, haptoglobin, urea, nonesterified fatty acids (NEFA), (etahydroxybutyric acid (BHBA), aspartate aminotransferase (AST), bilirubin, Glutamate deshydrogenase (GLDH), gammaglutamyl-transferases (gammaGT), Total Protein and Interleukin 6 (IL6). Assays were performed by GD Animal Health lab, Deventer, the Netherlands.

Clinical abnormalities and blood values outside the normal range (based on predefined cut-off values) were recorded. The total of abnormalities obtained by a cow during the 6 weeks after parturition was summarized into a Total Deficit Score (TDS). A total TDS encompassing all clinical deviations was calculated. In addition, seven specific TDS scores were calculated, each reflecting a relevant subset of health issues (Tables 3a and 3b). For instance a TDS reflecting the metabolic balance of the cow is the

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number of detected from Ca, Mg, Phosphorus, Beta-HydroxyButyrate (**BHBA**), NonEsterified Fatty Acids (**NEFA**), Total Protein Albumin Urea, Aspartate AminoTransferase (**AST**), Bilirubin, and Gamma Glutamyl Transferase (**GGT**) in blood.

Table 3a. Overview of special TDS scores with corresponding clinical values

Clinical value	TDS Score, points	Ref[a]	TDS score
Ears cold?	1 if yes	1	Inf, Met, Liver, Macro, Energy, Protein[b]
Excreta from nose?	1 if yes	1	Inf
High jugular pulse?	1 if yes	1	Inf
Rectal Temperature	1 if T < 37.5 or T > 39.2, 2 if T > 40	1	Inf
Breathing abnormal?	1 if yes	1	Inf
BCS	Difference between BCS in dry period and at measurement day,	2	Met, Liver, Macro, Energy, Protein
Rumen visible when standing behind cow?	1 if yes	1	Met, Liver, Macro, Energy, Protein
Rumen fill weak?	1 if yes	1	Met, Liver, Macro, Energy, Protein
Rumen score		2	Met, Liver, Macro, Energy, Protein
Udder oedema	1 if yes	1	Total
Udder score per quarter		2	
Firm LF[c]	0.5 if yes	2	Inf
Red LF	0.5 if yes	2	Inf
Firm RF[c]	0.5 if yes	2	Inf
Red RF	0.5 if yes	2	Inf
Firm LB[c]	0.5 if yes	2	Inf
Red LB	0.5 if yes	2	Inf
Firm RB[c]	0.5 if yes	2	Inf
Red RB	0.5 if yes	2	Inf
Abnormal uterus /excreta	1 if yes	1	Inf
Manure score		2	Met, Liver, Macro, Energy, Protein
Abnormal digestion	1 if yes	2	Met, Liver, Macro, Energy, Protein
Locomotion Score	0 if score 1 or 2; 1 if score = 3-5	2	Loco
LameLB	1 if yes	2	Loco
LameLF	1 if yes	2	Loco
LameRB	1 if yes	2	Loco
LameRF	1 if yes	2	Loco
Cow is ill	2 if yes	1	assigned to specific TDS depending on disease
Treatment	2 if yes		assigned to specific TDS depending on disease

[a]Reference 1: Hajer et al. 1988. 2: Score systems for BCS, manure score and rumen score according to Royal GD, Deventer the Netherlands, https://www.gddiergezondheid.nl/producten-en-diensten/producten/rundvee/klauwgezondheidsaanpak/handige-tools?sc_database=web
[b]Inf: TDS infectious; Met: TDS metabolic; Loco: TDS locomotion

[c]RF: Right front, RB: Right Back, LF: Left Front, LB: Left Back

Table 3b. Overview of special TDS scores with corresponding blood values.

Special TDS scores	Corresponding blood values
Locomotion	None
Macro minerals (Macro)	Ca, Mg and Phosphorus
Inflammation	Haptoglobin, IL6
Energy	BHBA and NEFA
Protein	Total Protein, Urea and Albumin
Liver	AST, Bilirubin NEFA and GGT
Metabolic	Ca Mg Phosphorus, BHBA NEFA Total Protein Albumin Urea AST Bilirubin GGT

Sensor data and calculation of activity descriptors

The activity of cows was recorded with sensors described in D7.3: the Smarttag Neck was used to monitor eating, rumination and inactive behaviour, and the Smarttag Leg sensor was used to monitor standing, lying and walking behaviour.

Sensor-based behavioural measures recorded during the two-week period prior to parturition were transformed into quantitative characteristics and metrics according to the methods described in D7.3. An overview of metrics is given in Table 4.

Table 4. Quantitative metrics obtained from sensor data.

Input	Calculation	Metric name
Minutes lying down	Autocorrelation	AC_LegmLie
Minutes stillstand time		AC_LegmSsta
Minutes standing time		AC_LegmStand
Minutes walking		AC_LegmWalk
Number of steps		AC_LegnStep
Number of bouts standing up		AC_LegnUp
Activity		AC_NeckAct
Minutes active		AC_NeckmAct
Minutes eating		AC_NeckmEat
Minutes inactive		AC_NeckmInact
Minutes ruminating		AC_NeckmRumi
Minutes lying down		AvgLegmLie
Minutes stillstand time	Average	AvgLegmSsta
Minutes standing time		AvgLegmStand
Minutes walking		AvgLegmWalk
Number of steps		AvgLegnStep
Number of bouts standing up		AvgLegnUp
Activity		AvgNeckAct
Minutes active		AvgNeckmAct
Minutes eating		AvgNeckmEat
Minutes inactive		AvgNeckmInact
Minutes ruminating		AVGNeckmRumi
Minutes lying down	Difference actogram before and after calving	DayLegmLie
Minutes stillstand time		DayLegmSsta
Minutes standing time		DayLegmStand

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Minutes walking		DayLegmWalk
Number of steps		DayLegnStep
Number of bouts standing up		DayLegnUp
Activity		DayNeckAct
Minutes active		DayNeckmAct
Minutes eating		DayNeckmEat
Minutes inactive		DayNeckmInact
Minutes ruminating		DayNeckmRumi
Minutes lying down	Fast Fourier	FFTLegmLie
Minutes stillstand time	Transformation [1]	FFTLegmSsta
Minutes standing time		FFTLegmStand
Minutes walking		FFTLegmWalk
Number of steps		FFTLegnStep
Number of bouts standing up		FFTLegnUp
Activity		FFTNeckAct
Minutes active		FFTNeckmAct
Minutes eating		FFTNeckmEat
Minutes inactive		FFTNeckmInact
Minutes ruminating		FFTNeckmRumi
Minutes walking		FFTLegmWalk
Minutes lying down	Non-periodicity	MSElegmLie
Minutes stillstand time		MSElegSsta
Minutes standing time		MSElegmStand
Minutes walking		MSELegmWalk
Number of steps		MSELegnStep
Number of bouts standing up		MSELegnUp
Activity		MSENeckAct
Minutes active		MSENeckmAct
Minutes eating		MSENeckmEat
Minutes inactive		MSENeckmInact
Minutes ruminating		MSENeckmRumi
Minutes lying down	Variance	VarLegmLie
Minutes stillstand time		VarLegmSsta
Minutes standing time		VarLegmStand
Minutes walking		VarLegmWalk
Number of steps		VarLegnStep
Number of bouts standing up		VarLegnUp
Activity		VarNeckAct
Minutes active		VarNeckmAct
Minutes eating		VarNeckmEat
Minutes inactive		VarNeckmInact
Minutes ruminating		VarNeckmRumi

[1]the sum of the heights of the amplitudes in the frequency domain at the frequencies 1, 2, 3 and 4

Statistical analysis

The activity metrics listed in Table 4 were used as predictors (covariables) of the total or specific TDS. TDS were log-transformed for the analysis to Log(1+TDS), which led to a less skew distribution and a better model fit. The analysis was a mixed model of covariance. The analysis comprised two steps:

(1) In a first step, the relationship between each activity metric and each TDS was examined in a univariate analysis. Parity of the cow was introduced as a fixed factor with three levels (level 1, parity 1; level 2, parity 2 or 3; and level 3, parity ≥ 4), and the farm was introduced as a random factor.

(2) In a second step, the predictors associated with a given TDS with P < 0.20 in the univariate analysis were included in a multivariable analysis. A backward selection procedure was used to obtain a final model with an optimal set of predictors. Partial confounding between predictors was automatically signalled, and in the final models only predictors that added significantly ($P < 0.05$) to the model were retained. No interaction between covariables and the fixed effect of parity were considered.

All analyses were performed with the statistical programming language R (R Core Team, 2017).

Results

Final models for each TDS with predictors and coefficients are presented in Table 5.

Using a combination of activity metrics, a first step is taken into predicting different disease outcome possibilities after calving. As expected, locomotion problems after calving could be detected with step and walking metrics only. What is interesting is that not the average level of steps or activity were predicitve, but the Fast Fourier Transform (**FFT**)[1] metric of both number of steps and minutes walk were relevant as well as the difference in minutes walk before and after calving. Meaning that specific patterns in behaviour during the day are relevant.

Total TDS was also related to FFT feature (negative link) and non-periodicity (**MSE**) (positive link). High MSE is indicative for a high non-periodicity, meaning that the cow does not have a good daily rhythm. The FFT feature is also indicative for patterns in the daily cycle. In Total TDS, high feature of FFTLegmSsta and low MSELegnUp were related to low TDS. This means that the more the cow shows these behaviours cyclicly before calving, the less problems it will get after calving.

For metabolic disorders and liver problems not only eating and ruminating behaviour were relevant, but also activity of the cow and especially differences between behavioural patterns before and after calving. This feature is influenced by management as cows are moved to different pens after calving with a different diet. It may therefore serve as an indicator for a need to improve management around calving.

Although a high average of time spent eating is often suggested as important feature to prevent diseases, this was only found in TDS related to infectious disease and not in the other metabolic TDS, with cows spending more time eating before calving being less affected by infectious diseases after calving.

[1] FFT converts a signal from the time or space domain into the frequency domain and vice versa. The signal (here the activity of the cow on successive intervals) is decomposed as a series of waves (sinusoids), the sum of which reproduces the original signal. The analysis can for instance be used to extract the variations of activity due to the circadian rhythm (sinusoid with a wave period of 24 h).

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Table 5. Linear prediction models for different health scores (TDS scores; response variables). Explanatory variables comprise sensor-based activity metrics (covariables) and the fixed effect of parity. For each prediction model, the intercept and the coefficients of the explanatory covariables are provided. Each level of the fixed effect of parity has its own intercept. The intercept corresponds to the reference level of the fixed effect of parity, which is parity 1, and coefficients mentioned under parity should be added to the intercept to obtain the appropriate intercepts for the second and third levels of the fixed effect of parity, respectively.

TDS	Intercept	Covariable	Coefficient	Parity	% variance explained (adjusted R^2)
Total	3.325	AvgNeckmInact	0.0234	2: -0.1131	38
		MSELegnUp	4.5350	3: 0.21888	
		FFTLegmSsta	-0.3841		
		DayNeckmInact	0.0012		
Protein	1.927	DayLegmStand	0.0020	2: -0.002	9
				3: 0.10901	
Energy	2.473	AvgNeckAct	-0.2193	2: 0.44388	27
		VarNeckmRumi	-0.0035	3: 0.63693	
		VarNeckAct	0.0203		
		AC_NeckAct	-1.0190		
		DayNeckmAct	-0.0117		
		DayNeckAct	0.0201		
		DayLegmStand	0.0023		
Macro	3.522	AvgLegmLie	-0.0204	2: 0.19914	20
		VarLegmLie	0.1678	3: 0.40017	
		VarLegmStand	-0.1695		
		DayLegnStep	-0.0001		
		DayLegmSsta	0.0023		
Liver	2.454	AvgNeckAct	-0.2213	2: 0.26869	30
		VarNeckmEat	-0.0026	3: 0.41159	
		VarNeckAct	0.0170		
		VarLegnStep	0.0000		
		VarLegmWalk	-0.1148		
		DayNeckmAct	-0.0257		
		DayNeckAct	0.0196		
		DayLegmStand	0.0019		
Metabolic	3.34065	VarLegmLie	0.1451	2: 0.08294	11
		VarLegmStand	-0.1461	3: 0.39309	
Locomotion	1.503580	FFTLegnStep	-1.4324	2: -0.24252	35
		FFTLegmWalk	1.2889	3: 0.495258	
		DayLegmWalk	-0.0161		
Infectious	4.09986	AvgNeckmEat	-0.0569	2: 0.41790	23
				3: -0.09297	

3 Conclusion

Cows behaviour, health and welfare status are interconnected:

- Infectious diseases and stress alter the activity of a cow. This was observed through alterations in drinking behaviour (transient decrease in water consumption in case of mastitis) and in the daily rhythm of activity (less marked in more than 90% health disorders). Such alterations can be detected before appearance of clinical signs of a disease.

- The behavioural phenotype of an animal during the dry period (especially the cyclicity of activity) seems to determine its robustness after calving in relation to health disorders. The drinking profile of a cow may predict the susceptibility to mastitis (cows with a more fragmented drinking behaviour are more susceptible).

Characterising the behaviour of animals can now be done on farms on a routine basis thanks to sensors automatically recording activities. This opens opportunities to better monitor or predict animal health, welfare and production. Such opportunities can in turn help farm management at operational (refinement of the daily interventions) and strategic (e.g. use of behavioural criteria for selection) levels. Nevertheless, there is still a long way from the identification of the links between behaviour and health (or welfare and production) as done in this deliverable, to Precision Livestock Farming tools ready to be proposed to farmers. Among others, we need to better characterise behavioural modifications in relation to the various disorders affecting animals (e.g. distinction between diseases) and to determine the sensitivity and the specificity of the methods to detect disorders or to characterise the sensitivity of an animal to disorders (Receiver Operator Characteristic or alike). Some of these issues are currently addressed by SmartCow partners and will be reported in D7.5.

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