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Short communication: Genetic variation in estrus activity traits

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ABSTRACT

Genetic variation in estrus traits derived from hourly measurements by electronic activity tags was studied in an experimental herd of Holstein (n = 211), Jersey (n = 126), and Red Dane (n = 178) cows. Both virgin heifers (n = 132) and lactating cows in the first 4 parities (n = 895 cow parities) were used, giving a total of 3,284 high-activity episodes indicating estrus. The first estrus after calving was predicted to occur on average, at 39, 44, and 45 d in milk for Red Danes, Holsteins, and Jerseys, respectively. Genetic variance was detected for the trait days to first high activity with a heritability of 0.18 ± 0.07. The heritability for the period of increased activity was small (0.02 to 0.08) and of similar magnitude as that for the level of activity (0.04 to 0.08). Compared with fertility traits based on artificial insemination field data, activity traits have higher heritability than traditional fertility traits, and could therefore be helpful in selection for improved fertility.
Key words: activity meter, heritability, estrus, fertility

The need for genetic improvement of dairy cow fertility has been emphasized lately in several reports as reproductive performance has declined in the recent decades (Miglior et al., 2005; Weigel, 2006). This is partly a consequence of the correlated response between reproductive efficiency and selection for higher milk yield (Veerkamp et al., 2000; Royal et al., 2002). However, traditional fertility traits (e.g., nonreturn rate, calving interval) have low heritabilities, which delay genetic progress. The period from calving to commencement of luteal activity determined from milk progesterone has been proposed as a genetic indicator of fertility (Royal et al., 2002; Petersson et al., 2007). However, electronic activity tags used for estrus detection represent another source of fertility information and deserve further study as initially suggested by Løvendahl and Chagunda (2006).

Detection of estrus in dairy cows and heifers using electronic pedometers or activity tags is based on distinct behavioral changes associated with estrus. Restlessness and general physical activity increase markedly during estrus (Farris, 1954; Van Eerdenburg et al., 2002). Other changes in behavior are "standing to be mounted" and "mounting." Pedometers and activity tags are designed to identify the restlessness and elevated physical activity of cows. Estrus detection based on activity measurements involves dedicated software supplied as part of the farm-management systems (e.g., AlproWin, DeLaval, Tumba, Sweden) together with the activity tags as a complete package. Algorithms for detection of estrus are part of the software and details are usually not disclosed to end users. Theoretical work on detection algorithms (De Mol and Woldt, 2001; Firk et al., 2002; Roelofs et al., 2005a,b; Løvendahl and Chagunda, 2009) show that detection efficiency varies greatly (50 to 100%) depending on the complexity of the method and the chosen criteria of success (Firk et al., 2002; Roelofs et al., 2005a).

Although the use of electronic estrus detectors is already widespread, information on their possible use in genetic evaluations for improving female fertility is scarce (Løvendahl and Chagunda, 2006). To implement electronic estrus detection records in breeding schemes, their predictive value in terms of estimated genetic parameters needs to be assessed. The current study, which is based on experimental herd data, aims at presenting genetic parameters for days to first estrus and other traits describing intensity and duration of estrus based on activity tag records.

This experiment was conducted in the experimental herd at the Danish Cattle Research Centre (Tjele, Denmark) between July 2001 and December 2008. The herd included 3 different breeds: Jersey, Holstein, and Red Danes. All cows and heifers had their pedigrees traced back at least 3 generations in the Nordic Cattle Database (NordicEBV, Skejby, Denmark) to establish a relationship matrix for the genetic analysis. The cow herd was divided into 3 groups, each assigned to an

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automated milking system (VMS, DeLaval, Tumba, Sweden). At any time each of the first 2 cow groups included approximately 55 cows, half of them purebred Holstein, the other half purebred Red Dane; the last group included 42 Jersey cows. The Red Danes in the 2 mixed groups were replaced by Holsteins during the fall of 2007. Culled cows were replaced with young stock to maintain group size over the experimental period. Cows were housed all year and fed a TMR ad libitum with supplementary concentrates during milking in the automated milking system. Details of the phenotypic aspects of the study were reported by Løvendahl and Chagunda (2009) and are briefly described below.

The experiment included both maiden heifers and cows in first to fourth parity. Maiden heifers (parity 0) were kept in a separate building in pens holding up to 12 heifers at any time. Heifers were fed a TMR ad libitum. Recording of activity data for the study was initiated in July 2001 (heifers in February 2004) and ended in December 2008. The activity data were obtained from heifers between 365 and 545 d of age and from lactating cows between 5 and 155 DIM.

The reproduction strategy at the Danish Cattle Research Centre aimed at initiating AI at first estrus after 15 mo of age in Holstein and Red Dane heifers and at 13 mo in Jersey heifers. The voluntary waiting period for AI after parturition was 35 d. Artificial insemination was repeated until established pregnancy or culling. Artificial induction of estrus was used if heat had not been detected before 120 DIM. Animals were equipped with electronic activity tags fitted on neckbands (Alpro version 6.60, DeLaval). Data, as counts per hour, were stored and used for the calculation of estrus traits applying an algorithm based on deviations from exponentially smoothed hourly counts for each individual cow (Løvendahl and Chagunda, 2009). Briefly, activity data for every hour, every day for each cow were ln transformed before being exponentially smoothed to provide 24 hourly baseline values. Deviations from reference values were again smoothed exponentially. An episode of high activity was initiated when 3 consecutive values exceeded a set threshold ($\boldsymbol{\alpha}$) and ended when another 3 consecutive values fell below the threshold. To protect against too many short episodes, a new episode was only allowed to start after the smoothed deviation value had been below zero for 3 consecutive hours. The duration of the pulse was counted as hours from start to end. The intensity or strength of the episode was measured as the mean of the 3 highest deviation values during the episode. The episodes were numbered starting from 1 at each new parity. The number of days from calving to first detected high-activity episode was seen as a measure of days to first detectable estrus (**DFE**). Over the following episodes, regularity was measured as days from start of the previous episode to start of the present episode. Days to first episode and regularity were ln transformed before further analysis. Direct activity counts were considered unsuitable for further analysis as activity tags were not uniformly calibrated (data not shown). The effect of threshold settings on detection and error rates was evaluated using a learning data set from 461 successful AI records giving either a calf or a confirmed pregnancy. Detection rate was the proportion of high-activity periods that occurred when there was an estrus that resulted in a successful insemination. Error rate was the proportion of high-activity periods that were not associated with any estrus. On the complete data set, threshold settings also affected genetic parameters for DFE. The optimal threshold setting for genetic analysis was assumed to give the highest heritability estimate for DFE. From this step, episode characteristics were subjected to further analysis as repeated records from the same animal using up to 5 episodes per animal per parity.

A single-trait mixed model was used to assess effects of systematic factors and co-variance components for individual animal (permanent environment) and genetic effect on traits. The model [1] also included a random year-season term:

$$y = \mathbf{Xa} + \mathbf{Z_1b_1} + \mathbf{Z_2b_2} + \mathbf{Ws} + \mathbf{Ie}. \qquad [1]$$

Variation in the trait variables y were modeled as dependent on systematic effects $\mathbf{a}$ given in the design matrix $\mathbf{X}$ including breed (Red Dane, Holstein, Jersey), age group (heifers, cows), parity within the cow age group (1, 2, 3, 4), a breed by age group interaction, and episode number (1, ..., 5) and episode number by age group interaction. Random effects from animals across and within parities were in $\mathbf{b_1}$ with incidence matrix $\mathbf{Z_1}$ with genetic effects in $\mathbf{b_2}$ with relationship matrix $\mathbf{Z_2}$. Random effects of year-months (used as "short seasons") were in $\mathbf{s}$ with incidence matrix $\mathbf{W}$ and random residuals in $\mathbf{e}$ assumed to be normally distributed. Additive genetic variance $\left(\sigma_A^2\right)$, permanent animal variance across parities $\left(\sigma_{P1}^2\right)$ and within parities $\left(\sigma_{P2}^2\right)$ were obtained together with year-season variance $\left(\sigma_{YS}^2\right)$ considered as noise, and residual variance $\left(\sigma_e^2\right)$. The model was also applied to data restricted to the first occurring activity episode in each parity, in which case the within-parity variance component was omitted, and with a further restriction to first parity alone. Estimates of variance components were obtained using average information REML in the DMU package (Madsen and Jensen, 2005).

Table 1. Characteristics of estrus-related high-activity episodes in cows and heifers

Trait[1]	n	Mean	SD	99% Confidence limit	
				Lower	Upper
Age at first episode in heifers,[2] d					
Red Danes	49	420	33	407	433
Holsteins	53	420	32	408	432
Jersey	29	419	36	401	438
Days from calving to first episode in cows[3]					
Red Danes	301	38.7	27.3	34.7	42.8
Holsteins	361	43.5	28.5	39.7	47.4
Jersey	213	45.1	29.1	40.0	50.3
Heifers					
Duration, h	558	8.93	5.53	8.32	9.53
Strength, ln units	560	1.09	0.37	1.04	1.13
Regularity, d	429	17.6	15.2	15.7	19.5
Cows					
Duration, h	2,723	8.09	4.63	7.86	8.32
Strength, ln units	2,724	1.09	0.39	1.07	1.11
Regularity, d	1,849	25.5	20.3	24.3	26.7

[1]Duration, strength, and regularity are means for up to 5 episodes per parity-animal. Detection threshold set at $\alpha = 0.75$.

[2]Activity of heifers was recorded from 365 to 545 d of age. First estrus may have occurred before activity recording commenced.

[3]Activity of cows was recorded from 5 to 155 DIM, during parity 1 to 4.

Holstein, Red Dane, and Jersey heifers all had their first activity episode at an average age of 14 mo (Table 1). In cows, the interval from calving to first detected estrus episode was 39, 44, and 45 d for Red Dane, Holstein, and Jersey, respectively, when considered as simple group means (Table 1). When considered across breeds, activity episodes lasted 8.12 h in cows and 9.24 h in heifers with a peak activity of 1.03 ln units in both age groups (Table 1). The regularity of estrus episodes was shorter and less variable in heifers than in cows when expressed in days between successive episodes, indicating that heifers have more short intervals possibly coming from non-estrus-related episodes (Table 1).

The settings of the threshold affected detection rates and daily error rates in a trade-off relationship (Table 2). High detection rates were only obtained when high error rates were also accepted, and conversely low error rates were obtained at the cost of lower detection rates. A compromise giving less than 1% error rate and maintaining a 71% detection rate was achieved at the threshold set at 0.75. Heritability estimates were moderate for DFE (ranging from 0.10 to 0.18) and were affected by the chosen threshold for episode detection (Table 2). The highest heritability estimates were obtained at the threshold set to 0.75, where the additive genetic variance was largest and the permanent animal and residual variances were smallest. However, at the threshold set to 0.80, results were rather similar. With increasing threshold the heritability estimates were based on data including an increasing number of cows without detected DFE, which were replaced by a default value (155 d), resulting in slightly lower heritability estimates when using this approach compared with ignoring the nonresponders (data not shown). At lower threshold settings, higher error rates gave more false positives and thereby inaccurate determination of days to first high-activity episode. At the higher settings, several episodes were too silent to exceed the threshold and became false negatives thereby failing to provide the expected signal. Both situations led to poorer signal to noise ratio and thus also lower heritability, so the 0.75 threshold was chosen on this basis.

Fixed effects are described in detail by Løvendahl and Chagunda (2009). Briefly, breed affected DFE, with Red Danes having the shortest, followed by Holsteins and Jerseys with the longest interval from calving to first detectable estrus (Table 3; $P < 0.01$). A slightly shorter interval to DFE was found in second parity compared with other parities (Table 3). Besides this, parity of lactating cows only affected regularity (Table 3). For the multiple episode data, episode number affected duration of episodes (data not shown).

In the first parity, DFE had a heritability of 0.12, whereas when data from cows of all parities were considered, the heritability was 0.18 (Table 4). For DFE the repeatability was similar to the heritability (Table 4) because the estimated permanent (animal) environmental variance was close to zero. The heritability estimate for duration of each estrus episode was largest, $h^2 = 0.08$, when only the first episode in first-parity cows was considered (Table 4). When parities higher than first were also considered, heritability decreased

Table 2. Detection rates (%) and genetic parameter estimates for days from calving to first high-activity episode (DFE), estimated at different settings of the detection threshold (α)[1]

	Learning data[2]		All cows: DFE,[3] ln units							
α	Detection rate, %	Daily error rate, %	Episodes,[4] n	DIM[5]	Cows,[6] n	σ_a^2	σ_p^2	σ_e^2	$h^2 \pm$ SE	$t_a \pm$ SE
0.60	83.1	2.26	929	30.5	519	0.0577	0.01753	0.310	0.15 ± 0.07	0.20 ± 0.07
0.65	79.4	1.70	917	34.6	515	0.0542	0.01047	0.348	0.13 ± 0.06	0.16 ± 0.06
0.70	74.6	1.33	897	38.7	507	0.0620	2.30e-6	0.341	0.15 ± 0.06	0.15 ± 0.06
0.75	71.2	0.93	877	42.0	496	0.0693	3.12e-6	0.326	0.18 ± 0.07	0.18 ± 0.07
0.80	67.5	0.67	846	44.8	489	0.0655	1.42e-6	0.310	0.17 ± 0.06	0.17 ± 0.06
0.85	60.3	0.49	804	47.3	476	0.0494	4.92e-6	0.308	0.14 ± 0.06	0.14 ± 0.06
0.90	56.4	0.38	769	50.9	462	0.0344	3.87e-6	0.312	0.10 ± 0.05	0.10 ± 0.05

[1]Detection rates are based on a learning data set of 461 artificial inseminations giving either a calf or a confirmed pregnancy. Genetic parameters are based on the complete data set where the number of cows showing activity episodes depends on the threshold.

[2]Detection rate = animals with episodes detected on the day of AI or the day before AI of the 461 possible; daily error rates calculated as the average number of episodes per day over d −14 to −2 and 1 to 14 relative to AI, per 100 cows.

[3]σ_a^2, σ_p^2, and σ_e^2 are variance components for additive genetic, permanent (animal) environment, and residual, respectively; h^2 = heritability calculated as $h^2 = \sigma_a^2 / \left(\sigma_a^2 + \sigma_p^2 + \sigma_e^2\right)$; and t_a = repeatability calculated as $t_a = \left(\sigma_a^2 + \sigma_p^2\right) / \left(\sigma_a^2 + \sigma_p^2 + \sigma_e^2\right)$.

[4]Number of "episode number 1" detected in the total data set from 936 possible cow-lactations. For cow-lactations without detected episodes, a default value of DFE = 155 d was used for variance component estimation.

[5]Mean DFE for first episodes.

[6]Number of cows having an episode number 1 at the given threshold.

to 0.02 and 0.05 when the permanent animal variance was separated from the genetic variance. The strength of estrus had low heritability (0.04 to 0.06) and low repeatability (0.08 to 0.10).

The results of this experiment show that behavior-based estrus traits obtained from activity tags on dairy cows are useful for identifying first occurrences of high physical activity and for characterizing the duration and intensity of estrus. The traits have low to moderate heritability and are repeatable across and within parity, similar to that obtained in previous studies using milk progesterone measurements (Royal et al., 2002). Genetic variation in age at first estrus for virgin heifers was not estimated because estrus episodes may already have occurred before activity tags were in place at 12 mo of age.

The number of days from calving to first estrus showed a heritability of 0.12 to 0.18. The repeatability for the interval from calving to first estrus was 0.18, showing that this trait is predominantly determined by the genetic component. Previous experimental studies have based detection of commencement of luteal activity on progesterone measurements in milk and obtained moderate heritability estimates. Royal et al. (2002) obtained an estimate of $h^2 = 0.17$ in British Holstein-Friesian cows when 3 milk samples were obtained per week, and Petersson et al. (2007) obtained a higher estimate ($h^2 = 0.30$) by expressing the trait as percentage of cows with luteal activity, using the same data set. In comparison, estimates of heritability for days to first AI or successful AI based on field records are low, around $h^2 = 0.03$ (Roxström et al., 2001a, b; Philipsson

Table 3. Effects of breed, age group, and parity on estrus activity episode traits[1]

	Days to first detectable estrus		Duration, h		Strength, ln-units		Regularity, d	
Factor and level	LSM ± SE	GM	LSM ± SE	GM	LSM ± SE	FOI	LSM ± SE	GM
Breed								
Red Dane	3.446 ± 0.049	31.4	1.990 ± 0.027	7.3	1.108 ± 0.018	3.03	2.636 ± 0.048	14.0
Holstein	3.581 ± 0.046	35.9	1.998 ± 0.026	7.4	1.097 ± 0.018	3.00	2.720 ± 0.046	15.2
Jersey	3.614 ± 0.055	37.1	1.843 ± 0.034	6.3	1.005 ± 0.024	2.73	2.774 ± 0.061	16.0
Parity								
Heifers			1.964 ± 0.030	7.1	1.066 ± 0.020	2.90	2.522 ± 0.054	12.5
First parity	3.562 ± 0.038	35.2	1.918 ± 0.021	6.8	1.058 ± 0.015	2.88	2.924 ± 0.042	18.6
Second parity	3.485 ± 0.042	32.6	1.942 ± 0.022	7.0	1.096 ± 0.015	2.99	2.831 ± 0.043	17.0
Third parity	3.539 ± 0.053	34.4	1.919 ± 0.028	6.8	1.080 ± 0.019	2.94	2.826 ± 0.053	16.9
Fourth parity	3.602 ± 0.092	36.7	1.910 ± 0.050	6.8	1.066 ± 0.020	2.90	3.011 ± 0.096	20.3

[1]Results are least squares means (LSM ± SE) in ln-units with corresponding geometric means (GM) in measured units or folds of increase (FOI). High activity episodes were detected using the threshold set at α = 0.75.

Table 4. Genetic parameters for traits describing episodes of high activity related to estrus in dairy heifers and cows[1]

Trait	Animals, n	$h^2 \pm$ SE	$t_a \pm$ SE	$t_w \pm$ SE
First episode, first-parity cows				
Days from calving to first episode	374	0.12 ± 0.11		
Duration, ln(h)	374	0.08 ± 0.11		
Strength, ln-units	374	0.06 ± 0.12		
First episode, all parities (1–4 or 0–4)[2]				
Days from calving to first episode	517	0.18 ± 0.07	0.18 ± 0.07	
Duration, ln(h)	517	0.02 ± 0.04	0.02 ± 0.04	
Strength, ln-units	517	0.04 ± 0.04	0.10 ± 0.04	
All episodes (1–5), all parities (0–4)[2]				
Duration, ln(h)	517	0.05 ± 0.02	0.08 ± 0.02	0.08 ± 0.02
Strength, ln-units	517	0.06 ± 0.02	0.08 ± 0.02	0.09 ± 0.02
Regularity, ln(d)	483	0.00 ± 0.02	0.04 ± 0.02	0.05 ± 0.02

[1]Data are restricted either to the first detected episode of activity or to all episodes detected within the observation window (DIM 5 to 155 d in cows, and 365 to 545 d of age in heifers). Results are estimates of heritability (h^2) and repeatability, across (t_a) and within parity (t_w). The episode detection threshold was set at $\alpha = 0.75$.

[2]Days from calving to first episode was analyzed only in cows, but duration, strength, and regularity were recorded in both heifers and cows.

and Lindhe, 2003; Wall et al., 2003), although higher estimates ($h^2 = 0.07 - 0.10$) were reported by Jamrozik et al. (2005). Characteristics of estrus behavior had low heritability for duration at around 0.02 to 0.08, and for strength between 0.04 and 0.06. Few other genetic studies have considered these traits. Roxström et al. (2001a), who obtained low heritability estimates (h^2 ~0.02) of heat intensity from subjectively scored field data, confirm the findings of the present study.

Estrus was assumed when the deviation between actual and baseline activity exceeded a given threshold for 3 consecutive hours. The baseline activity profile was calculated by exponential smoothing of activity recorded in each of 24 hourly periods. The deviation from the baseline was thereby adjusted for circadian variation and so expressing relative changes. Similar approaches have been used previously (At-Taras and Spahr, 2001; Roelofs et al., 2005a). Further exponential smoothing was effective in limiting the random noise on single hourly deviations. More protection against false positives was enforced by requiring the smoothed deviations to exceed the threshold for at least 3 consecutive hours. This restriction may in turn also have removed atypical and short estrus episodes. Such atypical episodes were found more frequently at spontaneous multiple ovulations (more than one dominant follicle producing oocytes) and in cows with low BCS or very high yield (Lopez et al., 2005). Thus, optimal detection algorithm settings will depend on whether the aim is detection of "normal" estrus episodes or both the normal and the atypical episodes.

The present study recorded activity in 1-h periods that allowed estimation of estrus duration, which lasted, on average, 8.1 h in cows and 9.2 h in heifers, respectively. In a comparable housing system, the duration of estrus was somewhat longer, 11.8 h when recorded by visual observation at 3 h intervals, and almost similar (10.0 h) when recorded by pedometers in 2-h periods (Roelofs et al., 2005b). The intensity or strength of estrous behavior was determined as a relative deviation from a moving average for the individual cow in ln units, which in linear scale expresses folds of increase (Table 3). The measured units are not fully comparable across studies because units are defined by the manufacturers and because tags are attached either to a neckband or to the leg (Maatje et al., 1997). A further complication to units is that activity tags, even from the same manufacturer, may not be calibrated. However, log-transformation is effective in stabilizing the variation and the deviations from baseline express the relative increase in percentage or fold. Indeed, for the chosen threshold of 0.75 the mean strength was equivalent to a 3-fold increase, which is similar to findings in other studies (Firk et al., 2002).

Red Dane cows had their first high-activity (estrus) episode at 39 DIM, 5 d before Holstein and 6 d before Jersey cows. In a comparative study, Brown Swiss had a calving interval 22 d shorter than that of Holsteins, and similarly Jerseys had on average a calving interval 14 d shorter than Holsteins (Garcia-Peniche et al., 2005). In the current study, breeds differed both in BCS and milk yield (Friggens et al., 2007), and differences between breeds in days to first estrus could partly be attributed to differences in BCS (Løvendahl and Chagunda, 2009). This is in agreement with previously reported negative relationships between fertility, BCS, and yield both at the genetic and phenotypic levels (Veerkamp et al., 2000; Wassmuth et al., 2000; Pryce et al., 2002; Royal et al., 2002).

The results of the present study have shown that automated heat detection using electronic activity tags may not only be of value in estrus detection, but could also be helpful in recording of fertility traits for genetic evaluations. Higher heritability was obtained compared with field data from AI services. A key point in a genetic selection strategy is to obtain large volumes of inexpensive and unbiased data allowing estimation of reliable breeding values. By using electronic activity tags higher heritability for days to first estrus could be obtained as shown in the present study. Other equipment giving unbiased information about fertility traits could have been used in similar ways, such as on-farm progesterone measurements (Friggens and Chagunda, 2005; Løvendahl et al., 2009). In conclusion, the results suggest that activity tag-based fertility traits may provide valuable information to dairy herd improvement programs.

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