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New activity-based fertility traits for Norwegian Red dairy cattle: definitions, heritabilities and comparison to traditional fertility traits

Nye fertilitetsegenskaper basert på aktivitet for Norsk Rødt Fe: definisjoner, arvegrader og sammenligning med eksiterende fertilitetsegenskaper

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It has almost been five years since I first came to Ås as a first-year student with little knowledge of what these years would mean to me, both personally and academically. After a bachelor's degree in biology, I found my true interest in breeding and genetics and I am grateful for the opportunity to write a thesis about my favourite topic and production animal.

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Abstract

The aim of this study was to define and calculate heritabilities for new activity-based fertility traits for Norwegian Red (NRF) dairy cattle. The traits were time from calving to first high activity episode (CFHA), first estrus in heifers (FEH), estrus duration (ED) and estrus strength (ES). Time from calving to first insemination (CFI) is a fertility trait already used in the NRF's breeding scheme and are included in the study for comparison to the new traits.

Relative activity change was measured with Heatime RuminAct (SCR, Netanya, Israel), where activity measured in a 2-hour interval is compared to the normal activity levels for each individual animal based on records from the previous week. A high activity episode is interpreted to be an indicator of estrus and was registered with at least three continuous recordings above threshold value and ended with two continuous recordings under threshold.

A total of 1104 NRF from 33 free stall herds in Norway wore activity units. CFI was calculated based on the first parity from 2007 to 2018 for 3820 registered NRF cows from the 33 herds. A total of 573 NRF animals from 27 herds had activity change data and were successfully linked to data from the Norwegian Dairy Herd Recording System. After editing, only 117 cows met the requirements for CFHA recording, 101 for FEH and 491 for ED and ES. Least square means showed a difference in expression of fertility traits for different seasons and parities. Autumn gave the best expressions, while parity one showed the weakest signs. Of the significant phenotypic correlations, it was a favourable correlation between ED and ES and unfavourable between CFHA and ES. Estimated heritabilities for the new activity-based traits were low (0.00-0.05) with large standard errors. Estimated heritability for CFI was 0.02 with a standard error of 0.02.

There are some challenges with using a herd management tool like Heatime RuminAct to register phenotypes for breeding purposes. First, most recordings started too late to register CFHA and FEH. Secondly, activity registrations must be continuous, without lack of recordings. Third, too few recording units on the farm will lead to pre-selection since there is no point recording activity of an animal that will not be inseminated. Fourth, proper identification of the animal using an activity unit is a must.

Consequently, this study has shown that recommendations for use is necessary if herd management tools are to be used for data collection for breeding purposes. The use of activity measurements is promising with enough data material.

Sammendrag

Målet med oppgaven var å definere, samt estimere arvegrader, til nye fertilitetsegenskaper til norsk rødt fe (NRF) basert på aktivitetsmålinger. Egenskapene var tid fra kalving til første aktivitetsøkning (CFHA), første brunst hos kviger (FEH), brunst lengde (ED) og brunst styrke (ES). Til sammenligning, er tid fra kalving til først inseminering (CFI) inkludert i oppgaven siden egenskapen inngår i det nåværende avlsprogrammet til NRF.

Aktivitetmåleren som ble brukt i oppgaven, Heatime RuminAct (SCR, Netanya, Israel), beregner en normal aktivitet til et individ basert på målinger hver andre time de 7 foregående dagene. En høy-aktivitetsperiode er en indikasjon på brunst og start ble definert ved minst tre sammenhengende resisteringer over en gitt terskelverdi og to sammenhengende resiteringer under terskelverdi ved endt brunst. Totalt 1104 NRF fra 33 norske løsdriftsgårder hadde aktivitetsenheter, hvorav 573 dyr fra 27 gårder ble identifisert i Kukontrollen og hadde registrert aktivitetsendring. Totalt 117 dyr møtte kriteriene til CFHA registrering, 101 for FEH og 491 for ED og ES. 3820 første laktasjons kyr med kalving mellom 2007 og 2018 fra de 33 gårdene ble brukt til å beregne CFI.

Utregning med gjennomsnitt av minste kvadrat (Least Square means) viser at fertilitetsegenskaper uttrykkes forskjellig etter sesong og laktasjonsnummer, der høsten gir best uttrykk bland sesongene, mens første laktasjonskyr viser de dårligste. Fenotypisk korrelasjon mellom ED og ES var gunstig, i motsetning til korrelasjonen mellom CFHA og ES som var ugunstig. De estimerte arvegradene for de nye egenskapene basert på aktivitet, var lave (0,00-0,05) og med stor standardfeil. Estimert arvegrad for CFI var 0,02 med lik standardfeil (0,02).

Det er utfordringer knyttet til bruk av teknologi slik Heatime RuminAct for å registrere fenotyper med tanke på avl. De fleste registreringer starter for sent til CFHA og FEH registrering. Det må være sammenhengende registrering av aktivitetsendring slik det blir et fullverdig datasett. For få registreringsenheter vil føre til en pre-seleksjon av dyr, da det ikke er hensiktsmessig for bonden med aktivitetsmålinger på dyr som skal utrangeres. I tillegg er det viktig at alle dyr kan identifiseres i Kukontollen.

Denne oppgaven har vist at det er hensiktsmessig med anbefalinger ved bruk av aktivitetsmålere, og med nok datamateriale, er fertilitetsegenskaper basert på aktivitet lovende med tanke på avl.

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1. Introduction

1.1 The importance of fertility

Cow fertility is an important trait that has a large impact on the economics of a dairy farm. Low reproductive performance will increase calving intervals causing cows to have a longer dry period with no milk production. Consequently, it will reduce profit by fewer calves, lower annual yield, and increase feed costs for cows out of production. Repeated, unsuccessful inseminations or medical treatment for fertility-related problems will increase costs by veterinary bills, culling because of poor fertility and replacement (Esslemont et al. 2001, Sewalem et al. 2008). Cow fertility is therefore an important trait in the dairy industry and improvement can be done genetically through breeding. However, there are some challenges regarding breeding for fertility traits.

1.2 Challenges

Cow fertility is a complex trait with several aspects, such as the ability to conceive, have a successful pregnancy, the ability to return to cycling and show estrus behaviour. Most fertility traits have low heritabilities, usually less than 5%, and are often largely affected by environment and management decision by the farmer which makes breeding for fertility traits challenging (Pryce et al. 1997, Andersen-Ranberg et al. 2005, Berglund 2008).

A problem regarding fertility is a lack of or inadequate detection of estrus, as timing of insemination is crucial for pregnancy (Ismael et al. 2015). Estrus is normally shorter than 24 hours and can, therefore, be easily overlooked by the farmer (Sveberg et al. 2015). In addition, environmental effects like stress, feeding or disease, can influence heat cycles and affect estrus detection and insemination. Fertility also has an unfavourable genetic correlation (0,2 -0,4) with milk yield, that will cause a decrease in fertility if the breeding focus is directed towards increased milk yield (Roxström et al. 2001, Andersen-Ranberg et al. 2005, Berglund 2008). Therefore, it is important to emphasize on fertility traits in dairy cow breeding programmes and ensure that enough weight is put on fertility relative to milk yield to obtain genetic progress for both traits (Hermas et al. 1987, Dematawewa et al. 1998, Veerkamp et al. 2000, Royal et al. 2002, Andersen-Ranberg et al. 2005).

1.3 Norwegian Red dairy cattle and fertility

Norwegian Red (NRF) dairy cattle has been the main dairy cattle breed in Norway since the 1960s with broad breeding goals and focus on a sustainable cow (Geno 2018). Fertility has been included in the breeding programme since 1972 and different fertility traits have been used for selection. Records of 56 days non-return rate (NR56) for heifers have been used for genetic evaluation since 1972, and NR56 for first lactating cows was included in 2002 (Andersen-Ranberg et al. 2005). NR56 measures the ability to conceive after first insemination. By using information of registered inseminations, the trait is defined as either “yes, pregnant by the first insemination” or “no, not pregnant by the first insemination” if there is a second insemination within 56 days after the first. In 2009, the interval from calving to first insemination (CFI) was included in the fertility index, which measures the ability for a cow to go into heat cycle after calving (Andersen-Ranberg et al. 2005, Larsgard 2009, Sveberg et al. 2015). The fertility index in today’s breeding programme for NRF includes the number of inseminations needed for a pregnant heifer, the number of inseminations for a pregnant dairy cow and CFI (Geno 2017). Because fertility has been included in the breeding programme for NRF for so long, and with a weight of 8-15% in the total merit index, breeding for fertility traits has given some desirable genetic progress (Andersen-Ranberg et al. 2005).

There has been a genetic improvement of NR56 for NRF heifers, but an unfavourable development of CFI and number of inseminations per animal (Andersen-Ranberg et al. 2005, Chang et al. 2006). This development is caused by selection and genetic correlation between the fertility traits where CFI and NR56 has a low and unfavourable genetic correlation (-0.24). Substantial weight of fertility traits in the NRF breeding programme and selection for NR56 in heifers have stabilized NR56 for first lactating cows, even though the genetic correlation between the two traits are low (0.04) (Andersen-Ranberg et al. 2005). Because most fertility traits have low heritabilities and are, to a large degree, affected by environmental factors, it is desirable to find new methods to register fertility phenotypes that are low cost, accurate and time effective.

1.4 Estrus detection

Proper detection of estrus is vital to find the right time of insemination and failure of detecting is a limitation to obtaining an effective reproductive performance and can falsely accuse a cow for having poor fertility (Lehrer et al. 1992, Nebel et al. 2000). Registration of mounting activity, milk yield, progesterone levels, body and milk temperature, are all measurements

that can be used as indicators for estrus detection (Lewis et al. 1984, Eradus et al. 1992, At-Taras et al. 2001, Mottram et al. 2001, Fleming et al. 2019, Lucy 2019).

A traditional method is to visually detect estrus by observing cow behaviour. Registrations are done either by live observations of the animals or by video recordings. Firk et al. (2002) concluded in their review paper, that the visual detection rate of estrus is low (54-58%). Rates can be higher (up to 80%), but this requires continuous monitoring. Improvement of estrus detection is expected by introducing technological devices since it can provide continuous and precise data (Firk et al. 2002).

Automatization of the dairy industry, together with developing technology, make it possible to detect estrus by other methods (Fleming et al. 2019, Lucy 2019). Milk yield will drop during estrus as a consequence of restlessness and lower feed intake, making it possible to use information from automatic milking systems as an indicator to detect estrus (Eradus et al. 1992). Body and milk temperature can also change significantly during the estrus cycle, but environmental factors have a large impact the cow's milk and body temperature as well as milk yield, which makes change of temperature and milk yield unreliable as a single source for estrus detection (Lewis et al. 1984, Firk et al. 2002).

The level of progesterone in milk can be measured by biosensors and these are possible to use in automatic milking systems (Mottram et al. 2001). Since progesterone levels in milk decline pro-estrus, detection is possible (Döcke 1994). Delwiche et al. (2001) achieved a 100% detection rate on 14 estrus events but also had 28% false positive registrations. So, even though there are biosensors on the market today, there are still challenges regarding cost and practical use (Brandt et al. 2010).

1.5 Activity measurements

Activity measurements are first and foremost a herd management tool used for heat detection, but it is also a promising method to register fertility traits. Hormone change during estrus is associated with higher activity levels, up to 400% increase in free stalled herds, which makes it possible to detect estrus by monitoring activity (Kiddy 1977, Wiltbank et al. 2006, Løvendahl et al. 2010, Aungier et al. 2012). Behavioural and activity changes can be measured by sensors and give a higher detection rate than visual detection as At-Taras et al. (2001) showed in their study (detection levels by using mounting sensors 71.7-86.8% vs. visual observations 54.5-54.7%). Registrations based on activity change (walking/movement)

gave a detection rate up to 93% and is considered an effective estrus detection tool that requires little human labour (Firk et al. 2002).

Constant monitoring of the herd can give an indicator if there is an animal in heat and makes it easier for the farmer to inseminate at the right time. Some devices, like Heatime RuminAct (SCR, Netanya, Israel), will also give an indication of abnormal activities and rumination that potentially could be caused by disease (Geno 2018). Therefore, activity monitoring can be a relatively inexpensive method to gather information about estrus for breeding interests, since a registration system already is established and can be used in both free and tie stalled herds (Geno 2019). Time from calving to first detected estrus by activity measurements showed a higher heritability than the traditional traits for fertility based on insemination records, making it promising to use activity phenotypes as selection criteria for genetic evaluation (Løvendahl et al. 2009, Fleming et al. 2019, Lucy 2019).

Activity tags that constantly monitor activity will show activity peaks that indicate estrus and will contribute to improve conception rates because the timing of insemination can be more accurate (Aungier et al. 2012). Monitoring of activity also gives the possibility to find new measurements of fertility traits to be used in genetic evaluation, for example, duration and strength of estrus (Løvendahl et al. 2010). Registration of days from calving to first estrus using activity measurements, including information about estrus duration and strength, have the potential to give higher heritabilities and reduce environmental noise such as farmers decision.

2. Aim

The aim of this study is to use field data on activity change information from Heatime RuminAct devices to define new fertility traits, estimate heritability for these traits for NRF and compare findings to a fertility trait used in the current genetic evaluation.

3. Material and methods

3.1 Data

All activity measurements were made with Heatime RuminAct (SCR, Netanya, Israel) collars fitted around the animal's neck. Measurements were taken from 17th November 2017 to 17th November 2018. A monitoring device on the collar tracks movement and sends activity information to a digital herd unit automatically every second hour. Data information were uploaded and saved in an external, digital cloud, which is accessible for SCR.

The dataset with activity measurements was delivered by SCR with a total of 1104 animals from 33 free stall herds in Norway. Information of raw activity, activity change, raw rumination and rumination change, as well as herd ID and cow's ear tag number, was included in the dataset. The focus of this study was on relative activity change, which is change in activity compared to normal activity levels. Normal activity levels for the individual cow is calculated based on 1 week (7 days) previous raw activity recordings and set to 0 (unit of measurement and algorithm is not known to the writer) (Mengshoel, Geno, personal communication, 2019).

The Norwegian Dairy Herd Recording System provided information about cow ID, birthdate, calving and inseminations to connect with information from the activity data. All animals had to be registered as purebred NRF to be linked by pedigree and used to calculate heritabilities. Pedigree was provided by NRFs breeding organization Geno and included 7384 animals with birth dates from 1950 to 2016 for activity-based traits, and a larger pedigree with 25981 animals born 1935 to 2017 for the trait used in in the current genetic evaluation, time from calving to first insemination (CFI).

Out of 1104 animals from 33 herds, 573 animals from 27 herds met the requirements for further use in the study for activity-based traits. Requirements were (1) breed registered as NRF, (2) have activity change data available and (3) successfully linked to the Norwegian dairy herd recording system by ID.

3.2 Defining new fertility traits based on activity measures

3.2.1 High activity as an indication of estrus

High activity was defined when activity change records were above the threshold value for at least three continuous readings and followed by two continuous readings below the threshold. The threshold for high activity given by SCR is when activity change has a value of 35. This is the same definition as used by Ismael et al. (2015). In this current study, recordings of high

activity are interpreted to be an indicator of estrus. An example of a high activity event is shown in Figure 1.

High activity information was used to define the following new fertility traits: days from calving to first high activity (CFHA), estrus duration (ED), estrus strength (ES) and first estrus for heifers (FEH). CFI was calculated for comparison as a traditional fertility trait that already have been used in the breeding programme for NRF (Larsgard 2009).

A total of 548 animals had an estrus recording, 397 cows and 151 heifers from 26 herds. Editing and calculations of data were done with SAS (version 9.4, SAS Institute, 2012).

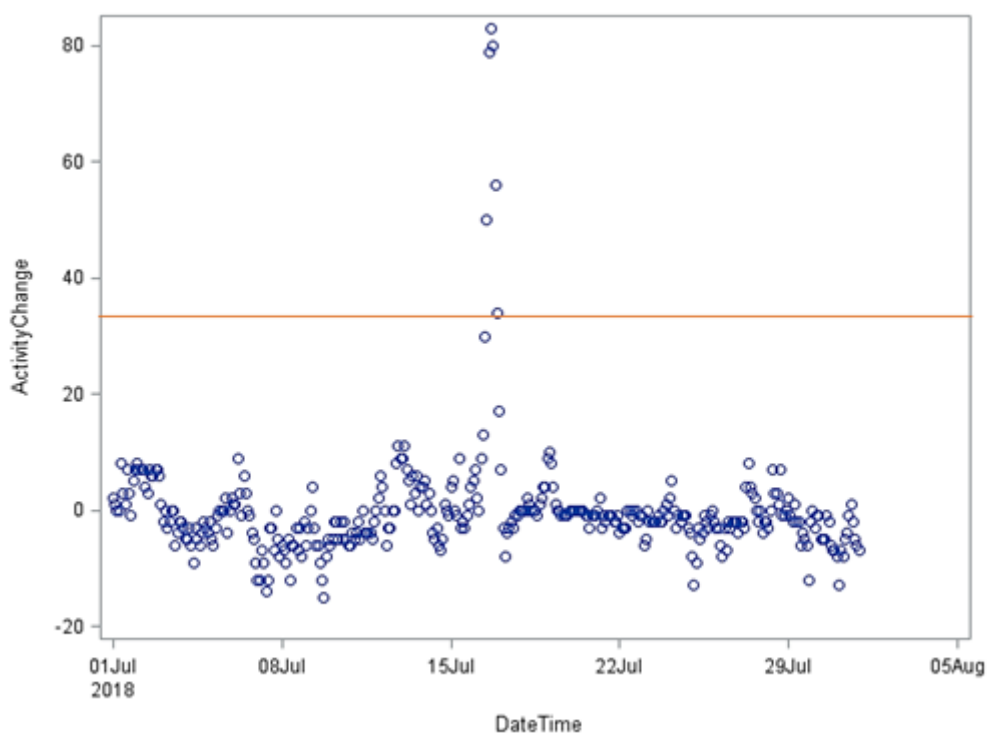


Figure 1: An example of activity change measured over time for a cow with a high activity event that is an indication of estrus, with at least three continuous registration over the threshold (orange line) followed by at least 2 continuous registrations below the threshold.

3.2.2 Time from calving to first high activity

Time from calving to fist high activity (CFHA) represents the number of days from calving to the first recording of high activity based on three continuous recordings over threshold, but no confirmed ending unlike described in section 3.2.1. The reason why no confirmed ending was required is because of few observations and further restrictions would reduce an already small dataset. Requirements for CHFA were (1) high activity was measured between 15 and 200 days after calving. The reason was to avoid false high activity measurements too soon after

calving and set a limit of how long it was acceptable with no high activity recordings. To avoid missing the first high activity episodes, (2) measurements of activity change had to start before 28 days after calving and (3) have no more missed recordings than 48 continuous hours. A total of 117 animals from 20 herds met the requirements.

3.2.3. First estrus in heifers

The first estrus in heifers (FEH) is based on the first registered high activity measurements for NRF heifers. The animals included were born in either 2016 or 2017 and had no recorded calving. Requirements were that high activity had to be measured between 180 (6 months) and 540 days (1,5 years of age).

3.2.3 Estrus duration

Estrus duration (ED) was defined as the time from start to end of the first recorded estrus. Given our definition of how to indicate estrus (see section 3.2.1), duration could not be shorter than 6 hours (minimum 3 records in a row above threshold). Other studies do not report ED longer than 72 hours, so maximum recording of ED was set to 72 hours (Roelofs et al. 2005, Løvendahl et al. 2010, Ismael et al. 2015, Sveberg et al. 2015).

3.2.4 Estrus strength

Estrus strength (ES) was defined as the highest activity change recorded for each animal in their first registered estrus. ED and ES are based on the same estrus registrations from the same animals. Heifer and cow records from 21 herds were included for both ED and ES, and no herd had less than 10 recorded animals.

3.3 Time from calving to first insemination

Time from calving to first insemination (CFI) is a trait that is currently used in genetic evaluation of cow fertility and CFI was included for comparison to the new activity-based fertility traits. All animals from the original 33 herds with activity data were included. CFI were calculated based on the animals first calving between 2007 and 2018 and following insemination. Inseminations had to be registered 15 to 200 days after calving and the animals had to be registered as NRF. A total of 3820 animals from 33 herds met the requirements.

3.4 Summary statistics

Table 1 shows the number of animals that met the criteria for each trait and summary statistics. FEH which is based on heifer information has fewest observations. ED and ES have the highest number of observations with both heifer and cow information. CFHA is based on cow information from the first lactation or higher, while CFI is based on first parity. Heifer tends to have a stronger ED and ES than cows, even though cows have a bigger range of ES.

Table 1: Number of observations (*N*), mean, maximum and minimum measurement, range and standard deviation (*Std Dev*) for traits used in the study.

<i>Traits</i> ¹	<i>N</i>	<i>Mean</i>	<i>Maximum</i>	<i>Minimum</i>	<i>Range</i>	<i>Std Dev</i>
CFHA (d)	117	94.8	197.2	15.8	181.3	56.1
FEH (d)	101	324.0	498.0	180.0	318.0	84.2
<i>ED Heifers (h)</i>	137	19.4	72.0	6.0	66.0	15.7
<i>ED Cows (h)</i>	354	19.1	70.0	6.0	64.0	16.1
ED Total (h)	491	19.2	72.0	6.0	66.0	16.0
<i>ES Heifers</i>	137	85.5	212.0	38.0	174.0	28.0
<i>ES Cows</i>	354	80.5	253.0	38.0	215.0	27.4
ES Total	491	81.9	253.0	38.0	215.0	27.6
CFI (d)	3820	80.3	200.0	16.0	184.0	31.2

¹CFHA = time from caving to first insemination, measured in days (d); FEH = first estrus in heifers, measured in days (d); ED = estrus duration, measured in hours (h); ES = estrus strength, unit of measurement not known; CFI = time from calving to first insemination, measured in days (d). Data for ED and ES shown separate for cows and heifers, and for all animals combined

3.5 Statistical analysis

A general linear model (GLM) procedure in SAS (version 9.4, SAS Institute, 2012) was used to find the relevant fixed effects to be included in the animal model. Least Squares mean (LSM) was calculated to assess the effects of season when inseminated for CFI and parity and season when in heat for CFHA, ED and ES.

Based on the results from the GLM procedure, the linear animal models used to estimate variance components are as follows:

$$y_{ijkl} = h_i + sh_j + p_k + a_l + e_{ijkl}$$

where

- y_{ijkl} is the observations of a fertility trait.
- h_i is the fixed effect for herd ($i = 1$ to 20 for CFHA, $i = 1$ to 21 for ED and ES)
- sh_j is the fixed effect of season when heat was registered ($j = 1$ to 4 where 1 is December to February, 2 is March to May, 3 is June to August and 4 is September to November).
- p_k is the fixed effect of parity ($k = 1$ to 5, where 1 to 4 is parity 1-4. 4 includes all parities from 4 and above, 5 is heifer data).
- The random genetic effect of animal $a_l \sim ND(0, \mathbf{A}\sigma_a^2)$ where σ_a^2 is the additive genetic variance and \mathbf{A} is the additive relationship matrix.
- The random residual is $e_{ijkl} \sim IND(0, \sigma_e^2)$.

For estimating variance components for ED p_k was excluded because the effect was not significant according to the GLM analysis. For CFHA and ES, the model was used as described.

The model used to estimate variance components for CFI was

$$CFI_{ijkl} = age_i + sj_j + hy_k + a_l + e_{ijkl}$$

- age_i is the fixed effect of the age (months) of the cow when she calved ($i = 1$ to 4, where age group 1 are all ages under 24 months, group 2 are 25 to 26 months, group 3 are 27 to 28 months and group 4 are all ages over 28 months).
- sj_j is the fixed effect of season when the cow was inseminated ($j = 1$ to 4 where 1 is December to February, 2 is March to May, 3 is June to August and 4 is September to November).
- hy_k is the fixed effect of herd year combination ($k = 1$ to 338).

There were few animals that met the criteria's for FEH (see Table 1) and an uneven frequency of fixed effects (95.05% born in autumn). Therefore, variance components were not calculated for FEH.

3.6 Heritability calculations

The DMU software (Madsen et al. 2013) with the DMUAI procedure was used to estimate variance components for the traits above with an inbred dam and sire model. Heritability was calculated as $h^2 = \frac{\sigma_a^2}{\sigma_p^2}$ where σ_a^2 is additive genetic variance and σ_p^2 is phenotypic variance ($\sigma_a^2 + \sigma_e^2$).

4. Results

4.1 Distributions

Figure 2 shows the percent distribution of CFHA based on 117 observations. The distribution illustrates an overall decline in proportion of observations from 25 to 200 days, except for a peak at 150 days.

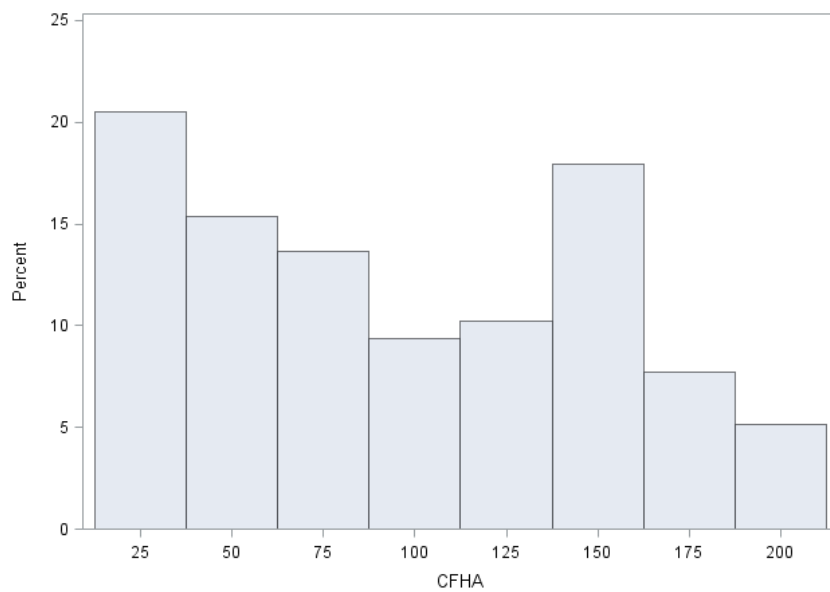


Figure 2: Distribution of number of days from calving to the first high activity episode (CFHA) based on 117 observations. The x-axis shows number of days and the y-axis shows percent distribution.

Figure 3 shows the distribution of FEH based on 101 observations. The distribution is almost uniform, except a peak around 300 days.

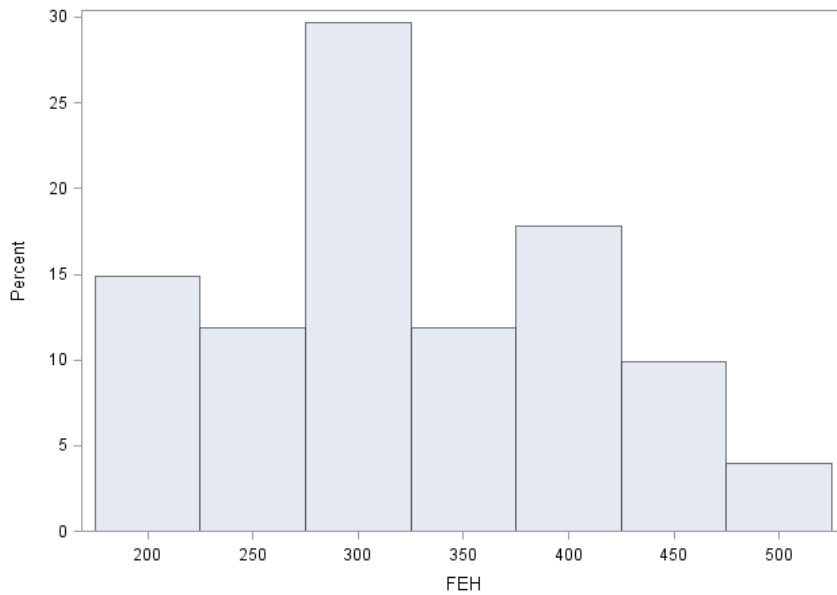


Figure 3: Distribution of time of first estrus in heifers (FEH) based on 101 observations. The x-axis shows age in days, while the y-axis shows percent distribution.

Figure 4 shows the distribution of ED in hours based on 491 observations. The figure has resemblance to exponential decline, where there are most observations of ED around 6-18 hours. Some observations are longer than 18 hours and increase up to 72 hours, which was the limit for ED registration.

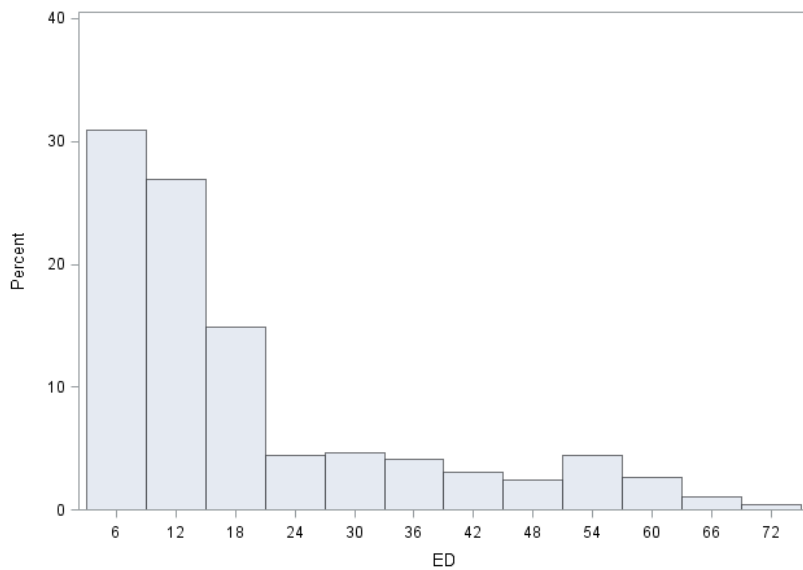


Figure 4: Distribution of estrus duration (ED) based on 491 observations. Shown with percentages on the y-axis, and the x-axis shows the duration in hours.

Figure 5 presents the distribution of ES. The figure resembles a normal distribution with a peak around 80. There is no activity change lower than around 40, which is some of the lowest possible numbers because the threshold for measuring ES is 35. Most of the observations are from 60 to 100. The distribution is somewhat skewed with a few observations that show a very strong estrus.

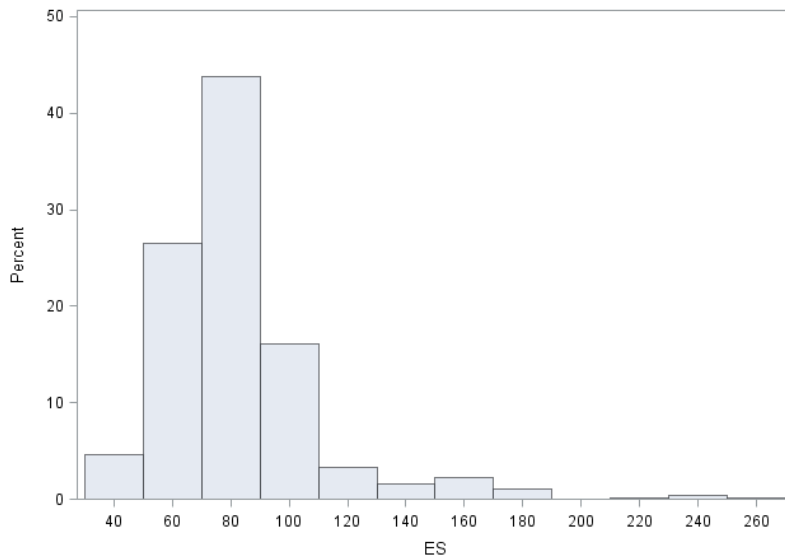


Figure 5: The distribution of estrus strength (ES) based on 491 observations. The x-axis shows max activity change during a high activity episode and the y-axis shows percent distribution.

Figure 6 shows the percent distribution of the CFI trait based on 3820 observations. The figure resembles normal distribution with a peak around 75 days that spreads out to 16 and 200 days. The distribution is slightly skewed with the right side of the peak (>75 days) longer than on the left side (<75 days).

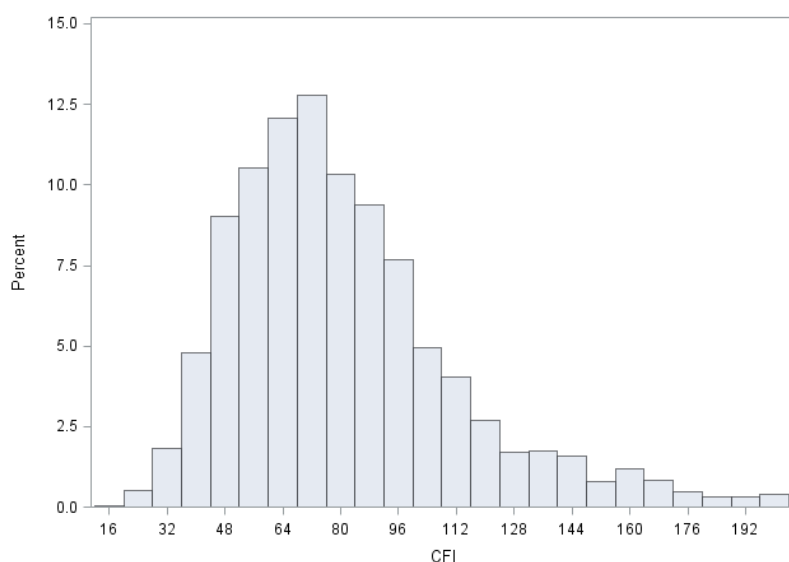


Figure 6: Distribution of number of days from calving to first insemination (CFI) based on 3820 observations. The x-axis shows CFI measured in days, while the y-axis shows percent distribution.

4.2 Least square means

Table 2 show least squares mean (LSM) for the fixed effects for seasons and parity. Both CFHA and CFI are shortest in autumn. ED and ES increases from winter to autumn. Autumn differ significantly for all traits compared to winter, except for ED.

For parity, CFHA decreases from first lactation to the fourth. ED decrease somewhat with increased parity, while ED has an overall decrease. Only parity for ES differed significantly, were party 1 have is different compared to heifers (parity 0).

Table 2: Least square means (LSM) for the fixed effects of season and parity for the traits time form calving to first insemination (CFHA), time from calving to first insemination (CFI), estrus duration (ED) and estrus strength (ES). LSM with different superscript differs significantly ($P < 0.05$).

	CFHA (d) ¹	CFI (d) ¹	ED (h) ¹	ES
Seasons²				
Winter	115 ^b	80 ^b	16 ^a	68 ^b
Spring	117 ^b	82 ^{bc}	18 ^a	63 ^b
Summer	101 ^b	83 ^{bc}	16 ^a	75 ^{ab}
Autumn	59 ^a	75 ^a	21 ^a	84 ^a
Parity³				
0	- ⁴	-	17 ^a	78 ^a
1	105 ^a	82	15 ^a	68 ^b
2	100 ^a	-	18 ^a	74 ^{ab}
3	98 ^a	-	18 ^a	70 ^{ab}
4	87 ^a	-	19 ^a	73 ^{ab}

¹ Values given in days (d) or hours (h).

² Winter includes the months from December to February, spring includes March to May, summer includes June to August and autumn includes September to November.

³ Parity 0 is heifer data. Parity 4 includes all parities form 4 and above.

⁴ Lack of numbers (-) is due to definitions of the traits.

4.3 Phenotypic correlations

Table 3 shows the phenotypic correlation between CFHA, CFI, FEH, ED and ES. Significant phenotypic correlations were estimated between CFHA and ES (0.22) and ES and ED (0.40) with P-values lower than 0.05. Correlations between ED and ES are favourable. Correlation between CFHA and ES are unfavourable, as an increase in ES will also increase CFHA. The other trait combinations had either very few observations and/or no significant correlations.

Table 3: Phenotypic correlations between the fertility traits time from calving to first high activity episode (CFHA), time from calving to first insemination (CFI), first estrus in heifers (FEH), estrus duration (ED) and estrus strength (ES). The numbers in each cell are Pearson correlation coefficient, P-value for correlation different from 0 (bold) and number of observations per trait combinations.

	<i>CFI</i>	<i>FEH</i>	<i>ED</i>	<i>ES</i>
<i>CFHA</i>	-0.01	0.20	0.03	0.22
	0.94	0.61	0.76	0.03
	97	9	104	104
<i>CFI</i>		-	-0.02	-0.02
		-	0.67	0.77
		0	307	307
<i>FEH</i>			0.11	0.10
			0.33	0.36
			86	86
<i>ED</i>				0.40
				<.0001
				491

4.4 Heritabilities

Table 4 shows the estimated variance components and the calculated heritabilities for CFHA, ED, ES and CFI. Variance components for all traits had large standard errors and none of the heritability estimates were significantly different from zero. Heritability of CFI is close to significant.

Table 4: Estimated variance components for additive genetic (σ^2_a) and residual (σ^2_e) variance and the corresponding heritability (h^2) with standard error (SE) for days from calving to first high activity (CFHA), interval from calving to first insemination (CFI), estrus duration (ED) and estrus strength (ES).

<i>Trait</i>	σ^2_a (SE)	σ^2_e (SE)	h^2 (SE)
CFHA	160 (1601)	3037 (1590)	0.05 (0.50)
ED	0 (20)	226(24)	0.00 (0.09)
ES	21(68)	595(75)	0.03 (0.11)
CFI	14(18)	790(25)	0.02 (0.02)

5. Discussion

5.1 Means and distributions

The average CFHA for NRF was 94,8 days, almost twice the average found by Ismael et al. (2015) for Holstein (49,5 days) with 11 363 records. Løvendahl et al. (2010) found time from calving to first estrus to be 44 days measured with progesterone based on 376 cow lactations, while in the same study, Red Dane showed shorter CFHA than Holstein and Jersey (36 vs. 41 respectively).

For a quantitative trait like CFHA a normal distribution is expected, but in this study, there was a decline in percent observed from 25 to 200 days, except a peak around 150 days (Figure 2). The form of the distribution is most likely caused by few CFHA observations (117).

Another limiting factor was that the activity units were not put on the animal early enough to detect the first estrus after calving, which is probably the reason why the CFHA mean in this study is almost twice the average of the mean found in other studies.

FEH was calculated based on the first high activity measured between 6 and 18 months of age. However, few animals met these criteria, mostly because of lack of activity data. The heifers were approximately 11 months old when they had their first registered estrus (shown in Table 1). Løvendahl et al. (2009) found an average age of FEH of 14 months for Holstein, Red Dane and Jersey combined, which may indicate that NRF has an earlier FHE than other breeds. Figure 3 indicates that there may be a peak of the first estrus in heifers around 300 days, which is around 3 months earlier than Holstein. Because of low registration numbers, it clearly has not been a priority for farmers to use activity measurement collars on animals younger than a year.

ED had a mean duration of 19.2 hours (Table 1), twice as long as Ismael et al. (2015) and Løvendahl et al. (2010) found in their studies with Danish Holstein (8,5 hours) and Red Dane, Holstein and Jersey (8,1 hours). Roelofs et al. (2005) found an ED of 10 hours based on readings from pedometers every second hour. Separation of heifer and cow data indicates that heifers may have a slightly longer ED than cows. Løvendahl et al. (2009) found heifers to have approximately an hour longer estrus than cows. Sveberg et al. (2015) found ED in NRF to be considerably longer than for Holstein-Friesian, with a mount estrus (based on 24 hours registered behavioural data) of 21.3 hours vs. 11.2 respectively.

The distribution of ED (Figure 5) bears large resemblance to an equivalent figure for ED in Ismael et al. (2015) and Aungier et al. (2012) studies, even though NRF seems to have a

longer ED than Holstein. Six hours is the shortest possible recorded estrus because of the definition of the trait (see methods) and most estruses are quite short (6-18 hours). The tail on the right is long and shows that some animals have an ED up to the set limit of 72 hours, Ismael et al. (2015) only showed durations up to 20 hours, where 22 hours was the maximum duration in the study, indicating NRF may have a longer ED than Holstein.

ES for heifers also showed to be somewhat stronger than for cows. However, this was not the case in the studies from Løvendahl et al. (2010) and Løvendahl et al. (2009), where there was no difference between heifer and cows. Since the algorithm for calculation of activity change for Heatime RuminAct is not known in this study, it was not possible to estimate activity increase in steps or range of movement. Nebel et al. (2000) reported that cows are four times more active during estrus and a 2.5 to 3-fold increase during estrus is reported from other studies (Firk et al. 2002, Løvendahl et al. 2009, Ismael et al. 2015). The distribution of ES show that some animals have a strong estrus (registrations over 120, see Figure 5) compared to the main percentages.

The mean CFI of 80.3 days calculated in this study, is in agreement with the findings of Andersen-Ranberg et al. (2005) where CFI for first lactation cows were 80 days. A study done on Swedish Red and White by Roxström et al. (2001) observed a CFI of 83.4 days for first lactating cows and Ismael et al. (2015) found a mean of CFI of 75.1 for Danish Holstein where parity 1 to 3 were included.

5.2 Least square means

Least square means (LSM) calculations from Table 2 shows that expression of fertility is best in autumn (September to November) as CFHA decreases and ED and ES increase. Winter is overall the weakest season regarding fertility traits. Petersson et al. (2006) found winter to be the season with longest interval from calving to first luteal activity, but that study only had two seasons (winter and summer) and not four as in this study. The reason for better fertility in summer and autumn may not only be based on climatic conditions during the different seasons, but also by environmental factors like feeding and housing that may affect the expression of fertility traits (Petersson et al. 2006).

First parity cows tend to have the weakest signs of estrus both for strength and duration and the longest interval of CFHA. First lactating cows are approximately two years old and are still using energy for own development besides calving and lactation, so it is reasonable that they show weaker fertility signs than older animals. The result of this study is in agreement

with Petersson et al. (2006), who found the time from calving to first luteal activity to be longer (14-18 days) for first lactating Swedish Red and White and Swedish Holstein compared to cows from older age groups.

5.2 Phenotypic correlations

The phenotypic correlation between ED and ES (Table 3) were in agreement with Ismael et al. (2015) who calculated phenotypic correlations between ED and ES of 0.44 (0.40 in this study). Phenotypic correlations between CFHA and ES and CFI and CFHA did not compare to this study, where Ismael et al. (2015) found correlations of 0.02 and 0.38 respectively (0.22 and -0.02 in this study). The phenotypic correlation between ED and ES were significant and favourable. This means that genetic improvement of either trait, will increase the other ones as well. For example, breeding for a longer duration of estrus also increases the strength, and vice versa.

There was not enough data in this study to calculate genetic correlations, but Ismael et al. (2015) found high and favourable correlations between CFI and activity-based fertility traits.

5.3 Heritabilities

The estimated heritabilities for CFHA, CFI, ED and ES are shown in Table 4. Few observations caused the standard errors to be high (except for CFI), and the results can only be considered preliminary at best. Ismael et al. (2015) estimated a heritability of CFHA to 0.16 for Holstein, which is in agreement with the estimated heritabilities from Løvendahl et al. (2009) for CFHA for Jersey, Holstein and Red Dane (0.12-0.18).

Both Ismael et al. (2015) and Løvendahl et al. (2009) estimated the heritabilities ranging from 0.02 to 0.08 for ED and 0.04 to 0.06 for ES, while in this study, estimation of ED was 0 and for ES it was 0.03, though it was not significant.

CFI is a trait already used in the breeding scheme of NRF and is included for comparison to the other traits. Other studies have estimated heritabilities of CFI ranging from 0.03 to 0.08, and Andersen-Ranberg et al. (2005) estimated the CFI heritability for NRF to be 0.03 for first lactating NRF cows (Wall et al. 2003, Sun et al. 2009, Ismael et al. 2015). In this study the estimation of CFI was somewhat lower (0.02) than the other studies.

Even though the results from this study are weak regarding estimation of heritabilities, other studies imply that activity traits, especially CFHA, have higher heritabilities than CFI and can

therefore be a useful trait in the breeding scheme of NRF (Løvendahl et al. 2009, Ismael et al. 2015).

5.4 Validation of estrus

Validation of a high activity episode is necessary if it is to be considered as a true, biological estrus. Activity measurements can give false positives and false negatives if progesterone levels are considered standard (Løvendahl et al. 2010). Given different thresholds and duration requirements, the detection rates on activity measurements differ. At-Taras et al. (2001) found high detection rates for pedometer data recorded every second hour (82.6% – 90.6%), which is somewhat higher than Løvendahl et al. (2010) found for activity tags, where the detection rate varied from 56.4 to 84.2% with a respective error rate of 0.36 to 3.85% depending on threshold value. This is consistent with findings from Aungier et al. (2012), where the detection rate were 72.0 – 87.8% depending on the limitation of duration of recorded estrus. Ismael et al. (2015) found an 82% detection rate with a daily error of 0.9% when the estimated heritability for CFHA was 0.16. Geno reports a 80% detection rate with the use of Heatime RuminAct in tie-stall herds (Geno 2019).

In this study, there has not been a validation of estrus, since it was based on excising field data from commercial herds that used Heatime RuminAct as a herd management tool. It was not possible to validate estrus based on hormone change as could have been done if it was a planned experiment with the possibility of hormone measurements. Estrus could indirectly be validated by use of insemination and calving data. A successful insemination will indicate it was a true estrus at the time. In this study validation has not been a priority and few animals (71) met the requirements for an indirect validation of estrus with activity measurements at the time of insemination.

5.5 Challenges with herd management activity systems

This study has revealed several challenges in using herd management tools for breeding purposes. Therefore, some recommendations are necessary to improve their usability.

First, for registrations of CFHA, the largest excluding and limiting factor was that the activity measurements did not start early enough and the first estrus after calving was probably missed. Since CFHA can be a valuable trait in the breeding scheme of NRF, it should be encouraged to use activity tags early enough, preferably before 14 days after calving.

Secondly, ensuring continuous measurements and complete downloading are essential for estrus detection and should be made a priority considering the short average of estrus duration and the possibility to miss estrus events.

Third, another challenge with using activity measurements based on a herd management tool is pre-selection of animals regarding phenotype registration. If a farmer does not have enough activity measurement units for every animal in the herd, he/she must decide which animals that will wear activity units. If there is no plan for further inseminations, animals with poor fertility expression may be excluded with no phenotype registration and the total number of registrations may therefore not be representative for the breed.

Fourth, it should be possible to properly identify all animals by their ID. The raw data had its own animal ID and herd information, which in most cases, was identical to the 4-digit ear tag number of the cow in the Norwegian Dairy Herd Recording System. However, for other animals, it was impossible to get a positive identification as the animal ID from the activity units did not match any other identification numbers.

These recommendations should be put in place if herd management systems with activity measurements shall be used to collect phenotypes for breeding purposes. Preferably all animals in a herd should have a measurement unit (at least after calving) so every cow get phenotype registrations and have an ID that can be linked to the Norwegian Dairy Herd Recording System and pedigree.

5.6 Recommendations for further studies

Recommendations for further studies are to encourage farmers and researchers to follow recommendations needed to register better data for estimation of genetic parameters and to validate estrus. The main problem in this study was lack of data, so a larger dataset with a larger number of herds and animals that have continuous recordings after calving is needed for more accurate estimation of genetic parameters.

For validation of estrus, progesterone levels or insemination data can be used to make sure detection and error rates for this method is acceptable for NRF.

6. Conclusion

In this study there has been defined new fertility traits and heritabilities have been calculated for those traits in NRF. The heritabilities had large standard errors, which means the results should only be considered preliminary at best. Nevertheless, this study has shown that it is essential with recommendations for use of activity measure units if herd management tools are to be used for data collection for breeding purposes. The use of activity data is promising with sufficient and good data material.

7. Literature

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