Improving dairy herd health monitoring and management using automated monitoring technologies

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INTRODUCTION

Health disorders (**HD**) affect a substantial proportion of dairy cows negatively impacting their health, welfare, and performance. In response, dairy farms spend substantial amounts of time and money to identify, treat, and care for cows that suffer from HD. For example, a systematic, once- or twice-daily evaluation of health is typically performed for the first 1–3 wk after calving in most dairy farms. Such clinical exams disrupt natural behavior and are time-consuming, labor intensive, and inherently subjective. The burden of cow health monitoring continues to growth as qualified personnel becomes scarce and labor costs rise limiting the amount of personnel and time available to evaluate individual cows in dairy herds that continue growing. Moreover, interest in improving cow care, cow performance, and dairy-producer quality of life, are driving automation of management tasks. Automated or semi-automated milking, estrus detection, and feeding are all being rapidly adopted by numerous dairy farms in the U.S. and the world. In this regard, there has been an explosion in the availability of automated monitoring systems that use sensors to measure behavioral, physiological, and performance parameters such as rumination, activity, lying time, body temperature, milk volume and components, milk conductivity, body condition score, and body weight.

Unlike the growing body of evidence that sensor-monitored parameters are altered in cows that experience HD, little is known about the effects of implementing health monitoring programs that rely primarily or exclusively on data from automated monitoring systems (**AMS**) to select cows for clinical examination. The potential benefits of the use of AMS to monitor health in dairy farms largely depends on the intensity of the monitoring strategies used on farms. For example, farms that are effective at identifying cows with health disorders may benefit from the implementation of AMS because of the potential to reduce labor needs, cow manipulation, or both. Conversely, for farms unable to implement traditional intensive health monitoring programs, the use of AMS may improve their ability to identify cows with HD that would benefit from prompt treatment or other interventions.

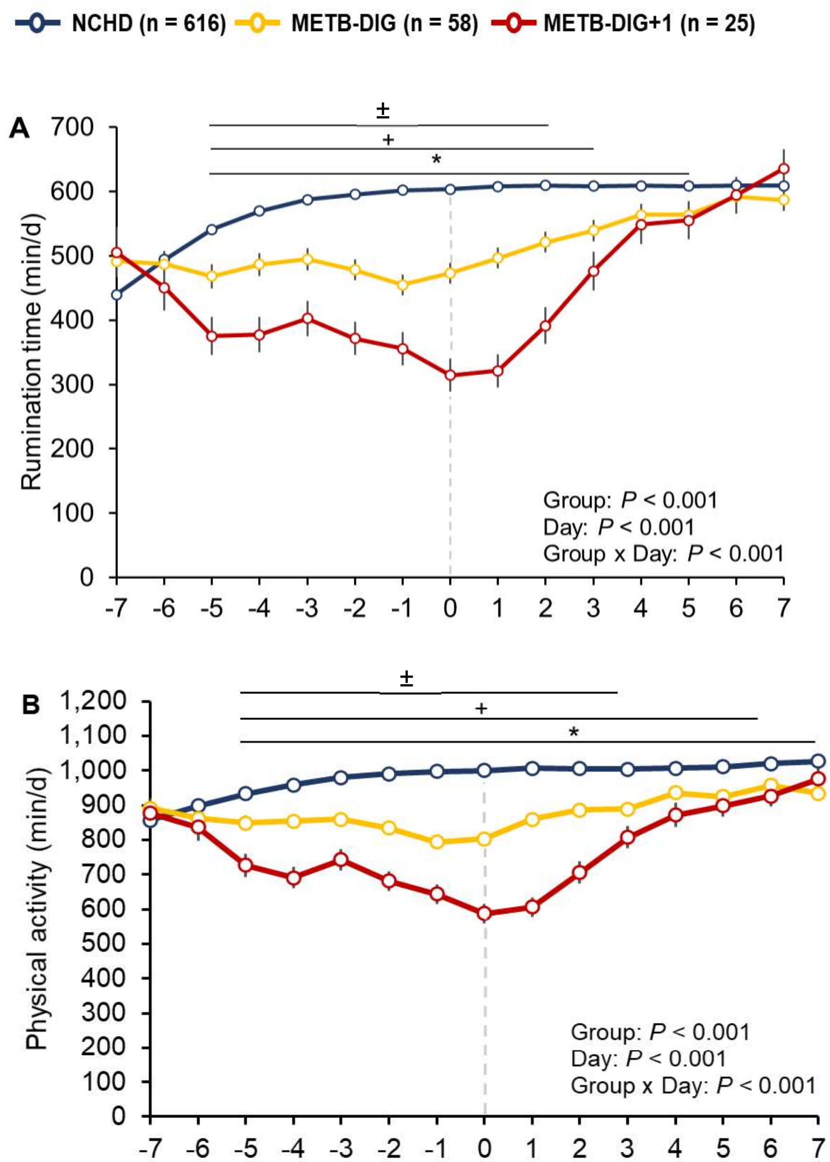
This review presents a summary of recent research focusing on the effects of early lactation disease on the patterns of behavioral and physiological parameters monitored by automated sensors and on the effects of health monitoring strategies that rely either exclusively or almost exclusively on AMS data on herd performance and management.

Effects of health disorders on the pattern of sensor-monitored cow data

Automated health monitoring technologies can only be effective if cows affected by HD present alterations of the patterns of sensor-monitored parameters. Moreover, the deviations from expected patterns and temporal shifts around clinical manifestation of

HD must be of sufficient magnitude to be detected through visual inspection, statistical methods, or data analytics techniques. Recent studies with

lactating dairy cows demonstrated that cows affected by health disorders manifest alterations of sensor-monitored parameters of sufficient magnitude to be detected through specific algorithms or visual inspection of data. For example, cows fitted with accelerometer-based neck- or ear-attached sensors and affected by HD presented different trajectories of rumination time, eating time, physical activity, and lying time immediately before, during, and after clinical diagnosis of HD in the early postpartum period. **Figure 1** presents an example of the effect of metabolic and digestive disorders on rumination time, physical activity, and lying time for lactating dairy cows monitored using an ear-attached automated sensor (Smartbow, Zoetis).



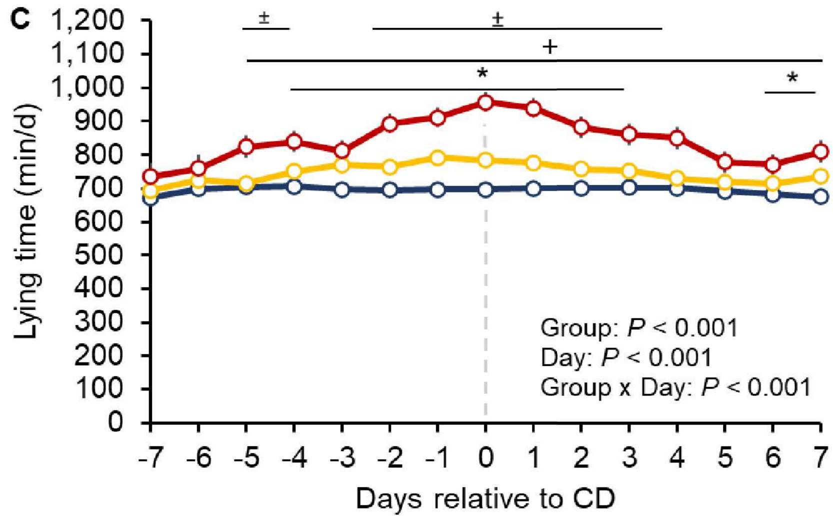


Figure 1. Pattern of daily rumination time (A), physical activity (B), and lying time (C) from 7 before to 7 d after clinical diagnosis (CD) of metabolic-digestive disorders for cows diagnosed with metabolic-digestive disorders only (METB-DIG; n = 58), a metabolic-digestive disorder and at least another health disorder (METB-DIG+1; n = 25), and cows with no clinical health disorders diagnosed (NCHD; n = 616) in a study in which lactating dairy cow behavior was monitored using an ear-attached automated sensor (Smartbow, Zoetis). For the NCHD group, the average DIM at CD for all cows with metabolic-digestive disorders (i.e., 9 DIM) was considered Day 0. Values are LSM ± SEM. Within a day, differences between groups based on the LSD test are represented as follows: *METB-DIG different from NCHD; +METB-DIG+1 different from NCHD; ±METB-DIG different from METB-DIG+1. Data from Rial et al. (2023)

The magnitude and temporal dynamics of changes for sensor-monitored parameters is also relevant because alterations in the pattern of a parameter of sufficient magnitude to be detectable before clinical manifestation of disease is critical to the ability of automated health monitoring systems to flag cows for clinical examination. Although there is substantial variation across automated health monitoring systems and types of parameters monitored, some studies have shown promising results. Data support the notion that there is an association between the degree of alteration of the pattern of behavioral parameters monitored by sensors and the clinical status of cows. Specifically, in some studies rumination, activity, and lying behaviors were affected considerably more in cows with multiple and potentially more severe clinical signs of disease (**Table 1**).

Table 1. Absolute values and relative changes from 5 d before clinical diagnosis of disorders of interest and the day of the nadir for daily rumination time, physical activity, milk yield, or peak for daily lying time for cows diagnosed with a single metabolic-digestive disorder or metabolic-digestive plus another health disorder diagnosed from 2 to 21 DIM. Rial et al. (2023)

Item[1]	Health Disorder Groups NCHD[2] (n = 616)	CKET[3] (n = 27)	INDIG[4] (n = 17)	MD[5] (n = 39)	P-value
Rumination time					
Absolute change, min	48.0 ± 7.4[a]	-153.9 ± 36.8[b]	-73.6 ± 47.7[b]	-255.8 ± 28.4[c]	< 0.001
Relative change, %	13.5 ± 1.7[a]	-25.1 ± 8.0[b]	-14.2 ± 10.9[b]	-54.8 ± 6.5[c]	< 0.001
Physical activity					
Absolute change, min	64.2 ± 6.9[a]	-243.0 ± 38.4[b]	-128.5 ± 9.0[b]	-451.8 ± 29.7[c]	< 0.001
Relative change, %	9.0 ± 1.0[a]	-24.5 ± 5.5[b]	-13.9 ± 7.1[b]	-58.0 ± 4.1[c]	< 0.001
Lying time					
Absolute change, min	-0.003 ± 5.6[b]	214.7 ± 28.6[a]	126.7 ± 36.8[a]	198.3 ± 22.8[a]	< 0.001
Relative change, %	1.4 ± 0.8[b]	29.2 ± 4.3[a]	20.6 ± 6.0[a]	30.1 ± 3.5[a]	< 0.001
Milk yield					
Absolute change, kg	5.7 ± 0.3[a]	-10.4 ± 1.9[b]	-7.9 ± 2.5[b]	-9.4 ± 1.3[b]	< 0.001
Relative change, %	26.5 ± 1.5[a]	-26.8 ± 8.2[b]	-23.7 ± 11.7[b]	-32.6 ± 6.4[b]	< 0.001

[a-b]Different superscripts within a row indicate differences ($P \leq 0.05$) between means based on the LSD post-hoc test.

[1]Data presented include the absolute difference or the relative change between 5 d before clinical diagnosis and the day of the nadir for RT, AT, and MY, or the peak for LT. Values are LSM ± SEM.

[2]Cows not diagnosed with clinical health disorders during the period of interest.

[3]Cows diagnosed only with clinical ketosis during the period of interest.

[4]Cows diagnosed only with indigestion during the period of interest.

[5]Cows diagnosed with metabolic-digestive health disorder and either another metabolic-digestive disorder or a non-metabolic-digestive disorder (i.e., mastitis, metritis, and pneumonia) during the period of interest.

Therefore, automated health monitoring systems that monitor and use behaviors such as rumination time, physical activity, and lying time either directly or indirectly to generate health alerts might be more effective for identifying cows affected by HD that cause more severe alterations to cow behavior and multiple HD because these cows manifest multiple and more severe clinical signs of disease at the same time or within a timespan of a few days. The observed temporal shifts of sensor data patterns, the magnitude of the absolute and relative changes, and the timing of the nadir and peaks for different parameters such as rumination time, physical activity, and lying time suggested that monitoring these parameters might be useful for screening cow health in early lactation. In this regard, some studies evaluated the ability of automated health monitoring systems including rumination and physical activity to identify cows with HD based on automated alerts and the interval between these alerts and the timing of clinical diagnosis disease. For example, Stangaferro et al. (2016a) reported that a majority of cows diagnosed with metabolic-digestive disorders had at least one automated health alert within 5 d before to 2 d after diagnosis of the disorder for cows diagnosed with a single disorder or cows with more than one disorder diagnosed at the same time (**Table 2**). Moreover, on average cows had the first automated health alert before the day of clinical diagnosis by traditional health monitoring methods (**Table 2**).

Table 2. Incidence of metabolic and digestive disorders, DIM at clinical diagnosis, sensitivity of health index score to detect cows with disorders, and interval between the first health index score positive outcome and clinical diagnosis of disorders by farm personnel.

	Cows	Incidence	DIM[1]	Sensitivity	HIS positive to CD[2]	
	(n)[2]	(%)	Mean ± SD	%	Mean (d)	*P*-value
All metabolic-digestive[3]	104	9.6	11.4 ± 8.3	93 (97/104)	-2.1	< 0.01
Metabolic-digestive only	55	5.1	13.2 ± 10.5	93 (51/55)	-1.7	< 0.01
Metabolic-digestive with other disorders	49	4.5	9.3 ± 4.2	94 (46/49)	-2.5	< 0.01

[1] DIM = days in milk at event.
[2] HIS positive to CD = interval in days between the first positive health index score (HIS) outcome (positive outcomes only) and clinical diagnosis (CD).
[2]n = number of events diagnosed.
[3]Metabolic-digestive = metabolic and digestive disorders combined (DA, ketosis and indigestion).

This research demonstrated that most cows affected by metabolic-digestive disorders had health alerts at the same time or before clinical diagnosis, whereas the ability to detect cows with metritis and mastitis was moderate (Stangaferro et al. (2016b,c). For uterine and udder health disorders, cows were identified through automated alerts only in cases that affected cows systemically or if cows were affected concomitantly by another health disorder .

Effect of targeted clinical examination based on alerts from automated health monitoring systems versus intensive traditional health monitoring

More recently, some experiments explored if implementing health monitoring strategies that rely primarily on automated health alerts can be as effective as intensive traditional health monitoring programs that rely heavily on extensive clinical examination of cows. For example, in an experiment conducted by our group (Perez et al., 2023), we evaluated a fresh cow health monitoring program for which cows were selected for clinical examination based primarily on automated health monitoring systems alerts (**Figure 2**).

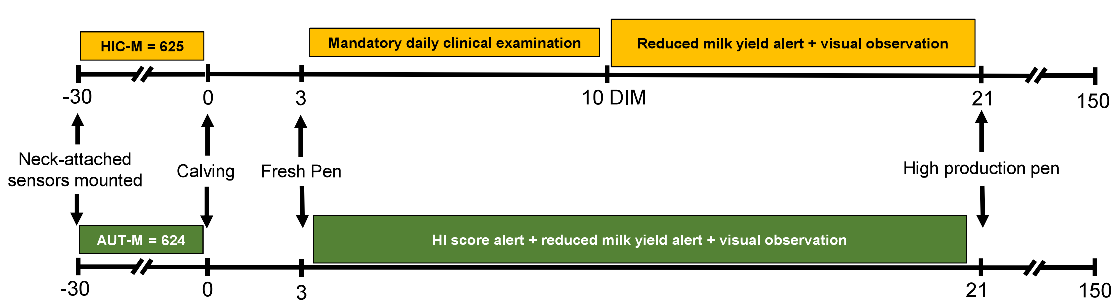
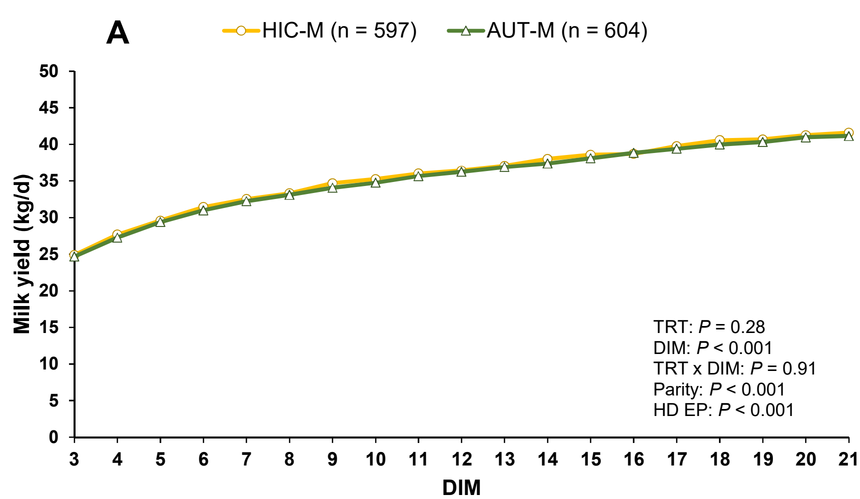


Figure 2. Experimental procedures for a controlled randomized block experiment where Holstein cows were randomly assigned to a high intensity clinical monitoring (**HIC-M**; n = 625) or an automated monitoring (**AUT-M**; n = 624) treatment and were fitted with a neck-mounted rumination and physical activity monitoring sensor tag. For the HIC-M treatment, the list of cows for clinical examination for cows between 3 and 21 DIM included all cows from 3 to 10 DIM, cows with reduced milk yield alerts, and cows suspected to have clinical mastitis or other health disorder based on visual observation before and during milking. Reduced milk yield alerts were a reduction of ≥15% in milk production rate. For the AUT-M treatment, clinical examination for cows between 3 and 21 DIM was conducted on cows with Health Index (**HI**) score alerts (i.e., ≤86 HI score AU), reduced milk yield alerts, and cows suspected to have clinical mastitis or other health disorders based on visual observation as defined for the HIC-M treatment. Health Index (HI) score alerts were created based on rumination time and physical activity by a neck-mounted rumination and physical activity monitoring sensor tag (HR-LDn-Tag, SCR Engineers Ltd.).

We were interested on the effect of this novel monitoring program on herd performance and the ability to identify cows with HD when compared with a more traditional monitoring program based primarily on compulsory clinical examination of cows. The only difference between experimental treatment groups was the method used to select cows for clinical examination. For the traditional monitoring strategy, all cows underwent an extensive clinical examination up to 10 d after calving. Thereafter, cows with a reduction in milk yield, or suspected sick by visual observation during a walk-through of the fresh pen underwent clinical examination. Conversely, for the program designed to rely primarily on automated health alerts, cows only underwent extensive clinical examination if cows had alerts from a health index score created based on rumination and activity, milk yield reduction alerts, or detected visually if missed by the alerts.

Data from this experiment supported the hypothesis that implementation of a program designed to rely primarily, but not exclusively, on identification of cows for clinical examination based on alerts from automated health monitoring systems would not have detrimental effects on herd exit dynamics, productivity, and reproductive performance outcomes (**Figure 3 and 4 and Table 3**).



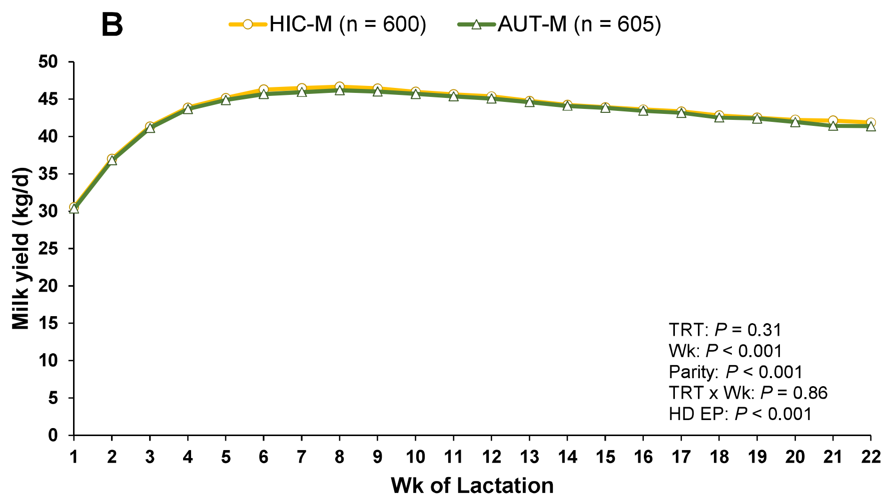


Figure 3. Milk yield data from the experiment of Perez et al. (2023) (A) Daily milk yield from 3 to 21 DIM and (B) weekly mean milk yield to 22 wk of lactation, for primiparous and multiparous Holstein cows randomly assigned to be identified for clinical examination during the early lactation period using a high intensity clinical monitoring (HIC-M) or automated monitoring (AUT-M) program. Values are presented as LSM ± SE (maximum SE for data in both figures was 0.3 kg/d). TRT = treatment, HD EP = at least one health disorder diagnosed during the experimental period.

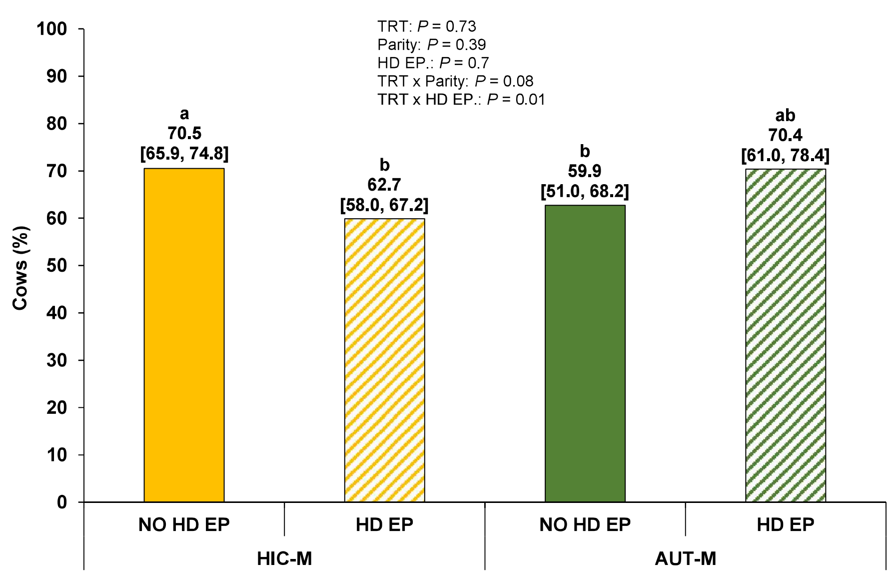


Figure 4. Percentage of cows inseminated at detected estrus for primiparous and multiparous Holstein cows randomly assigned to be identified for clinical examination during the early lactation period using a high intensity clinical monitoring (HIC-M) or automated monitoring (AUT-M) program. Values are presented as LSM. TRT = treatment, NO HD EP = no health disorders diagnosed during the experimental period, HD EP = at least one health disorder diagnosed during the experimental period.

Table 3. Percentage of cows that exited the herd due to sale, death, and both, to 60, from 61 to 150, and total to 150 DIM for primiparous and multiparous Holstein cows randomly assigned to be identified for clinical examination during early lactation using a high intensity clinical monitoring (HIC-M; n = 600) or automated monitoring (AUT-M; n = 605) program in the experiment of Perez et al. (2023).

	Treatment[1]		
Item	HIC-M	AUT-M	*P*-value
Sold to 60 DIM, %	0.8 [0.3, 1.9]	1.2 [0.5, 2.7]	0.35
Died to 60 DIM, %	0.5 [0.2, 1.7]	0.5 [0.2, 1.7]	0.99
Sold and died to 60 DIM, %	1.5 [0.7, 3.1]	2.1 [1.0, 4.0]	0.38
Sold from 61 to 150 DIM, %	5.9 [3.9, 8.8]	4.0 [2.5, 6.3]	0.09
Died from 61 to 150 DIM, %	0.7 [0.2, 2.1]	0.6 [0.2, 1.9]	0.79
Sold and died from 61 to 150 DIM, %	6.7 [4.5, 9.8]	4.7 [3.1, 7.2]	0.09
Sold to 150 DIM, %	6.8 [4.7, 9.8]	5.5 [3.6, 8.1]	0.26
Died to 150 DIM, %	1.2 [0.5, 2.8]	1.1 [0.5, 2.6]	0.84
Sold and died to 150 DIM, %	8.4 [6.0, 11.6]	6.9 [4.8, 9.8]	0.28

[1]Values for binomial outcomes are presented as LSM [95% CI].

Notably, similar herd performance was observed despite a 30% smaller risk of diagnosis of health disorders and a 4 percentage point smaller total cows diagnosed with HD for the program using automated alerts. Collectively, results of this first of its kind experiment indicated that dairy farms may be able to successfully implement a health monitoring program that relies primarily but not exclusively on automated health monitoring systems data. Farmers could expect that a majority but not all cows that need attention will be identified. Some cows affected by HD might only be identified by other traditional methods such as visual observation or compulsory clinical examination.

Health monitoring based on automated health alerts versus non-intensive health monitoring

There is a knowledge gap about the benefits of health monitoring programs that rely on AMS alerts compared with less intensive strategies that rely exclusively or almost exclusively on visual observation (**VO**). This is important because many farms still use exclusively or almost exclusively VO for selecting cows for clinical examination. Because of continuous and objective monitoring of cow health, AMS that record behavioral, physiological, and performance parameters in real time may offer benefits when compared to programs that use intermittent and subjective observations of cow health such as VO of sickness behaviors. For example, it is plausible that more cows with health disorders could be identified and cows identified might be detected earlier with AMS than through VO only.

Therefore, in a recent experiment conducted by our group (Rial et al., unpublished) we hypothesized that a health monitoring program that relied only on AMS data would detect a greater percentage of cows with clinical health disorders and would detect cows earlier than a health monitoring program that relied exclusively on VO of signs of sickness behavior (**Figure 5**). Moreover, we hypothesized that a consequence of detecting more cows with health disorders and earlier detection would be improved herd performance outcomes. We expected that the use of AMS would result in greater milk production, fewer cows exiting the herd, and improved first service reproductive performance.

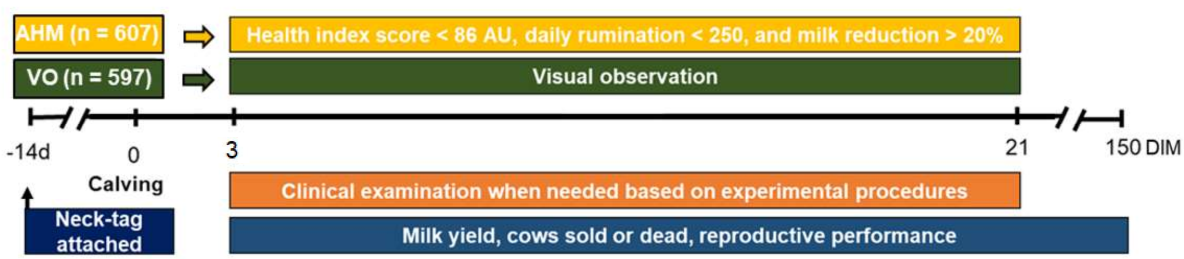


Figure 5. In a randomized controlled trial Rial et al. (unpublished) evaluated effects of health monitoring programs to select cows for clinical health examination from 3 to 21 DIM. Cows were selected for a clinical exam based only on visual observation (**VO**; n = 597) or based on alerts generated by automated health monitoring (**AHM**; n = 602) systems (neck-attached collar and daily milk weights). A health alert was at least one of the following: a Health Index Score <86 AU, daily rumination <250 min, or a reduction of >20% daily milk yield. Health Index Score and rumination time were from Heat and Rumination Tags (Merck & Co., Inc.,). Once selected for examination, the procedures used to diagnose health disorders were the same for both treatment groups. All cows were fitted with a neck-attached sensor tag of an automated monitoring system at least 14 d before the expected date of parturition. From 2 to 150 DIM, herd exit, daily milk yield, and reproductive performance data were collected.

In support of our hypothesis, we observed that more cows in the AHM group underwent clinical examination and were diagnosed with diseases (**Table 4**). These data suggested that health monitoring strategies that include AHM systems alerts such as those used in this experiment to select cows for clinical examination might result in more cows diagnosed with health disorders than a non-intensive traditional health monitoring program that relied exclusively on VO. However, to detect more cows with health disorders, more cows might undergo clinical examination. In this experiment, this was evident for cows in the AHM treatment which were more likely to be selected for a clinical exam and being diagnosed with a health disorder. Approximately 60% of the cows enrolled in the AHM group were selected for clinical examination at least once during the experimental period and 38% of these cows were diagnosed with clinical health disorders. On the other hand, for the VO group, approximately 30% of the cows were selected for clinical examination and 74% of these cows were diagnosed with clinical health disorders. Thus, cows in the AHM group were more likely to be selected for a clinical exam but less likely to be diagnosed with a health disorder once examined. The opposite was observed for cows in the VO group.

Table 4. Incidence rates and incidence rate ratios of cows that underwent clinical examination, cows diagnosed with HD out of the total cows in the treatment group, and cows with no clinical HD diagnosed for Holstein cows randomly assigned to treatments that selected cows for clinical examination from 3 to 21 DIM using only visual observation (**VO**; n = 597) or alerts from automated health monitoring (**AHM**; n = 602) systems in a randomized controlled trial.

	IR[1]			IRR[2]	
	VO	AHM	*P*-value	AHM-VO (Ref)	*P*-value
Rate of cows examined	0.033	0.090	< 0.001	2.8	< 0.001
Rate of cows with CHD[3]/cow-day total	0.024	0.034	< 0.001	1.4	< 0.001
Rate CHD/cow-day examined	0.74	0.38	< 0.001	0.51	< 0.001

[1]IR: incidence rate.

[2]IRR: incidence rate ratio.

[3]HD: health disorder. Cows diagnosed with any of the clinical health disorders of interest (metritis, mastitis, displaced abomasum, clinical ketosis, indigestion, pneumonia).

Cows diagnosed with health disorders in the AHM group had greater milk yield than cows diagnosed with health disorders in the VO group (**Figure 6**). Although earlier identification and treatment in relationship to the onset of health disorders might be a plausible explanation for the greater milk yield, this could not be confirmed or properly tested in this experiment for a number of reasons. Previous research has shown a positive association between treatment for different health disorders and milk production. However, limited or no data is available about the effects of timing of treatment on production responses and this cannot be evaluated in our experiment because cows were only examined if had automated alerts rather than every day. Thus, the onset of clinical health disorders could not be determined. Results for the comparison of DIM at diagnosis of diseases are also not an indication of timing of diagnosis in relationship to the onset of health disorders unless it is assumed that all disorders started on the day of diagnosis. Thus, more research is needed to confirm our findings and better understand the association between timing of disease onset with treatment on the productivity of cows. As for our observations for cows in the AHM group, it is plausible to suggest that cows diagnosed with health disorders in the VO group produced less milk because of a delay in diagnosis and treatment.

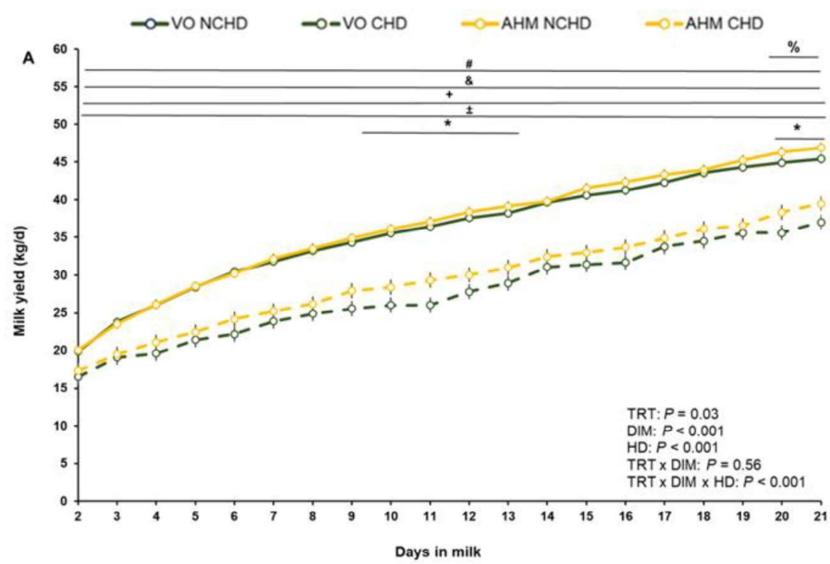


Figure 6. Daily milk yield from 2 to 21 DIM for cows assigned to a health monitoring program that selected cows for clinical health examination from 3 to 21 DIM only by visual observation (**VO**; green lines) or by alerts generated by automated health monitoring (**AHM**; yellow lines) systems (neck-attached rumination and physical activity monitoring sensor and milk yield deviations based on daily milk weights) and were diagnosed with at least one clinical health disorder (**CHD**; dashed lines; VO-CHD: n = 102; AHM-CHD: n = 175) or no CHD (**NCHD**; solid lines; VO-NCHD: n = 495; AHM-CHD: n = 432) from 3 to 21 DIM. Trt = treatment; HD = health disorder group (CHD vs. NCHD). Within a day, differences between groups based on the LSD test are represented as follows: *VO-CHD different from AHM-CHD; +VO-NCHD different from VO-CHD; ±AHM-NCHD different from AHM-CHD; #AHM-NCHD different from VO-CHD; &VO-NCHD different from AHM-CHD; % VO-NCHD different from AHM-NCHD .

In this experiment, we did not observe notable differences in the herd exit dynamic and reproductive performance at first service. Except for a tendency for a greater percentage of cows sold for the VO treatment, no statistical differences between treatments were observed for the percentage of cows that exited the herd up to 21 DIM.

Collectively, the results of this experiment suggested that implementation of a health monitoring program for early lactation cows that relies exclusively on AMS alerts based on rumination time, physical activity, and milk yield for selecting cows for clinical examination might be a more effective strategy to identify cows for clinical examination than the use of VO alone.

CONCLUSIONS

Current research evidence suggests potential to improve health monitoring and management of dairy cows using automated health monitoring systems including sensors that monitor behavioral, physiological, and performance parameters of cows automatically and in real time. Available evidence supports the use of automated health monitoring systems for health monitoring and management; however, the limitations of these technologies must be considered. Our recent work suggests that it might be reasonable to implement health monitoring programs that rely primarily on alerts generated by automated health monitoring systems combined with minimally invasive, less intensive visual inspection of cows or other traditional methods to identify cows with HD. Combination of automated health monitoring systems data and traditional methods ensures that all cows that need immediate attention are examined and care is provided. A major benefit of incorporating health monitoring technology is the potential reduction in the number of cows that need clinical examination in farms that use intensive traditional health monitoring programs. This can help reduce labor dedicated to health monitoring and management. Reducing the frequency of clinical examinations also reduces the number of times during lactation that cows are disrupted. Ultimately, this might be beneficial for cow well-being and productivity as fewer disruptions allow cows to express their natural behaviors and spend less time restrained or isolated from herd mates. On the other hand, farms that use non-intensive health monitoring programs based on visual observation only or other simple methods to detect cows with health disorders, might benefit from a greater ability to identify cows with HD and increased milk production due to improved health.

ACKNOWLEDGEMENTS

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