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Validation of a technology for objectively measuring behaviour in dairy cows and its application for oestrous detection

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ABSTRACT

Devices (IceTag® ActivityMonitor) using accelerometer technology to determine the behaviour of cows (proportion of time lying, standing, active and step count) were attached to 15 cows (2 per cow) and validated between devices and against observed behaviour. For standing and active, 95% of paired (within cow) one minute data points were within 7% points, 95% of the lying data points were within 1% point, and 95% of stepping data were within 3 steps. The device recorded 100% of lying bouts within ±1 minute of visually observed data. In a second experiment, 16 lactating dairy cows were fitted with IceTag®s and the relationship between behaviour profiles and oestrus evaluated. Blood progesterone concentration and twice-daily visual observations were used to identify precisely ovulation events and four algorithms, based on active and lying behaviour, were developed. A 24 hour rolling mean of activity and a slope threshold of 0.2 calculated for either the previous 10 hours (Activity24/10) or 5 hours (Activity24/5) correctly identified 93% of oestrous events, with 21% and 18% false positive alerts, respectively. Two further algorithms, Lying<20% or Active>5.5% between midnight and 05:00hrs identified 50% and 64% of oestrous events, with 36% and 18% false positive alerts, respectively. In a third experiment using 30 cows, 56 oestrous events were identified through milk progesterone profiles and visual observation. Algorithm Activity24/10 and Activity24/5 identified 84% and 76% of oestrous events respectively. The IceTag® accurately recorded several types of cattle behaviour suggesting useful applications as both a research and industry tool.

Keywords: activity monitor; accelerometer technology; behaviour; oestrus; dairy cow.

INTRODUCTION

Changes in the behavioural patterns of cattle are used by farmers and animal health professionals to identify poor health (*e.g.* lameness) and reproductive state (*e.g.* oestrus). To date there have been limited means of easily measuring a range of behaviours simultaneously. Devices using accelerometer technology are now available that allow the monitoring, recording and reporting of cow activity at intervals of one second. Lying, standing, movement and stepping behaviour (step counts) can be monitored in detail with these devices. This allows development of algorithms for activity monitoring technology that will aid or replace some of the manual monitoring tasks currently carried out by stockpersons.

Oestrous detection is one of the most labour intensive and skilled tasks that farmers and their staff are required to perform. The costs of poor performance in this aspect of the farming operation are high because of later calving, lost milk production and fewer artificially bred replacement heifers. Recent reports have estimated the annual costs to the industry at around $65 million for missed heats alone with additional costs incurred as a result of inseminating cows when they are not in oestrus (Burke *et al*., 2007). In addition, the quantity and quality of labour required for successful heat detection is an important limiting factor to productivity gains, especially on larger farms, in New Zealand.

Changes in behaviour can be used to provide information to assist in determining the cow's reproductive state. At least a dozen behavioural characteristics of oestrus have been documented (Burke *et al*., 2007). Mounting activity is the behaviour most commonly targeted, but change in walking activity has also been used. Given the increase in activity typically observed during oestrus, it is highly likely changes in other maintenance behaviours also occur. For example a cow in oestrus may spend less time lying and grazing and more time walking and standing. Additionally, a cow in oestrus may alter grazing or lying times or other behaviour, relative to the rest of the herd and/or behaviour during the non-oestrous state.

The aims of the present study were to: firstly, validate the IceTag® ActivityMonitor; and secondly, use this device to quantify behaviour during oestrus and identify indices that could be used for remote identification of oestrus in dairy cows.

MATERIALS AND METHODS

IceTag® ActivityMonitor

The IceTag® ActivityMonitor (IceRobotics, Scotland) uses accelerometer technology to determine the proportion of time an animal is lying, standing or active (which total 100% for each time period) and also generates a count of steps taken in a given period. Each device weighs 190g and is contained in a plastic housing (96 x 81 x 31 mm). The device is strapped to a cow's back leg just above the hoof. Data are stored until downloaded to the IceTagAnalyser® software on a PC via a USB cable. The data can be exported in time periods of seconds, minutes, hours or weeks.

Experiment 1: Validation of IceTag® ActivityMonitor

Animals and procedure: An IceTag® was attached to each back leg of 15 mixed age, non-lactating dairy cows (*i.e.* two devices per cow). Cows were allowed two days to become accustomed to the IceTag® then recorded data were compared to visually observed behaviour over three day periods. On recording days 1 & 3 the cows were walked as a group along farm races for 38 and 41 min respectively, then returned to their paddock and offered their daily pasture allocation. After two hours grazing, the group was held in yards (approx 11 x 13 m) for 1 hour. On day 2 the cows were observed continuously by three observers from 09:30hrs until 15:30hrs when lying and standing events were timed for each cow.

Data analysis: All 30 IceTag® devices remained on the cows for the duration of the experiment. One IceTag® failed to record any data once activated, and two devices recorded accurate activity but the standing/lying switch was faulty. These data were excluded from analysis. The differences in lying, standing, active and step data between devices on the same cow were calculated at 1 minute intervals and the distribution of differences for each behaviour calculated across all cows in the group to determine consistency of the data for each behaviour. The frequencies and timings of lying and standing events were compared between IceTag®s and visual observations.

Experiment 2: Examination of relationship between behaviour and oestrus

An IceTag® was fitted to the back leg of 16 non-pregnant lactating dairy cows, all at least 40 days post calving (mean 66 days). The cows were managed in one herd and their diet was solely pasture with a fresh area offered after each AM milking.

Cows were visually observed for signs of oestrus twice daily at milking times (07:00hrs, 15:00hrs) for 21 consecutive days. Behavioural signs of oestrus including chin resting, bellowing, mounting and standing, as well as any observed milk holding or mucus discharge, were recorded. Before the experiment all cows had tail paint applied, which was scored at every milking on the 0 to 5 scale described by Macmillan *et al*. (1988) (5, paint untouched; 0, all paint removed).

A blood sample from each cow was collected from the tail vein after every AM milking. The samples were collected into evacuated tubes containing an anti-coagulant (sodium heparin) and stored on ice for up to one hour before centrifugation (1500 x *g*, 7°C, 15 min). The plasma portion of the sample was stored at –15°C until progesterone analysis. Concentrations of progesterone in the blood were estimated using a Coat-A-Count kit (Diagnostic Products Corporation, Los Angeles, California, USA) validated for use in cattle (McDougall *et al*., 1995). Blood progesterone profiles were used to identify the approximate timing of ovulation events within the 21 day experiment.

Data were downloaded from each IceTag® at the end of the experiment. Four algorithms were developed using the data to identify indices of behavioural change that coincided with the identified ovulation events. Sensitivities (% of oestrus events detected) and false positive levels (% of alerts that didn't correspond to an oestrus event) were calculated for each algorithm.

A 24 hour rolling mean of percent time active at hourly intervals was calculated by taking the mean of the previous 24 hour data for each cow. The slope at each point of this moving mean was calculated using regression analysis of either the previous 10 hour moving mean (Activity24/10) or the previous 5 hour moving mean (Activity24/5), to detect when activity increased. A slope threshold value of 0.2 %/h was used for both the 10 hour and 5 hour regressions, *i.e.* to exceed the threshold of 0.2 the 24 hour mean of percent time active must be at least 2% or 1% greater than the 24 hour mean 10 or 5 hours previous, respectively. Events where the slope value exceeded 0.2 for at least 3 hours (10 hour regression model) or 5 hours (5 hour regression model) were accepted as 'genuine' oestrus alerts.

Because cows managed on pasture exhibit a period of relative inactivity after midnight (Cross *et al*., 2004; Jago *et al*., 2002) two further algorithms were calculated. Daily means for percent of time spent lying and active between the hours of 24:00hrs and 05:00hrs were calculated for each cow. Oestrous alert thresholds were established for this time period when lying was <20% (Lying<20%:12-5AM) and active was >5.5% (Active>5.5%:12-5AM).

Experiment 3: Evaluation of behaviour algorithms

The Activity24/10 and Activity24/5 algorithms described previously were evaluated using an independent group of 29 non-pregnant lactating dairy cows. An IceTag® was attached to the rear leg of each cow two weeks prior to start of mating. The IceTag®s remained on the cows for 60 days. The herd was managed according to normal farm practice and the cows were observed by farm staff daily at the AM and PM milkings for signs of oestrus, using tailpaint as an aid (Macmillan *et al*., 1988). Milk progesterone was measured in fresh whole milk samples, collected at Tuesday and Friday AM milkings, using an ELISA kit (Ridgeway Sciences, Gloustershire, UK) validated for use in cattle (Sauer *et al*., 1986). The profiles of milk progesterone concentration were used to identify all ovulation events. Ovulation was deemed to have occurred when concentrations of progesterone initially declined to basal (< 3.0 ng/mL) and subsequently returned to levels consistent with the luteal phase of the oestrous cycle (> 3.0 ng/mL). Identification of ovulation events was further supported with visually observed oestrus.

The IceTag®s of most cows were removed once during the experimental period to download data. Devices were refitted at the next milking and timing of the download coincided with the non-oestrous stage of the cycle. Data collected between removal of the device and for 24 hours after refitting were excluded from oestrous alert analysis. One of the 29 cows was excluded because her progesterone profile suggested luteal dysfunction. The Activity24/10 and Activity24/5 algorithms were used to generate oestrous alerts, the timing of which were compared to identified ovulations supported with visual oestrous identification.

RESULTS

Experiment 1: Validation of IceTag® ActivityMonitor

The distribution of difference in data recorded between each of the two IceTag® devices fitted on the same cow, for lying, standing, active and number of steps, are shown in Figure 1. A percent point variation of zero means each of the devices recorded the same value. For standing and active, 95% of the 1 minute data points were within 7% points. For lying, 95% of data points were within 1% point, and for number of steps, 95% of data points were within 3 steps of each other.

Figures 2a and 2b show that the IceTag®s recorded the changes in activity that occurred during the periods of forced walking or standing on days 1 and 3 respectively. Minimal values for time active were recorded while animals stood in the yards. Maximal values for time active were recorded during enforced walking for both day 1 and 3. The IceTag®s recorded no lying behaviour during the periods of forced activity and inactivity.

There were 17 lying and 17 standing events recorded by observers during 6 hours of continuous observation on Day 2. The IceTag®s recorded 100% of these lying bouts, and all to within ± 1 minute of the observers recorded observations. The total lying time was measured equivalently by observers (10h 5min 39s) and IceTag®s (10h 1min 0s).

Figure 1: Variation of difference between data recorded by two IceTag® devices fitted on the left and right back legs of 15 cows in Experiment 1 (A– standing, B – active, C – lying, D – steps).

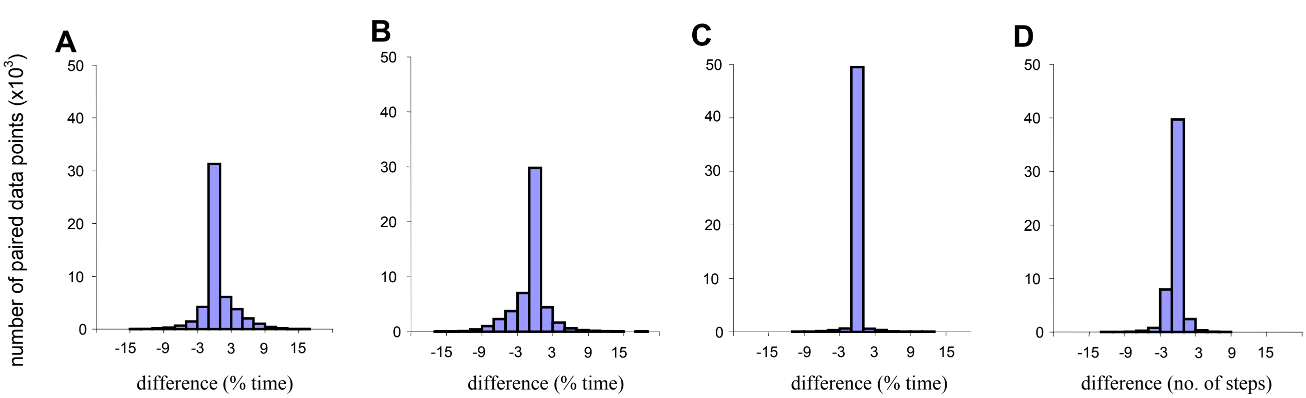
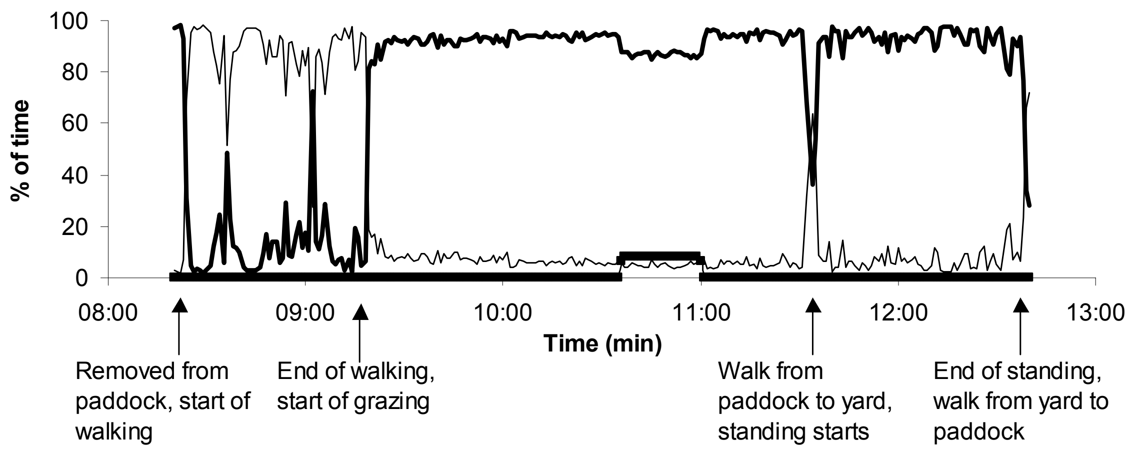


Figure 2: Mean time standing, active, lying (%) and number of steps for 15 animals on day 1 (a) and 3 (b) of Experiment 1 (Standing ▬▬, Active ——, Lying ▬▬).

A



B

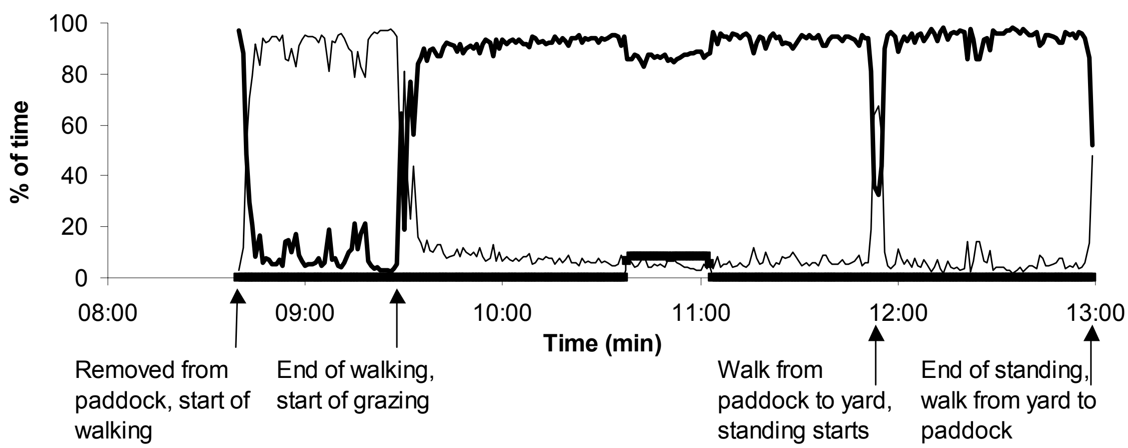
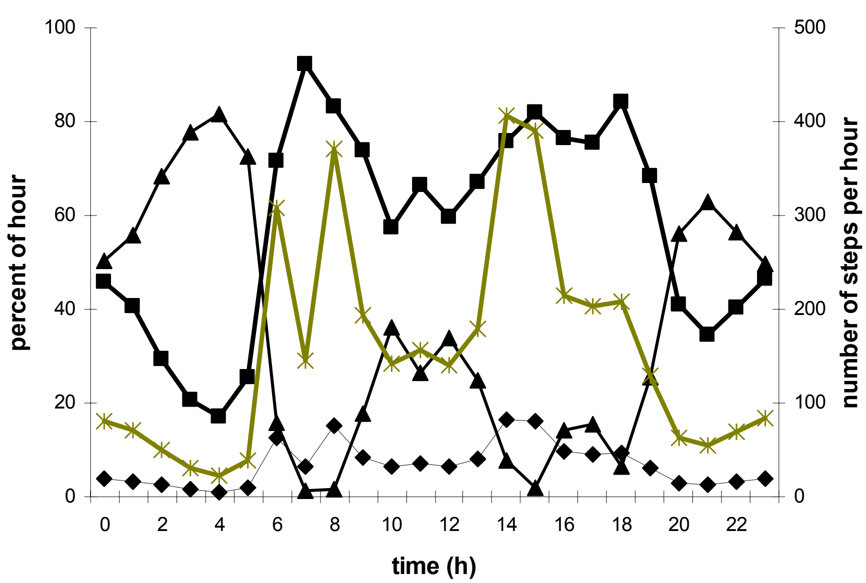


Figure 3: Mean daily activity profile of 16 cows over 21 days (Standing ■, Active ◆, Lying ▲, Steps ✳). There is a decrease in activity level overnight with an associated increase in lying compared to during the day and a marked increase in steps, activity and standing and decrease in lying at milking times (06:00hrs-09:00hrs and 14:00hrs-16:00hrs).



Experiment 2: Examination of relationship between behaviour and oestrus

The mean daily activity profile of the 16 cows is shown in hourly intervals in Figure 3. These data show increased activity at milking times (06:00hrs – 09:00hrs and 14:00hrs-16:00hrs) and a diurnal pattern of activity and lying (predominant in late-evening to early morning).

There were 17 identified ovulations among the 16 cows during the 21-day period. One of these was the first ovulation of a heifer since calving and this ovulation was not accompanied by an observed oestrus. Another two of the 17 ovulations were preceded by delayed inter-luteal activity and were not accompanied by an observed oestrus. Of the 14 normal ovulations, twelve had a confident oestrus recorded by visual observation (86%). The other two ovulatory occasions were considered visually "silent" oestruses. Oestrus was initiated during the night in nine of 12 occasions, but during the day for the other three oestrous events.

The ability of the four algorithms to identify oestrus correctly is summarised in Table 1. The Activity24/10 algorithm successfully identified 13 (93%) of the normal oestrous events, including one visually silent oestrus. The first hour that each alert occurred fell within the period during which visual oestrus started. Six false positive alerts were recorded during the 21 days of the experiment, two of which were due to irregularities in the IceTag® recording (*e.g.* 100% lying for 12 hours during the day). Alerts were not recorded for any of the three abnormal ovulations. The Activity24/5 algorithm also identified 13 of the 14 oestrous events and three true false positives were recorded.

The Lying<20%:12-5AM algorithm identified seven (50%) of the 14 normal oestrous events including one visually silent oestrous event. The six visually detectable oestrous events identified all began overnight (first sign observed at morning milking). Six false positive alerts were recorded, two of which were due to irregularities in the IceTag® recording function.

The Active>5.5%:12-5AM algorithm identified nine (64%) of the 14 normal oestrous events, including one visually silent oestrus. Seven of the nine visually detectable oestrous events identified began overnight. Three false positive alerts were recorded, one of which was due to an irregularity in the data recording.

Experiment 3: Evaluation of behaviour algorithms

A total of 56 oestrous events were identified by examination of the progesterone profiles and visual observations. One event was excluded because it occurred within 24 hours of the IceTag® being removed to download data. Seven alerts using Activity24/10 and six alerts using Activity24/5 were excluded as they occurred as a result of irregular recording by the IceTag®. The ability of the two algorithms to identify oestrus correctly is summarised in Table 1. The Activity24/10 algorithm had a sensitivity of 83.6% (46 detected of 55 oestrous events). Of the 59 alerts generated using the Activity24/10 algorithm 13 were false positive alerts (22.0%). The Activity24/5 algorithm had a sensitivity of 76.4% (42 detected of 55 oestrous events) and generated six false positive alerts (6/48=12.5%). Four of the oestrous events identified by progesterone profiles were not detected by visual observation but two were alerted by the Activity24/10 and one alerted by Activity24/5.

DISCUSSION

A series of experiments set out to validate the IceTag® ActivityMonitor as a technology for remotely recording the activity of cows. The results showed that the IceTag® was able to record the activity patterns of dairy cows accurately and is particularly reliable at recording lying events. While the validation experiment showed consistent recording and acceptable performance, there were several subsequent instances where irregularities in the operation of some devices were identified. The irregularities were presumably a device fault, and the extent to which these would detract from the value of using these devices would depend on the application.

Table 1: Sensitivities and false positive alerts (%) of visual observation and four algorithms developed in Experiment 2 calculated from activity and lying behaviour data for 16 cows, and evaluated in Experiment 3 using activity behaviour data for 28 cows, in reference to progesterone assisted identification of ovulatory events.

	Experiment 2 – Development of algorithms		Experiment 3 – Evaluation of algorithms	
Detection Method	**Sensitivity**	**False Positives**	**Sensitivity**	**False Positives**
Visual Observation	12/14 (85.7%)	0/12 (0%)	51/55 (92.7)	Not evaluated
Activity24/10	13/14 (92.9%)	4/17 (23.5%)	46/55 (83.6%)	13/59 (22.0%)
Activity24/5	13/14 (92.9%)	3/17 (17.0%)	42/55 (76.4%)	6/48 (12.5%)
Lying<20%:12-5AM	7/14 (50%)	4/11 (36.4%)	Not evaluated	Not evaluated
Active>5.5%:12-5AM	9/14 (64%)	2/11 (18.2%)	Not evaluated	Not evaluated

The activity monitoring technology clearly has potential application as a research tool for objectively measuring behaviours continuously, automatically and without human interference, and also as a tool for objective remote monitoring of animal state on farms. For example, lying and locomotion are important indicators of welfare in dairy cows and deprivation of lying can cause behavioural and physiological stress responses (Munksgaard & Simonsen, 1996). Lame cows have been shown to spend more time lying than non-lame cows (Galindo & Broom, 2002) and cows approaching parturition have been shown to spend more time standing (Huzzey *et al.*, 2005).

Detection aids that use changes in the behaviour of cows to identify oestrus have to date been restricted to pedometers that measure walking activity (Woolford *et al*., 1993), motion recorders attached to the collar (CowTrakker™, Bou-Matic, USA, Verkerk *et al*., 2001) and electronic mount-counting devices such as HeatWatch™ (Xu *et al.*, 1998). Uptake on New Zealand dairy farms of these devices has been negligible, mainly due to high capital and maintenance costs, as well as only marginal benefit over visual recording systems (Verkerk *et al.*, 2001). However, increasing herd sizes and greater reliance on unskilled labour are modern features in dairying that will drive the need to develop a reliable and cost effective tool for automatic oestrous detection. Accelerometer technology is one potential approach to developing such a product, as well as having other animal monitoring capabilities.

In Experiment 2, a small number of cows were studied intensively and blood progesterone concentrations measured daily to accurately determine the timing of ovulation and expression of oestrus. The continuous recording of behaviour state in 1-hour intervals allowed a 24-hour rolling mean of activity to be calculated and the slope (>0.2) of the moving mean was used as the trigger-point for an alert. Both the Activity24/10 and the Activity24/5 algorithms were very sensitive, identifying 13 of the 14 (93%) oestrous events, including one that was not visually detected. The timing of the alerts coincided with a time consistent with the commencement of oestrus, and more accurately than twice daily visual observations. This degree of precision may have implications for more precise application of reproductive technologies, although previous studies have demonstrated a reasonable degree of flexibility with timing of artificial insemination when liquid semen is used (Vishwanath *et al.*, 2004). As with most algorithms for detecting oestrus, there were a number of false positive alerts, presenting a problem in terms of reliability and illustrating the need to consider multiple cues for accurately identifying cows in oestrus.

The daily behaviour profiles of cows clearly showed an overnight decline in activity level with an associated increase in lying compared to during the day. This is consistent with a decrease in grazing behaviour that has previously been reported for cattle during this time (Fraser & Broom, 1990; Jago *et al*., 2002). The two algorithms that targeted the period between 24:00hrs and 05:00hrs were less successful at identifying oestrus than the algorithms based on rolling average of activity level. Not unexpectedly, the algorithms were relatively successful at identifying oestrus when the first signs occurred at the AM milking (*i.e.* started overnight), but were unable to consistently identify heat when it began during the day (first visual signs identified at the PM milking).

In the third experiment, a larger number of animals were used to further evaluate the performance of the two most successful algorithms developed in Experiment 2. The sensitivity of using the Activity24/10 algorithm was slightly lower at 84% (compared to 92.9% in Experiment 2) while sensitivity using Activity24/5 was much lower at 76%. However, the Activity24/5.5 algorithm produced fewer false positive alerts.

The IceTag® technology compares well to other automatic oestrous detection systems, which have achieved similar sensitivities in recent studies. Examples are the Bou-matic Heat Seeker pedometers at 85% (Woolford *et al*., 1993), HeatWatch at 91% (Xu *et al.*, 1998) and the CowTrakker™ at 81.5% (Verkerk *et al.*, 2001). A camera-software system reported by Alawneh *et al.* (2006) achieved 85% sensitivity and a false positive level of 12%. In these studies the sensitivities achieved using visual detection with tailpaint as an aid ranged from 71.6% to 98.4% and the level of false positive alerts through visual observation ranged from 12% to 49%.

An apparent failure of cows to show oestrus is more likely a problem of inadequate heat detection, with only low incidences of truly silent oestrus in New Zealand (Williamson *et al*., 2006; Kilgour & Dalton, 1984). When using tailpaint as the primary oestrous detection tool, dominant cows may have intact tail paint despite showing oestrus because other cows are reluctant to mount them. In Experiment 2, progesterone profiles identified two heats that had no visual observations recorded, despite considerable effort to identify oestrus visually. Encouragingly, the algorithms developed in this study were able to detect one of these apparently silent heats.

Measuring the change in behaviour over shorter intervals than has previously been typical shows promise as a technique to assist in the identification of oestrus in dairy cattle. As with other heat detection aids, accelerometer technology is a useful tool to assist staff but needs to be either further developed or used with other forms of oestrous detection to minimize false positive events.

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