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Development of an improved field protocol to assess lamb vigour

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Abstract

Lamb vigour scores (LVSs) are usually assessed during tagging and measurement of the lamb within the first 12 to 18 hours of life and are based on a combination of subjective assessments of the degree of struggling and vocalisation, and the rate of the lamb's return back to the ewe. The trait has a low heritability and has been shown to be genetically associated with lamb survival to 3 days of life. However, it is unclear which behavioural elements of LVS are most important and at what point after birth is it best to assess. This study assessed individual elements of the LVS at intervals in the first 24 hrs post birth, in 236 lambs. Furthermore, a subset of ewes were fitted with SmartTag sensors in order to assess whether key pre-partum behaviours, that could be used to predict the birth, could be remotely assessed using wireless sensor technology.

The objectives of the project were a) to develop improved field-based measures/protocols for the assessment of lamb vigour; and b) to develop prediction algorithms of lambing behaviour in ewes and neonatal lamb behaviour using a novel remote sensing measurement platform (Smart Tags)

Sire variation was evident in bleat responses following restraint at 3 and 4 h post birth. Sire rankings were similar at 3 and 4 h post-birth and there was also some congruence with EBVs for time to bleat. The rankings were less consistent at 8 and 12 h post-birth, suggesting that the trait has some repeatability particularly early post-partum. The bleat response of lambs can be a simple, practical test to assess lamb vigour in the field. It should be carried out after the ewe and lamb have moved away from the birth site, and preferably before the lamb is 12 hours old. However, questions remain with respect to how best to estimate the age of a lamb in the field, once mother and lamb have moved away from the birthing site; and also the impact of stressful procedures such as tagging and birth weighing on the lamb's bleat response. Further research is recommended to address these questions.

In terms of remote sensing, many challenges were encountered during the data collection phase of the experiment, however, clear evidence of changing behaviours was obtained. Unfortunately, within the time constraints of the project, we were unable to complete development of a birthing predictor. Further work is required to develop a true predictive algorithm, which should then undergo pilot testing prior to in-field validation.

Executive summary

The inclusion of lamb vigour assessments in genetic improvement programs has the potential to improve lamb survival. LVS are typically based on subjective assessments of the lamb's response to restraint, ability to vocalise and return back to the ewe. The time taken for a lamb to progress through a set of critical neonatal behaviours (stand, seek udder, suckle) has also been measured and used as an indicator of lamb vigour. In the current study, these neonatal behaviours were measured in 236 lambs which were produced from six Merino sires selected for their divergence in estimated breeding values (EBVs) for traits associated with lamb survival. Based on the EBVs, three of these sires were considered "high lamb vigour" sires, and three "low lamb vigour" sires. Each lamb was subjected to a restraint test at 3, 4, 8 and 12 hours post birth, and specific behaviours were recorded (latency to bleat, stand and return to the ewe). The performance of the lambs against each of these measures at each time point was analysed to determine how the current field based assessment of lamb vigour could be improved.

The objectives of the project were a) to develop improved field-based measures/protocols for the assessment of lamb vigour; and b) to develop prediction algorithms of lambing behaviour in ewes and neonatal lamb behaviour using a novel remote sensing measurement platform (Smart Tags)

In terms of lamb morphometric measures, single-born lambs were heavier and had higher rectal temperature at 3 h of age (after adjustment for birthweight) compared with twin lambs. In the immediate post-partum period, single lambs were slower to stand than twins, and also slower to bleat following restraint at 3 h of age, although parturition duration was not significantly associated with delayed performance of early neonatal behaviours. Males also were slower to bleat than females; and in the twin lambs, male twins were slower to suckle than female twins. Significant sire differences were only observed in the time to bleat after release at 3 and 4 h post-partum. The sire rankings at these two time points were similar and there was also some congruence with the sire EBVs for time to bleat. The lack of significant sire differences at the subsequent test times at 8 h and 12 h may be a function of several factors such as habituation to the test conditions or that the expression of the trait was overridden by other cognitive functions in the developing lamb. Assuming that latency to bleat is a reflection of innate cognitive function in the neonate, then performing the test earlier post-partum may be preferable before learned or experiential factors influence its expression. The evidence from the current study suggests that there may be benefits in performing lamb vigour assessments between 4 and 8 h of age. However, questions remain with respect to how best to estimate the age of a lamb in the field, once mother and lamb have moved away from the birthing site; and also the impact of stressful procedures such as tagging and birth weighing on the lamb's bleat response. Further research is recommended to address these questions.

In addition to this, the project investigates a new measurement platform technology (SmartTags). The Smart Eartag prototypes developed for CSIRO Livestock Industries include a three axis accelerometer (posture), magnetometer (posture,

orientation), four channel light sensor, audio sensor (vocalisations), pressure sensor, temperature sensor, high efficiency solar panel power, and radio localisation (position in the field) and communications. The tag is the same size as a large conventional cattle eartag. Given the measurement capacity, these could be applied in lambing ewes under natural field conditions to collect specific periparturient (birth site selection), parturient (duration/ease of birth, time at birth site) and neonatal behaviours (time to bleat). All are known to be highly relevant to lamb survival and reproductive success. Within this project, data is collected and interrogated with a view to developing preliminary algorithms that may detect and predict some of these important behaviours. Unfortunately, within the time constraints of the project, we were unable to complete development of a birthing predictor. Further work is required to develop a true predictive algorithm, which should then undergo pilot testing prior to in-field validation. We believe this to be the first attempt at developing algorithms to remotely predict birth events in pregnant merino ewes using Wireless Sensor Network (WSN) technology. Many challenges were encountered during the data collection phase of the experiment. These insights will aid development of future WSN technologies deployed on livestock.

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1. Background

There is widespread agreement that increasing lamb survival is central to improved productivity and animal welfare within sheep production systems. The rates of lamb mortality up to marking are estimated at 30% which is a major economic loss and is sufficiently high enough to raise genuine concern on animal welfare grounds. Clearly, there are significant economic and welfare drivers associated with lifting lamb survival rates.

Improvements in lamb survival will occur through the implementation of both management and genetic strategies. The potential for genetic improvement in lamb survival is challenging as such traits are difficult to assess in commercial production systems, so more practical indicator traits are required. The assessment of lamb vigour score (LVS) has been applied in this context. LVS is typically assessed during tagging and measurement of the lamb within the first 12 - 18 h of life. It is composite trait based on subjective assessments of the degree of struggling and vocalisation and the rate of return back to the ewe. The trait has a low heritability (0.13 ± 0.02) and has been shown to be genetically associated with lamb survival to 3 days of life (Brien et al 2010). More recently, Hergenhan et al (unpublished) has shown a moderately strong association between sire (Merino and Border Leicester) ASBVs for LVS and the time to suckle (r^2=0.59). Furthermore, they also observed a similarly potentially useful association between ASBV for LVS and rectal temperature 10 min after birth (r^2=0.50).

These important associations suggest that LVS, as an indicator trait, may have value in genetic improvement programs focused on lamb survival. However, being composite and subjective in nature, questions arise about what behavioural element(s) of LVS are important and whether it is possible to measure these more objectively, and when post-partum, to improve the precision of the trait? Recent analyses of the Sheep INF data suggests that some of the component measures such as time taken to bleat on release was more highly correlated with lamb survival (r_g= -0.44) compared with the composite vigour score. Indirect selection based on this trait alone would achieve 0.8% genetic improvement in lamb survival/yr which is very similar to that achieved through direct selection using lamb survival to weaning from sire progeny testing (1.08%/yr). This project specifically identifies the relevant critical neonatal behaviours that are amenable to be practically and objectively measured in the field. Ultimately, the goal is to develop an improved, more objective LVS that has demonstrable association with lamb survival for application in commercial sheep flocks.

In addition to this, the project investigates a new measurement platform technology (SmartTags). The Smart Eartag prototypes developed for CSIRO Livestock Industries include a three axis accelerometer (posture), magnetometer (posture, orientation), four channel light sensor, audio sensor (vocalisations), pressure sensor, temperature sensor, high efficiency solar panel power, and radio localisation (position in the field) and communications. The tag is the same size as a large conventional cattle eartag. Given the measurement capacity, these could be applied in lambing ewes under natural field conditions to collect specific periparturient (birth site selection), parturient (duration/ease of birth, time at birth site) and neonatal behaviours (time to bleat). All are known to be highly relevant to lamb survival and reproductive success. Within this project, data is collected and interrogated with a view to developing preliminary algorithms that may detect and predict some of these important behaviours.

2. Project objectives

1. To develop improved field-based measures/protocols for the assessment of lamb vigour
2. To develop prediction algorithms of lambing behaviour in ewes and neonatal lamb behaviour using a novel measurement platform – SmartTags

3. Methodology

The study protocol was approved by the CSIRO Armidale Animal Ethics Committee, protocol number ARA 12/09.

3.1 Ewe management

A total of 280 Merino ewes (147 multiparous and 133 primiparous) were joined in five weekly cohorts by AI to six Merino sires in April/May 2012 at the CSIRO FD McMaster Field Station at Armidale. Sires were selected for high and low vigour based on their EBVs for lamb survival to weaning (LSW) and for traits associated with lamb vigour/survival; time to bleat (Bleat), rectal temperature (Rect. Temp.) and crown-rump length (C-R length) (Table 1). The choice of sires was also dependant on semen availability. Based on EBV for LSW, sire H3 ranks highest, and sire L1 ranks lowest.

During gestation, the ewes were pregnancy scanned (day 50-80) and maintained on pasture at Body Condition Score (BCS) 2.5-3. One month prior to lambing of the first AI cohort, the ewes were managed as 5 separate cohorts and provided with supplementary feed. From day 100 of gestation, ewes were supplemented with lupin/corn mix at 250g per ewe, given three times weekly. From day 124, they were given ad-libitum lucerne hay, and lupin/corn mix at 500 g/ewe once daily. From day 134 they were introduced to the pelleted ration to be used in the lambing shed (Ridley Agriproducts, Tamworth, NSW; Metabolisable Energy 9.0 MJ/kg DM, Crude Protein 16.2%), increasing to 500 g per ewe per day.

Table 1: Information Nucleus Flock (INF) estimated breeding values (EBVs) for selected sires (relative ranking in brackets)

Sire ID	Sire Vigour Group	Sire EBVs*			
		LSW	Bleat	Rect. Temp.	C-R length
H1	High	0.01741 (3)	-1.793 (2)	-0.0077 (2)	0.2386 (5)
H2	High	0.02274 (2)	-2.773 (1)	-0.2196 (4)	1.155 (3)
H3	High	0.02372 (1)	-0.9295 (3)	0.2934 (1)	3.597 (1)
L1	Low	-0.0243 (6)	0.596 (5)	-0.6021 (6)	0.1617 (6)
L2	Low	-0.0235 (5)	0.1876 (4)	-0.2493 (5)	0.8834 (4)
L3	Low	-0.0159 (4)	2.386 (6)	-0.1708 (3)	2.676 (2)

*Source: F. Brien pers. comm., March 2012

3.2 Lambing

Ewes were penned individually in a lambing shed at day 145 of gestation and fed an *ad libitum* lucerne based feed ration (ME 9.0 MJ/kg DM, CP=16.2%), supplemented with lucerne hay and a 3:2 lupin/corn ration 200gm/day. They were monitored 24 h per day. Ewe numbers in each cohort ranged from 45 to 63 ewes.

At the first sign of pre-partum behaviour, video monitoring was initiated and maintained until 3 h post birth. The time when chorio-allantoic sac membranes and lamb body parts were first observed was recorded and lambing assistance was only given if the ewe failed to lamb within two hours after the initial signs of lambing were observed (i.e. expression of pre-partum behaviours or presence of the chorio-allantoic sac membranes) or if there was clear evidence of mal-presentation. Duration of parturition was determined to be from first appearance of membranes and/or lamb body parts to complete expulsion of lamb. Video data was analysed to determine neonatal behaviours including times to attempt to first stand, stand, reach the udder and suck.

At 3 h a bleat response test (adapted from INF lamb test protocols) was taken by restraining each lamb on its side for 5 sec at a distance of 1 m from the ewe's pen, releasing and recording the time taken for the lamb to first bleat. If lambs did not bleat within the first 90 s of the test, the measurement was recorded as TE (time elapsed). Lamb birthweight, rectal temperature, crown to rump length and girth circumference were recorded followed by ear-tagging.

3.3 Vigour testing

At 4, 8 and 12 h from birth, the ewe and lamb(s) were taken to an outside arena where the ewe was restrained in a pen 2.5 m from the lamb (Figure 1). Video monitoring was used to record the time of the bleat response when the lamb was released after being restrained on its side at the 'X' for 5 s, and the time taken for the lamb to stand and then travel to the ewe (achieved if the lamb reached the 0.5m contact zone in front of the penned ewe). If lambs did not reach the ewe within 3 minutes, or bleat within the first 90 secs of the test, the measurements were recorded as TE (time elapsed). Twin lambs were tested individually in the same order of their birth. All lambs and ewes were released after the 12 h test into an enclosed area outside the shed for another 24 h prior to release to the paddock.

Figure 1: Test arena used for 4, 8 and 12 hour lamb vigour tests

3.4 Remote sensor technology

The CSIRO has nearly a decade of experience in developing Wireless Sensor Network (WSN) technologies for agricultural applications. Their most recent WSN devices are specifically designed for their target applications, rather than a one-size-fits-all approach. However, the core computing (MSP430 microcontroller) and radio (CC1101) are common to all devices within the family of the “Pervasive Autonomous Computing Platform” (PACP). This offers the advantage of devices that are very custom-specific to their task, but also able to communicate with other devices and leverage many of the software advances developed for other devices within the family. The WSN device needed for this experiment required a small form factor with the ability to sense movement, orientation and audio. Inertial (movement via accelerometers, orientation via magnetometers and gross-height movement via a pressure sensor) and digital audio are inevitably high sample-rate sensors. This means that significant amounts of data are recorded on a continuous basis and as such requires storage beyond the standard capability of the microcontroller or on-board flash. To address this need, the device supports micro-SD memory cards, and specifically 16GB SDHC cards were used for this experiment. The culmination of these capabilities yielded the PACP “Salus” device which is a mere 29x42mm in area and weighs less than 6 grams (Figure 2). The device requires a Li-ion battery to operate and was selected based on the requirement to record inertial data for up to 7 days and up to 7 hours of audio with the ability to change mode of operation via the radio. The smallest commercially available case that could house the Salus device was sourced and the device secured inside of it. Originally it had been intended that the battery would also be housed inside the case, however the energy required for up to 10 days continuous operation required a battery capacity greater than what could be housed in the casing. An external Li-ion (Tenergy 18650, 3.7V, 2600mAh) battery was attached to the back of the halter and then connected via shielded wire to the device. Initial experimentation revealed that the microphone internal to the housing yielded extremely muffled audio and so a hole was drilled into the case, a rubber tube placed around the microphone and a felt cover (visible top-right in Figure 2b) placed over the hole to provide wind dampening and some weather resistance.

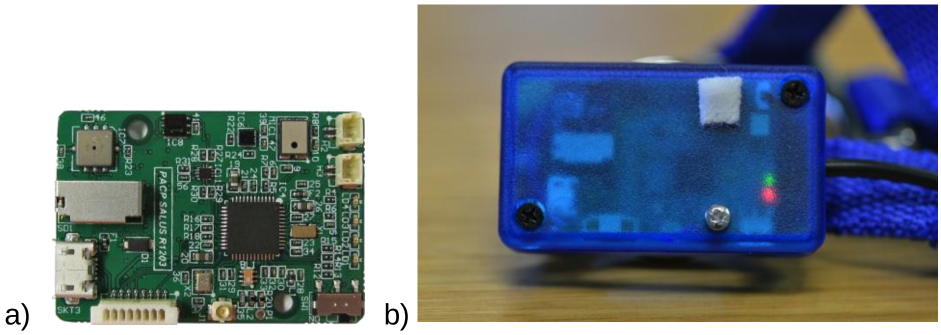

Figure 2: Left (a): PACP Salus WSN device (to scale). Right (b): Housed Salus device

A randomised selection of 61 ewes was used to investigate the use of CSIRO remote sensor technology to detect parturition behaviours in Merino ewes. The ewes were fitted with halters with activated nodes attached (Figure 3) and monitored 24 hrs per day in a separate section of the shed with minimal traffic and noise level (Figure 4). After an 8 hour adjustment period following halter fitting, each ewe was filmed by video camera for approximately 12 hours to capture baseline (normal range) penned behaviour.

Figure 3: Fitting of remote sensor device node to chinstrap of halter

At the first indication of commencement of pre-partum behaviours (restlessness, circling, sniffing ground, vocalisation), video monitoring to collect data on parturient behaviour was initiated and maintained until 3 hr post birth. Where possible audio mode on the sensor device was also initiated at this stage to allow collection of audio data. Halters were then removed and node data collection ceased at this time. The sensor nodes were sent to CSIRO ICT for downloading and analysis; and video data annotated for relevant behaviours by use of an Excel spreadsheet.

Figure 4: Visual and video camera monitoring of penned ewes

Just prior to attaching the device to the animal, the device was turned on and a timestamp sent wirelessly to the device from a computer with a “base node” device attached. This activated the recording of the inertial data. The 3-axis accelerometer and 3-axis magnetometer data from the LSM303 sensor was sampled at 100 Hz and 10 Hz respectively. The BMP085 sensor sampled atmospheric pressure and temperature at a rate of 30 Hz. The recording of audio data was activated via a radio command during or just after birth. The audio was sampled at 22.4 kHz which was a deliberate compromise between audio quality and the amount of data generated.

It is hypothesised that a number of inertial-based behaviours exhibited by the ewes will provide predictive power (correlate in advance to) the birth event. The inertial sensor data is highly dynamic and susceptible to significant noise due to local environmental factors. As such, individual inertial readings provide little information about the animal’s true activity and for practical purposes, no predictive power about birth time. Multiple consecutive readings, known as a window of data, however can provide detail about the animal’s activity, though determining the activity remains a challenging task due to the dynamic and noisy nature of inertial sensors. Which activities will provide the best prediction of when a birth is imminent remains an open question and is outside the scope of this experiment. For this experiment, we focus on detecting rotation events based on anecdotal evidence that the frequency of when rotation events occur increases leading up to the birth event. To develop algorithms that can detect rotation events and be performed on the SmartTags, we contrast the ‘raw’ inertial data in windows of rotation activity and windows of non-rotation. Algorithms will then be developed to maximise the discrimination between these two classes of activity, however the computational constraints of the microcontroller must be kept in mind when developing the algorithms. The training and validation of these algorithms requires annotated windows of data. To achieve this, periods of activity, both pre-birth by a few days (baseline) and perinatal were recorded via a HD handycam and CCTV video camera for a number of animals. A selection of these videos was then annotated by visual inspection.

Communications to the devices was achieved via a “Base Station” comprised of a PACP Salus device connected to an embedded Linux PC (Alix PC) and connected to a 3G modem (Datacall) and Apple Airport Express. Note that the trial location had no readily available internet connection which is why the 3G modem was required. Information from the on-animal devices was wirelessly transmitted to the Base Station’s Salus node and sent to the embedded Linux PC via RS-232 serial communications. The data is then distributed via the network switch (Airport Express) to local PCs on the wireless network and to the internet via a 3G modem. A laptop on the local wireless network was dedicated as an interface for sending commands to the devices and monitoring their activity. Engineering data (such as battery voltage, current SD page number) from the devices was sent via the 3G modem to be stored into an Oracle database with a user-friendly web front-end.

3.5 Statistical analysis

The data were analysed using the GLM and MIXED procedures in SAS. The lamb measures of birth weight, crown-rump length, girth circumference, rectal temperature, time to stand, time to suckle and 3 h bleat response were analysed using ANOVA (Proc GLM). The model included the fixed effects of cohort, parity, sex, litter size and sire; and birth weight was included as a covariate (in all models except for that for birth weight). The actual duration of birth was also fitted as a covariate in the models for neonatal behaviours and rectal temperature. Interactions were retained in the model if significant at $P<0.05$. An additional ANOVA was conducted on twin lamb data to investigate the effect of birth order.

A repeated measures analysis (Proc MIXED) was applied to examine the lamb vigour test measures (time to bleat, time to stand and time to travel to the ewe). The model comprised the fixed effects of cohort, sex, litter size and sire with animal (i.e. lamb ID) included as the random term. Birth weight was fitted as a covariate as was the duration of birth.

All timed behaviour measurements were normalised by transformation to $\log_n$ values.

4. Results

In total, 279 lambs were born and of those, 236 lambs with complete records were included in the analysis.

There were 170 single lambs born to 98 multiparous and 72 primpiparous ewes, and 70 twin lambs born to multiparous ewes. The number of twins born to primiparous ewes was quite low – only 11 sets of twins. Consequently, a decision was made to exclude this subset from the analysis.

4.1 Lamb physical measures

The effects of sire, cohort, parity, litter size and sex on neonatal physical data are summarised in Table 2. Significant interactions between cohort x parity (birthweight and crown-rump length), cohort x lamb sex (crown-rump length, girth circumference), cohort x litter size (girth circumference) and sire x cohort (girth circumference) were observed. The biological importance of these is relatively minor and attributable to differences in magnitude. For example, for the cohort x parity interaction, the differences in birth weight due to parity (typically multiparous > primiparous) varied between the individual cohorts. The significant interaction between sire x litter size for birthweight (Figure 5) was also one of magnitude. In addition to birth weight, a significant sire effect was observed for girth circumference but not for crown-rump length or rectal temperature (Tables 2 and 4). Lambs from sire L1 (lowest rank in terms of EBV for LSW) (mean 3.83 kg) and H1 (mean 3.86 kg) weighed significantly less than lambs from sires L2 and H2 (mean 3.56 and 3.52 kg, respectively); while lambs from sire H2 had significantly smaller girth circumferences than sire L1 (37.19 and 38.26 cm, respectively).

As expected, single lambs were heavier than twins (P<0.001), and had a higher rectal temperatures (P<0.01). Male lambs were non-significantly heavier than female lambs but the girth circumference on the female lambs was significantly larger (P<0.01).

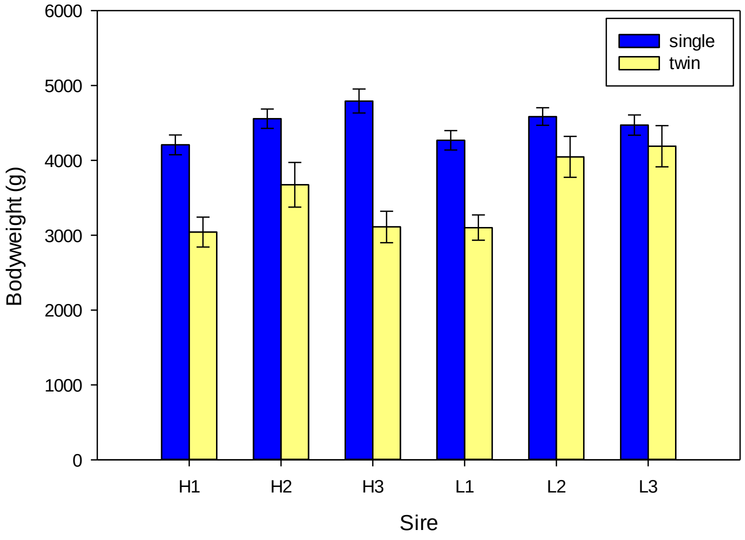

Figure 5: Birthweight least square means for the interaction between sire x litter size

4.2 Neonatal behaviours and 3 h bleat test

The effects of sire, cohort, parity, litter size and sex on neonatal behaviours (latency to stand and suckle) are summarised in Table 2 (all lambs) and 3 (twin lambs). A significant parity x lamb sex interaction was observed for latency to bleat: female lambs were faster to bleat at 3 hrs than male lambs, and this difference was more marked in primiparous ewes than in multiparous ewes.

There was a significant effect of cohort on time to suckle (Table 2), lambs in cohort 2 being slower to suckle than lambs in the other cohorts. Single lambs were slower to stand ($P<0.01$) and slower to bleat at 3 h of age ($P<0.001$) compared with twin lambs; while males were slower to bleat than females at 3 h of age ($P<0.05$). In the analysis of the twin data subset, a sex effect was only observed for time to suckle where males were significantly slower than females ($P<0.05$) (

Table 3). Birth order did not influence the time to perform the critical neonatal behaviours.

Sire effects are presented in Table 2 and 4 (all lambs) and

Table 3 and 5 (twin lambs only). There were no significant effects of sire on latency to stand or suckle, but there was an effect on latency to bleat at 3 h of age, which was not evident in the twin data. Lambs from sire H2 and L2 were significantly faster to bleat (mean 2.07 and 2.56 s) than lambs from sire L3 (7.28 s).

The covariates birthweight and parturition duration were not significantly correlated with any of the neonatal behaviours (all lambs and twins).

Table 2: Summary of main effects on physical measures, early behaviours and bleat response (at 3 hours) of all lambs

	Physical measures								**Neonatal behaviours**					
	Birth weight (kg)		**Crown Rump (cm)**		**Girth (cm)**		**Rectal temp (°C)**		**Time to stand (min)**		**Time to suck (min)**		**Latency to bleat 3 hr (s)**	
Fixed effect	**LSM**	**P-value**	**LSM**	**P-value**	**LSM**	**P-value**	**LSM**	**P-value**	**LSM**	**P-value**	**LSM**	**P-value**	**LSM**	**P-value**
Sire	ref table 4	<0.01	ref table 4	NS	ref table 4	<0.05	ref table 4	NS	ref table 4	NS	ref table 4	NS	ref table 4	<0.05
Cohort		<0.05		<0.05		<0.05	-	NS	-	NS	-	<0.01	-	NS
Parity		0.06		NS		NS		NS		NS		NS		NS
Mature	4.14		45.60		38.04		39.39		20.11		42.91		3.45	
Maiden	4.35		45.74		37.71		39.37		17.81		44.28		3.20	
Lamb sex		NS		NS		<0.01		NS		NS		NS		<0.05
Male	4.27		45.71		37.59^{a}		39.46		20.55		46.52		4.21^{a}	
Female	4.13		45.63		38.15^{b}		39.31		17.44		40.85		2.59^{b}	
Litter size		<0.001		NS		NS		<0.01		<0.01		NS		<0.001
Singleton	4.49^{a}		45.80		38.15		39.62^{a}		24.19^{a}		47.77		5.24^{a}	
Twin	3.52^{b}		45.54		37.60		39.15^{b}		14.81^{b}		39.77		2.00^{b}	
Covariate														
Birthweight	-			<0.0001		<0.0001		NS		NS		NS		NS
Parturition duration	-		-		-		-	NS		NS		NS		NS
Interactions														
Sire*Cohort		NS		<0.05		NS		NS		NS		NS		NS
Sire*Parity		NS		NS		NS		NS		NS		NS		NS
Sire*Lamb sex		NS		NS		NS		NS		NS		NS		NS
Sire*Litter size		<0.01		NS		NS		NS		NS		NS		NS
Cohort*Parity		<0.05		<0.05		NS		NS		NS		NS		NS
Cohort*Lamb sex*		NS		<0.05		<0.05		NS		NS		NS		NS
Cohort*Litter size		NS		NS		<0.01		NS		NS		NS		NS
Parity*Lamb sex		NS		NS		NS		NS		NS		NS		<0.05
Parity*Litter size		NS		NS		NS		NS		NS		NS		NS
Lamb sex*Litter size		NS		NS		NS		NS		NS		NS		NS

Different superscripts within columns within effect indicate means which differ significantly (P<0.05); NS = not significant

LS means for timed behaviours and bleat latency are backtransformed

Table 3: Summary of main effects on neonatal behaviours and bleat response (at 3 hours) of twin lambs

	Time to stand (min)		Time to suck (min)		Latency to bleat 3 hr (s)	
Fixed effect	**LSM**	**P-value**	**LSM**	**P-value**	**LSM**	**P-value**
Sire	ref table 5	NS	ref table 5	NS	ref table 5	<0.05
Cohort	-	NS	-	NS	-	NS
Lamb sex		NS		<0.05		NS
Male	21.40		51.83^{a}		2.65	
Female	14.98		32.61^{b}		2.37	
Birth Order		NS		NS		NS
First	16.26		36.30		3.18	
Second	19.71		46.55		1.95	
Covariate						
Birthweight		NS		NS		NS
Parturition duration		NS		NS		NS
Interactions						
Sire*Cohort		NS		NS		NS
Sire*Parity		NS		NS		NS
Sire*Lamb sex		NS		NS		NS
Sire*Litter size		NS		NS		NS
Cohort*Parity		NS		NS		NS
Cohort*Lamb sex*		NS		NS		NS
Cohort*Litter size		NS		NS		NS
Parity*Lamb sex		NS		NS		NS
Parity*Litter size		NS		NS		NS
Lamb sex*Litter size		NS		NS		NS

Different superscripts within columns indicate means which differ significantly (P<0.05)

LS means for timed behaviours and bleat latency are backtransformed

Table 4: Sire least square means for physical measures, early behaviours and bleat response (at 3 hours) of all lambs

		Physical measures				Neonatal behaviours		
		Birth weight (kg)	Crown Rump (cm)	Girth (cm)	Rectal temp (°C)	Time to stand (min)	Time to suck (mins)	Latency to bleat 3 h (s)
Sire	***n***							
H1	44	3.63^{ab}	45.47	38.07^{ab}	39.26	23.47	46.83	2.97^{ab}
H2	36	4.12^{bc}	46.56	37.19^{a}	39.35	19.47	40.52	2.07^{a}
H3	32	3.95^{ab}	45.86	37.78^{ab}	39.49	21.74	53.43	3.02^{ab}
L1	49	3.69^{ab}	45.35	38.26^{b}	39.41	14.79	38.29	3.51^{ab}
L2	42	4.32^{bc}	45.08	37.85^{ab}	39.16	14.25	37.10	2.56^{a}
L3	36	4.33^{bc}	45.68	38.08^{ab}	39.61	21.96	47.63	7.28^{b}

Different superscripts within columns indicate means which differ significantly (P<0.05)
LS means for timed behaviours and bleat latency are backtransformed

Table 5: Sire least square means for neonatal behaviours and bleat response (at 3 h) of twin lambs

	Neonatal behaviours		
	Time to stand (mins)	Time to suck (mins)	Latency to bleat 3 h (s)
Sire			
H1	22.19	54.34	1.33
H2	18.64	27.78	1.09
H3	20.82	64.42	2.20
L1	8.67	23.77	3.72
L2	21.99	56.24	1.58
L3	20.04	37.12	5.67

Different superscripts within columns indicate means which differ significantly (P<0.05)
LS means for timed behaviours and bleat latency are backtransformed

4.3 Lamb vigour test behaviours

There were no significant effects of cohort, parity, litter size or sex on any of the lamb vigour test measures (all lambs). Sire differences on latency to bleat (Table 6) were observed where lambs from sire L3 were significantly slower to bleat than lambs from sires H2 (P<0.001) and L2 (P<0.05). There was a significant effect of test time on time to stand and time to travel to ewe (P<0.05). There were no significant interactions and the covariates birthweight and parturition duration were also not significant in any of the models.

Table 6: Sire effects on lamb vigour test arena behaviours

Sire	Latency to bleat (s)	Time to stand (s)	Time to travel to ewe (s)
H1	2.20^{ab}	4.68	31.63
H2	1.41^{a}	3.83	13.41
H3	1.93^{ab}	4.27	18.44
L1	2.07^{ab}	5.28	19.22
L2	1.83^{a}	4.41	19.57
L3	3.01^{b}	3.67	21.66

Different superscripts within columns indicate means which differ significantly (P<0.05)
LS means for timed behaviours and bleat latency are backtransformed

Table 7: Sire bleat EBVs and least square means for time to bleat during the 3 and 4 h tests (ranking in brackets)

Sire ID	Sire Vigour Group	Bleat EBV	Latency to bleat 3 h	Latency to bleat 4 h
H1	High	-1.793 (2)	2.97 (3)	2.20 (5)
H2	High	-2.773 (1)	2.07 (1)	1.41 (1)
H3	High	-0.9295 (3)	3.02 (4)	1.93 (3)
L1	Low	0.596 (5)	3.51 (5)	2.07 (4)
L2	Low	0.1876 (4)	2.56 (2)	1.83 (2)
L3	Low	2.386 (6)	(7.28 (6)	3.01 (6)

As discussed, sire differences were only observed for the 3 and 4 h latency to bleat. A comparison was then performed to examine the sire rankings for these behaviours against the sire EBV (Table 7). Although some caution needs to be exercised in the interpretation, it was rather interesting to observe that the rankings were similar for the top and bottom ranked sires based on the original EBV.

The mean latencies at each test time point by sire are presented in Figure 6. Although the interaction between sire x test time was not significant, it is interesting to note that the greatest differences between sires were observed at 8 hours for latency to bleat, and at 4 hours for latency to stand. These figures also illustrate the relative ranking of sires at each time point. Lambs were generally quicker to stand and quicker to travel to the ewe at 8 and 12 hours than at 4 hours.

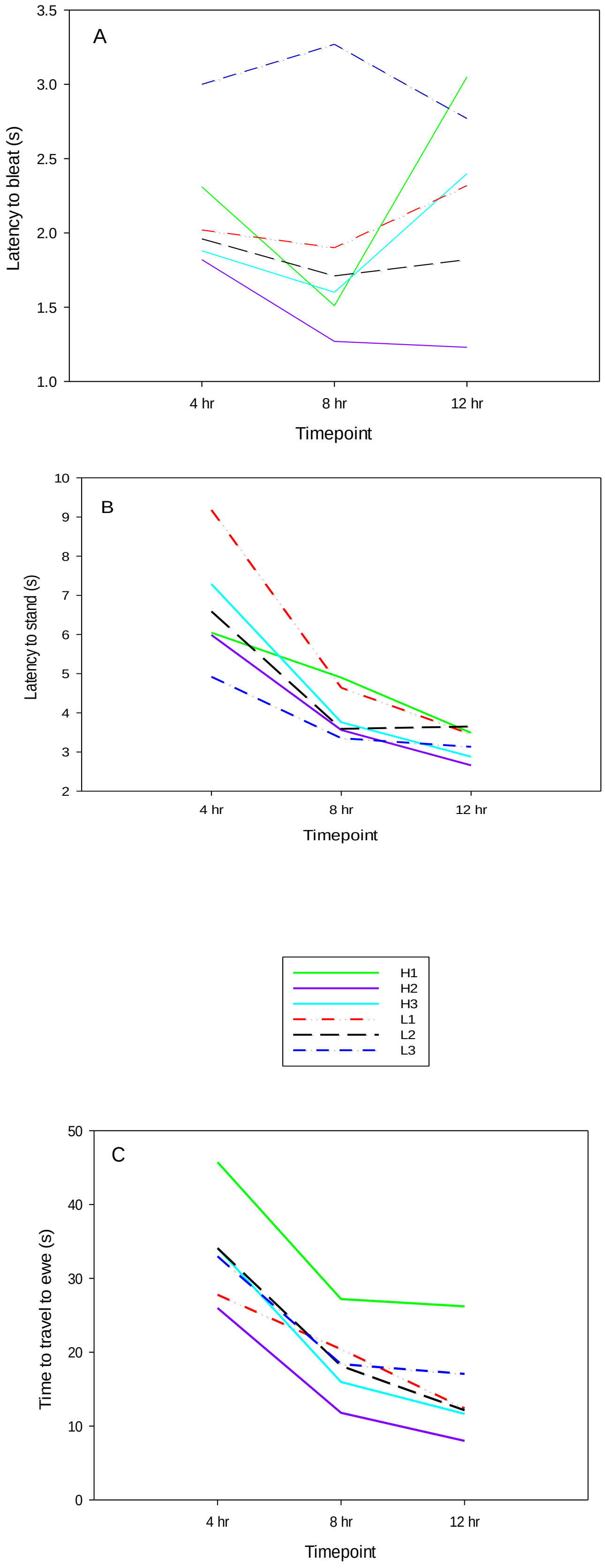

Figure 6: Sire least square means at each time point for: a) latency to bleat; b) latency to stand; c) time to travel to ewe

4.4 Performance of the remote sensor system

(A) Sensing device hardware

The housing proved robust to withstand rubbing and movements of the animal and protect the node. Despite the potential issue for water entering the device through the microphone hole when the animal was drinking, no nodes were compromised by water. The external battery however became disconnected in 2 cases through excessive force applied to the connecting cable when the animal rubbed against objects and the wire got caught. Additionally, the exposed external battery would not be suitable for outdoor conditions, so it is recommended that future deployments also house the battery.

A prototype low-power, single hop wireless communications protocol was employed for this experiment due to the requirement to activate the devices' audio recording at any moment, but while still achieving a node life of up to 10 days. Ideally a multi-hop radio protocol would be employed to enhance radio coverage; however, at the time of deployment, available multi-hop protocols were not mature. A significant challenge to the wireless communications was the presence of metal sheeting (walls, roof) and steel-mesh fencing (partitions between each animal at approximately every 1.2m). This resulted in a significant decreasing of range as well as unpredictable signal strength and when combined with the limitations of single-hop transmissions and instability of the prototype low-power communications driver, the overall wireless communications was quite poor. The prevented a significant number of devices from activating the audio recording at the desired time and also led to the premature depletion of the battery in some cases as the audio could not be deactivated when no longer required.

The proximity of the device to metal sheeting and steel-mesh fencing also interfered with the magnetometer readings, mostly evidenced by abnormally large magnetic readings.

A bug in the microcontroller real-time clock (RTC) driver resulted in significant time drift in the order of up to 15-20 seconds per hour. Unfortunately this was not identified until after all experiments had been completed.

(B) Server/Base station

The complexity of base station interactions between the Airport Express, 3G modem, embedded Linux PC and WSN device resulted in significant periods where the devices could not be communicated with. This required a substantial amount of human resources to be dedicated to the inspection and frequent resetting of the base. Post-trial analysis of the configuration revealed a number of issues which have since been addressed.

4.5 Video surveillance

It was evident during the analysis that precise time synchronisation between the video and the sensor data is critical. Ideally, every frame of the video would be timestamped with the exact time of the sensor device; a feature that was not available in the current trial. Recent improvements to the time management of the devices has resulted in minimal clock drift on the devices as well as tight time synchronisation between all devices within a deployment (<100ms difference). This means that in future trials, a device with a LED display could be dedicated to displaying the “network” time and kept within the video field of view at all times. This would ensure that the video is always synchronised to the sensor data to within 100ms.

While higher resolution video enables better determination and discrimination of behavioural activity, managing the large volume of data generated by High Definition (HD) video proved problematic. When using the video for annotation, it was evident that a much lower resolution video (with higher compression) would have sufficed. This would have allowed for longer continuous video recording (due to not needing to replace the limited capacity of the SD cards) as well as easier distribution of the files. A further recommendation would be to stream the video from permanent mounted cameras to a centralised server rather than to local SD cards. The management of cameras (setting up cameras, connecting power, changing SD cards, etc) proved to be another potential point of failure in the process as the personnel involved were already very busy managing the animals and collecting other data that required human involvement.

The annotation of the video data was a highly time-consuming process. Annotators had to source the videos which were often very large (~20GB) and often it was challenging to jump, forward or backward, or fast forward the video due to the specific codec the video camera employed. When a behaviour was identified, the annotator then had to pause the video, switch to the MS Excel spreadsheet, record the video time offset of when the activity began as well as which activity was being seen, and then watch the video for the end of the activity, again pause and again record the end of the activity in the spreadsheet.

4.6 Node data and development of algorithms

Despite the many issues encountered during the deployment of the nodes, a substantial amount of data was ultimately obtained. Using this data, the hypothesis that the occurrence of circling/rotation behaviour events becomes more frequent leading up to the birth event was investigated. A subsequent aim was to then utilise the rate of circling/rotation events to predict the birth event with an algorithm that could be implemented on the wireless sensor device.

“Extreme” rotation events, identified by animal experts watching the video footage, were used as a starting point for the inertial data analysis. The inertial data during these events were analysed and compared to the inertial data during a number of other non-rotation events. The first appreciable aspect of rotation events is the sinusoidal pattern of ***both*** the X and Y magnetometer values during a rotation or head turning event (Figure 7). This is evident even though the values have not been calibrated or normalised as is typically done when employing magnetometer readings. However, the speed of rotations, number of rotations and overall duration of the event varied considerably between various annotated events. From this, it became evident that defining circling/rotation behaviour was somewhat subjective since specific thresholds for the amount of rotation and event duration were unlikely to yield consistent classification of rotation events between animals. In addition to the sinusoidal pattern, it was also observed that the standard deviation of the magnetometer readings was higher than typical during these events.

Since gross motor body movements are of interest, a smoothing filter over a short time period was applied to reduce noise from environmental factors as well as small movements by the animals. A median filter was chosen since this better retains features of the waveform such as preserving the sharp transition from one steady state to another better than an averaging filter which will typically smooth the transitions. Again the raw data was used since it is easier for the device to compute on these values as opposed to converting to calibrated values which is computationally complex, requires calibration to be performed on each device prior to deployment and is subject to large errors when the magnetometer experiences interference from the environment. The standard deviations (STD) for the X, Y and Z axis magnetometers are calculated at each point using the same window of time used by the smoothing filter. The X,Y and Z STD's are combined to amplify the signal when the magnetometers fluctuate simultaneously. We term this product as the "Agitation Index", A, as it responds to both micro-movements of the head as well as significant whole body rotations and intuitively as an animal becomes more agitated, the spectrum of these behaviours will be biased towards more pronounced movements and hence a higher agitation value. Two methods of combination were employed: multiplying all axes STD's to yield $A_\times$ and summing all axes STD's to yield A_+ .

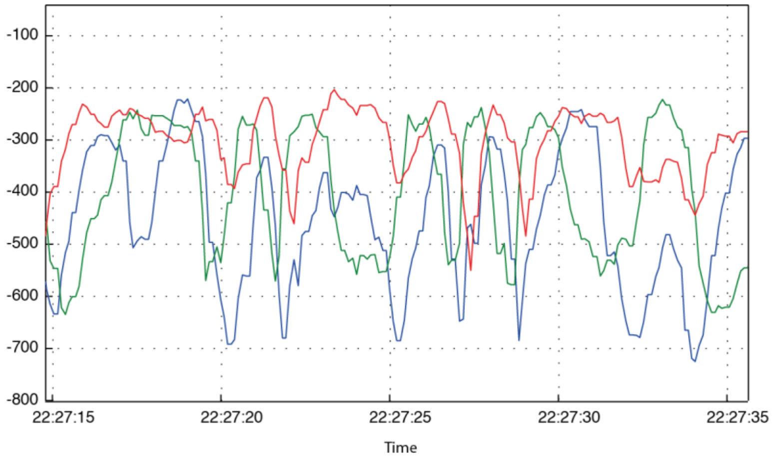

Figure 7: A zoomed in segment of the raw three axis magnetometer readings showing a rough sinusoidal characteristic when the ewe is circling.

Analysis of the agitation indices revealed that a generic threshold did not provide a reliable indicator of when the birth event occurred. This is likely to be due to the discrete and stochastic nature of the occurrence of rotation events. A detection algorithm was then designed to capture significant rotation events which were defined as sustained rotation of the ewe over a predefined duration. These corresponded to peaks in the agitation index which remained above a particular threshold for at least a specified period of time. This is useful in filtering out minor head turns and slow body turns. Figure 8 shows a segment of data with detected rotation events (pink bars).

Figure 8: Automatically classified rotation events with the agitation index (Magenta trace). The red, blue and green traces are individual 3-axis magnetometer data; pink bands are detected circling/rotation events; red triangles are circling/rotation events identified by video annotation.

The cumulative sum of the non-thresholded agitation index, $\sum A_{+}$ was performed to see if taking all movements into account, small and large, would exhibit any noticeable change prior to birth. As can be seen by the blue curve in Figure 9, the cumulative sum of the non-thresholded agitation index did in fact demonstrate a noticeable deviation (toward exponential) from the mostly linear behaviour observed prior to the birthing period (i.e. during the baseline period) for a number of ewes. It was also observed that generally after the birth the behaviour reverted back to a linear behaviour. In some instances it was difficult to observe the inflection after the birth. Conveniently however, another metric, the Masked Sum, provided indications of birth activity when the cumulative sum of the non-thresholded agitation index did not. The Masked Sums, $\sum M_{+}$ and $\sum M_{\times}$ are the cumulative sum of periods where significant rotation events were detected by the detection algorithm. It represents detected (masked) periods of significant rotation events defined by the agitation index being above a specific threshold for a sustained period. This is further illustrated in Figure 10 which shows the raw magnetometer readings, the agitation index, the significant rotation events detected by the algorithm and the corresponding cumulative sum and the masked cumulative sum. By combining the metrics $\sum M_{+}$ and $\sum A_{+}$, a new metric, $\sum AM_{+}$, was devised that exhibited similar behaviour between ewes leading up to the birth event. Figure 9 shows all three of these metrics for a particular ewe. Finally, the first derivative of this new metric $\sum AM_{+}$ was calculated at each point to extract the rate of variation.

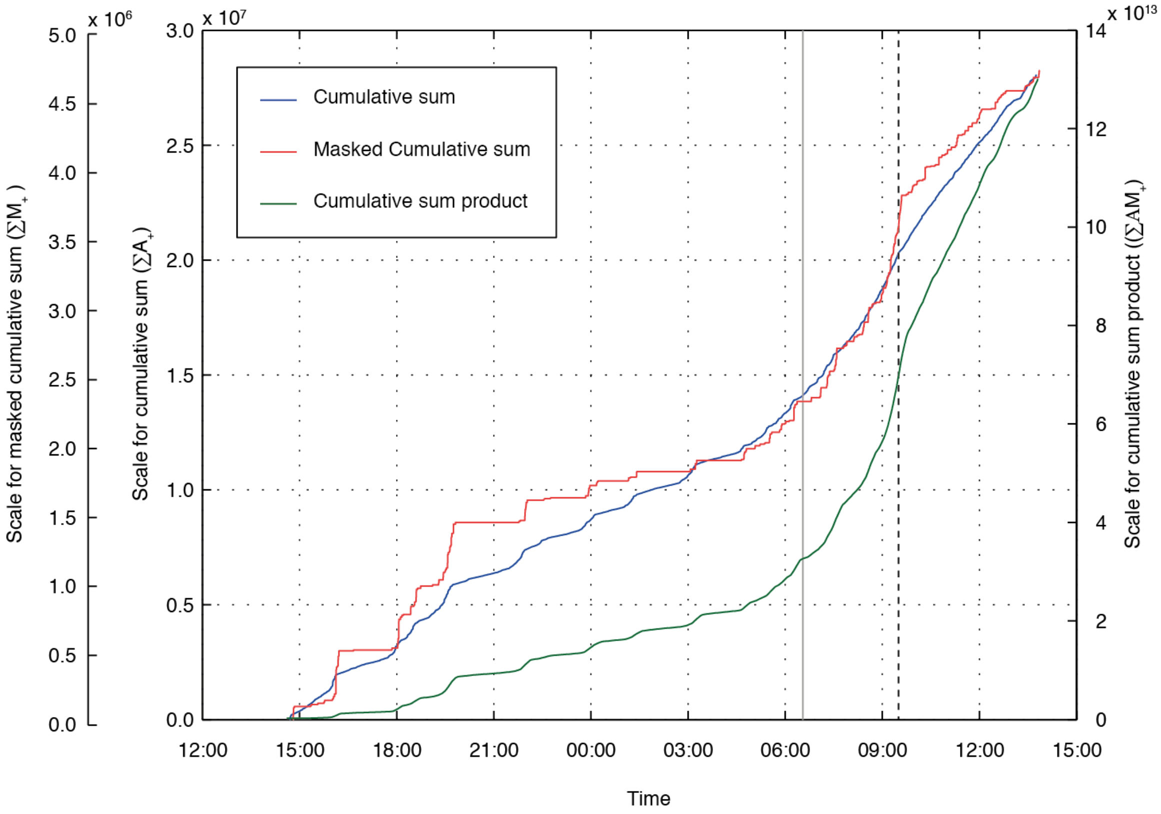

Figure 9: Cumulative sum, masked cumulative sum and the combined cumulative sum product metrics for Ewe 264. The solid grey vertical line is when the human observer detected parturition behaviour and the vertical dashed line is when the birth occurred.

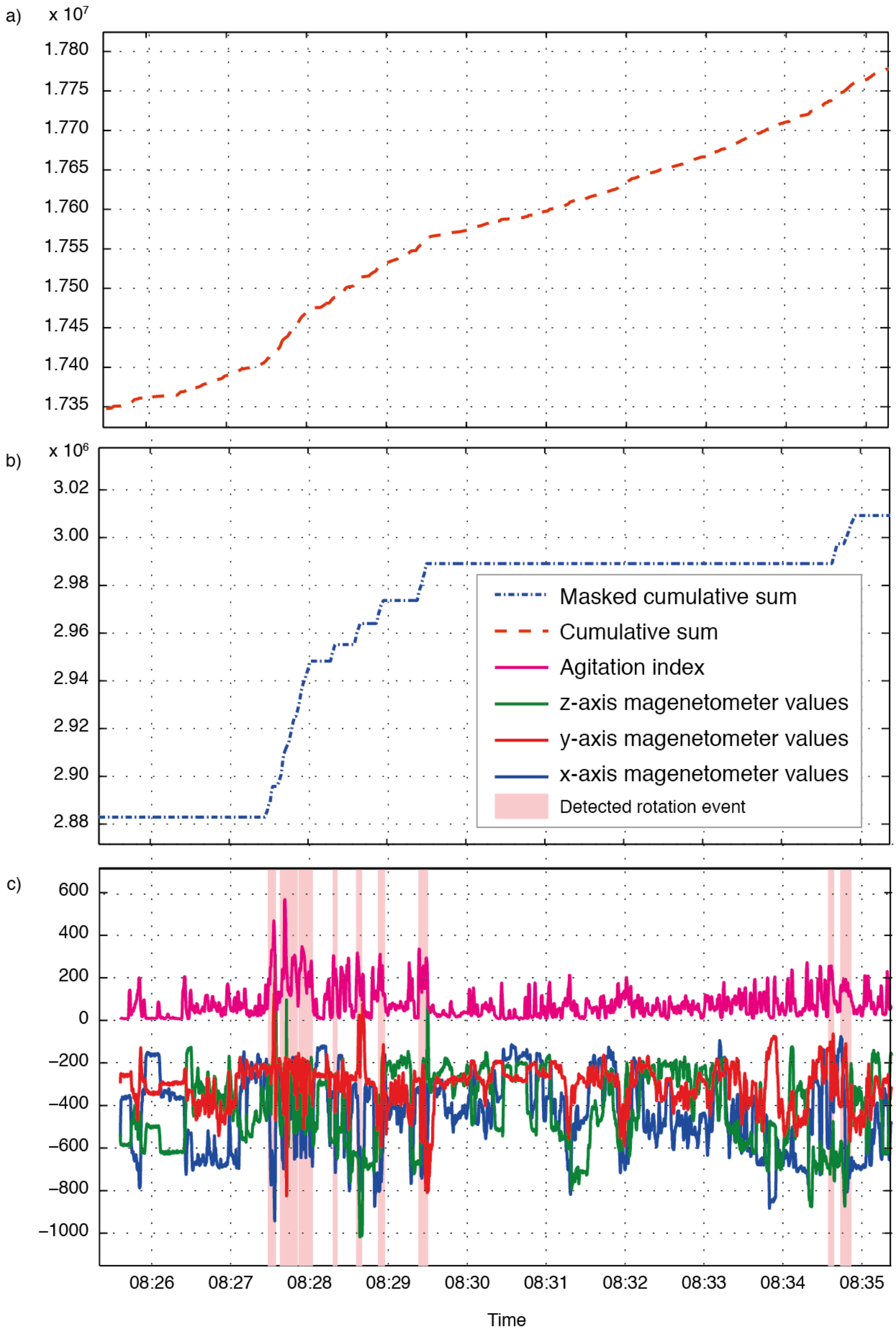

Figure 10: Plots showing the relationship between the agitation index, cumulative sum and the masked cumulative sum. Only the segments of the agitation index which corresponds to ‘detected’ rotation events (pink bars) contributes to the masked cumulative sum.

Figure 11 shows the response of the derivative of the combined metric $\sum AM_+$ for a number of ewes in the 20 hours leading up to birth (vertical dotted line normalised as the time of birth of first lamb, t=0). The * on each curve correspond to the time when the video was activated, which as previously stated, is when the supervising staff believed the ewe was showing the first signs of pre-imminent birth behaviour. It appears likely that prediction of the birth from the slope can be achieved; however, the challenge will be to keep false alarms to a minimum. This means that the point at which imminent birth is likely to be classified will be some way into the rising curve. Interestingly however, it is still likely to be well in advance of when the supervising staff noticed the pre-imminent birth behaviours. It should also be appreciated that any algorithm will have false positives (incorrectly classifying that birth is imminent) and ewe 149 in Figure 11 around 17:00hrs is one such instance where this is likely to occur. However, it should be remembered that humans also incorrectly classified pre-birth behaviours in a number of instances where it was noted that the animal was exhibiting such behaviours.

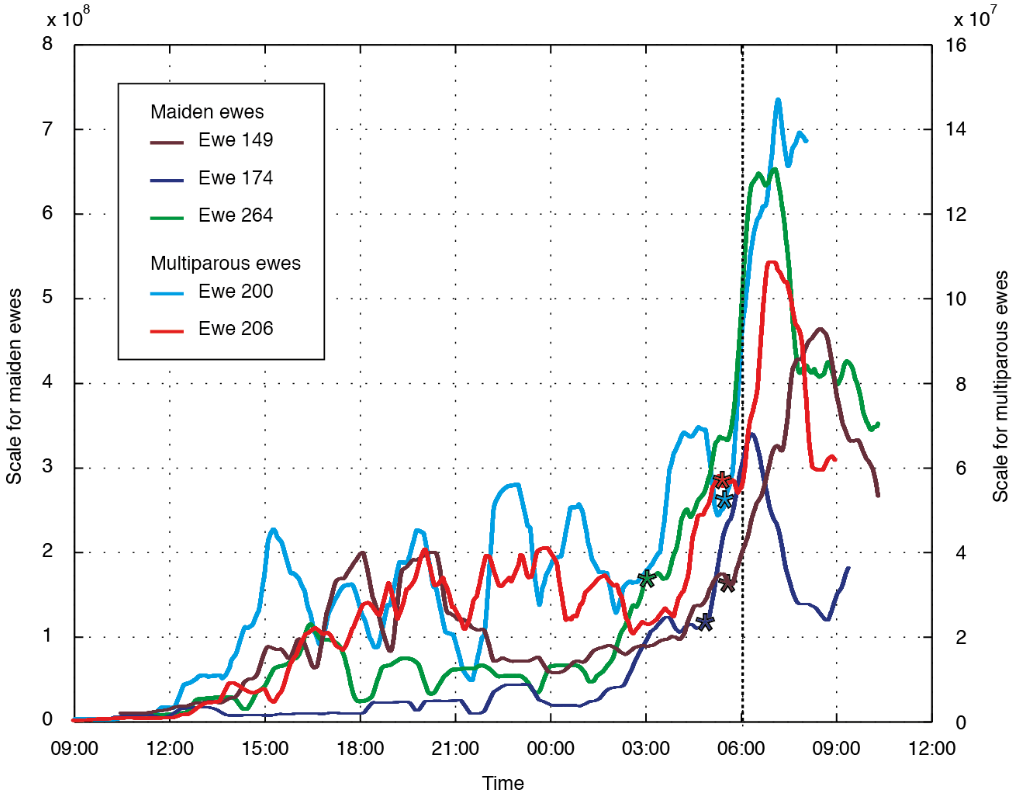

Figure 11: Plots of the first derivative of $\sum AM_+$ for five different ewes with all birth times artificially cued to 6.00am (vertical dotted line) to show the consistent trend in the curves. The * on each curve represents the video start time which indicates when a human observer noticed parturition behaviour. Two scales are used for maiden ewes and multiparous ewes.

Another interesting artefact of the combined metric was the variation in magnitude of the indices between maiden and multiparous ewes. Strikingly the magnitude of the maiden indices was fairly consistently around 10 times that of the multiparous counterparts. We hypothesise that maiden ewes experience more discomfort and agitation due to the novel experience of the birth process, while multiparous ewes are more physically and psychologically relaxed having previously experienced the birth process.

Further investigation and analysis will be necessary to devise a good predictor of when the birth is imminent and if the birth has occurred. However, since the algorithms designed in this investigation are based on simple mathematical operators performed on the raw magnetometer readings, we believe that achieving a prediction algorithm that can be performed in situ on the animal can be realised.

Time synchronisation between the video and the device data is necessary so that algorithms that use windows of data can be correctly trained. For our algorithms, we were interested in rotation events which could occur over a duration as short as 1 second, and therefore it is necessary to have the time synchronised to at least 1 second accuracy. Unfortunately, the deployed devices had been programmed to use the internal crystal to the microcontroller and not the more stable external crystal which was present. This caused significant clock drift (up to 20 seconds per hour) and since devices could be operational for over a week, the cumulative clock drift could be as much as an hour before the device was removed. The approximate start of the video recording was known due to the camera being pointed at the CCTV display which has a clock as part of its interface. Note however that the CCTV time will also have a clock drift offset, though probably less than a minute. The start time of the device (also known as the embedded PC time) is sent to the device to activate the initial recording of inertial data. Note that the embedded PC uses Network Time Protocol (NTP) to periodically synchronise it’s time to the internationally recognised time providers and so maintains UTC time to sub-second accuracy. A further complication was that the embedded PC had not corrected for daylight saving and so initial attempts to match inertial data with the video data were already offset by 1 hour.

Through visual inspection of the raw inertial data, it was obvious that there were periods of significant ‘stillness’ where the variation of all the individual magnetometer and accelerometer values was minimal for durations of up to several minutes. An algorithm to automatically detect these stillness periods was developed using the sum of the standard deviation over a sliding window. This was then thresholded (based on a manually chosen value which appeared to be universal to all datasets) to classify stillness on a per reading basis. The duration of each period of stillness was computed and the detection algorithm limited to events that were at least 20 seconds in duration. This process was applied to periods of data that approximately coincided with matching video (including half an hour before and after the approximate video recording times to account for the significant clock drift). Using the approximate times and durations of the detected stillness events, the videos were watched and the actual times (start and/or end) of the stillness event (in video offset) were recorded. Note that sharp transitions into stillness or out of stillness were deemed more useful due to the difficultly in pin pointing the first moment of movement within the video which in turn increases the error in the timestamp. For example, the end of the first stillness event (pink bar) in Figure 12 and the start of the second event are almost imperceptible in the video sequence, unlike the end of the second and third events which are clearly distinguishable in the video. A simple linear regression was then applied to the differences of the data timestamps to that of the video based times, thereby establishing a first order clock drift correction (offset and scale) which was subsequently applied to the data. This yielded synchronised (±1 second) inertial data across the video which is necessary in order to utilise the annotations for training a classifier.

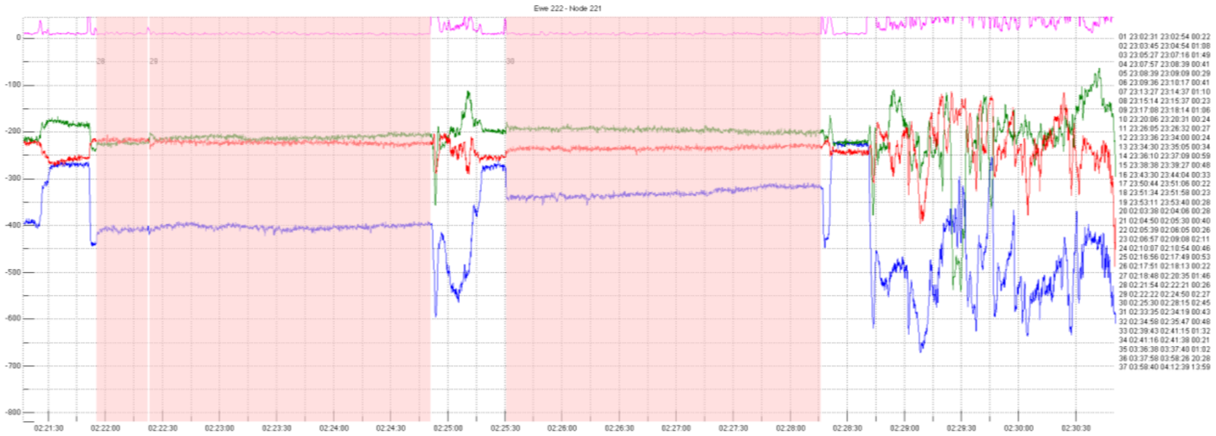

Figure 12: Three automatically classified stillness events. Green, blue and red traces are magnetometer data; pink bars indicate detected stillness events.

4.7 Summary of challenges encountered

Device deployment

- Ewes required a period of adjustment to halters. This was less than 3 hours, following which behaviour did not appear to be impacted by the presence of the device.
- Steel construction materials of the pens and shed hampered wireless communications.
- There were software issues with the device clock controller; and in communication between the various devices that made up the data transfer system.

Video surveillance

- There were challenges matching up the video timestamp with the node timestamp.
- Loss of video data occurred due to large power demands of video cameras, if the camera was not attached to mains power.
- The large amount of video data downloaded was difficult to store and share, with data files for baseline and birth videos often being over 20GB in file size.
- Manual annotation of video data is exceedingly time-consuming.

Animal behaviours

- There is an inherent difficulty in predicting commencement of parturition behaviour, despite 24-hour monitoring of ewes. Some animals do not display overt pre-parturition nest-building activities; some animals seem to demonstrate false pre-parturition behaviours (false alarms) for up to two weeks prior to birth.

- Behaviour in penned environment may not accurately mimic behaviour in the natural environment, and frequency of turning/circling events during the baseline periods is likely to be significantly different in the paddock.

5. Discussion

Assessments of lamb vigour scores (LVS) are suggested for use in genetic improvement programs (Brien et al 2009; Macfarlane et al 2010; Matheson et al 2010). LVS are based on subjective assessments of the lamb's response to restraint and its ability to vocalise and return to the ewe. The time taken for a lamb to progress through a set of critical neonatal behaviours (stand, seek udder, suckle) has also been measured and used as an indicator of lamb vigour (Owens et al 1985; Slee and Springbett 1986; Cloete 1993; Dwyer et al 2005). However, the assessment of these specific behaviours in the field is obviously very difficult and hence preference has been given to assessment of LVS which is deemed more practical and is typically performed during lamb tagging within the first 24 h of birth.

In the current study, neonatal behaviours were measured in the progeny of six Merino sires that varied in estimated breeding values (EBVs) for traits associated with lamb survival to weaning. Based on the combination of EBVs, three of these sires were selected as "high lamb vigour" sires, and three as "low lamb vigour" sires. Each lamb was subjected to restraint test at 3, 4, 8 and 12 hours post birth, and its 'latency to bleat' was assessed on release. In addition the times to stand and return to the ewe were measured at 4, 8 and 12 h.

Significant sire differences were only observed in the time to bleat after release at 3 and 4 h post-partum. The sire rankings at these two time points were similar and there was also some congruence with the sire EBVs for time to bleat based on the INF data. The INF heritability of time to bleat was quite low (0.05 ± 0.01) however, this trait was moderately genetically correlated with lamb survival to weaning (0.44 ± 0.23) (Brien et al 2011). Based on the current study, there is a suggestion the trait was heritable (at least in the top and lowest EBV sires) and the expression of the trait was repeatable early post-partum. The latter result is quite salient given that the 3 h and 4 h test conditions were slightly different. The lack of significant sire differences at the subsequent test times at 8 h and 12 h may be a function of several factors such as habituation to the test conditions or that the expression of the trait was overridden by other cognitive functions in the developing lamb. The timing of lamb vigour assessment is quite important. Movement away from the birth site is a critical period in early life, and this typically occurs at around 4 hours post birth. The lamb needs sufficient cognitive capacity to be able to respond to the ewe's behaviour and vocalisations. However, it is recognised that the ability to perform discriminatory cognitive functions develops over the first 24 hours of life or more, and a very young lamb may have difficulty (Nowak et al 1987; 1989; Lindsay et al 1990; Bickell et al 2009). Indeed, we observed in the current study that the lambs at the 4 hr test seemed 'bewildered' or 'confused', and more likely to be distracted by the foreign environment or any movement cue; whereas lambs at 8 and 12 hours were more able to identify the ewe and move towards her. Indeed, this was reflected in the faster times to travel to the ewe at 8 h compared with 4 h. There was some plateauing in these times between 8 and 12 h and this could be attributed to habituation to the test but also to the observation that at 12 h, the lambs demonstrated more exploratory behaviour of their immediate area before walking towards their dam.

If in fact we assume that time to bleat is a reflection of innate cognitive function in the neonate, then performing the test earlier post-partum may be preferable before learned or experiential factors influence its expression. Whether this assumption or an alternative hypothesis such as the expression of neonatal vocalisation may be a “hard-wired” survival behaviour is correct is worthy of further investigation. The evidence presented suggests that there may be benefits in performing lamb vigour assessments between 4 and 8 h of age.

The results also showed that there were differences in lamb morphometric measures between the AI cohorts. Despite the fact that the cohorts were managed contemporaneously post-AI, it is plausible this could be associated with forage composition or quality differences. As expected, single-born lambs were heavier and had higher rectal temperature at 3 hrs of age (after adjustment for birthweight) compared with twin lambs. Hergenhan (2011) also demonstrated that singletons had significantly higher basal temperatures compared with twin lambs and in response to a noradrenaline challenge, also displayed higher temperature responses suggestive of higher thermogenic capacity. In the immediate post-partum period, single lambs were slower to stand than twins, and also slower to bleat following restraint at 3 hrs of age. Males also were slower to bleat than females; and in the twin lambs, male twins were slower to suckle than female twins. It could be surmised that prolonged labour associated with large single lambs might affect their latency to stand and suckle, but parturition duration was, in this study, not significantly associated with delayed performance of early neonatal behaviours.

Sire effects on birthweight, girth and latency to bleat at 3 hours of age were also evident, but the association with ‘high vigour’ and ‘low vigour’ sires was not marked.

6. Conclusions

- Sire variation was evident in the Merino lamb bleat responses following restraint at 3 and 4 h post birth.

- The sire rankings were similar at 3 and 4 h post-birth and there was also some congruence with INF sire EBVs for time to bleat. The rankings were less consistent at 8 and 12 h post-birth. This would suggest the trait has some repeatability, particularly early post-partum. The biological basis for the associations between time to bleat, lamb vigour and ultimately survival are still unclear but worthy of further investigation.

- The bleat response of lambs can be a simple, practical test to assess lamb vigour in the field. It should be carried out after the ewe and lamb have moved away from the birth site, and preferably before the lamb is 12 hours old.

- We believe this to be the first attempt at developing algorithms to remotely predict birth events in pregnant merino ewes using WSN technology. Many challenges were encountered during the data collection phase of the experiment. These insights will aid development of future WSN technologies deployed on livestock.

7. Recommendations

7.1 Field testing protocols

Sire selection for improved lamb survival may be enhanced by use of a bleat response test in genetic improvement programs. Based on the preliminary results presented above, *t*he bleat test may prove to be a useful, easy to perform indicator of lamb vigour. It should be carried out after the ewe and lamb have moved away from the birth site, but within 12 hours of birth.

Further research needs to be conducted to determine repeatability of the test in a field situation, and to assess whether tagging procedures conducted before the test (as in the INF protocol) affect results and reliability of the test. The physiological basis of variation in latency to bleat should also be assessed in more detail.

7.2 Remote sensing technologies

Further work will be needed to develop this technology to a commercial product. In the first instance, work will be needed to validate and refine the classifier to suit field conditions. Later, commercialisation and extension activities will be needed.

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