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Pervasive Sensing and Behavior Tracking in Small Ruminants

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Pervasive sensing in small ruminant production is transforming livestock management by enabling continuous, automated monitoring of animal health, behavior and environmental conditions. Advanced technologies such as structural vibration sensing, radio frequency identification, computer vision, GPS tracking and wearable devices are increasingly integrated into production systems. These tools, which include both fixed (static) and mobile (animal-borne) sensing nodes, generate real-time data on climate, pasture status and animal-environment interactions. Behavioral tracking provides valuable insights into social structures, grazing activity and feeding behavior, all of which are influenced by environmental conditions and forage availability. When combined with Precision Livestock Farming (PLF) approaches powered by Artificial Intelligence (AI) and Machine Learning (ML), these systems enable early disease detection, accurate monitoring of parameters such as body weight and milk yield and targeted interventions to optimize resource use. Adoption is driven by the potential to improve animal welfare, health and safety; however, challenges remain. High installation costs, limited technical knowledge among farmers and variable adoption rates hinder widespread implementation. Addressing these barriers through education, capacity building and supportive policy frameworks is essential.

Introduction

Pervasive sensing in livestock production involves continuous, automated data collection using advanced technologies to monitor animal health, activity and environmental conditions. This approach integrates various sensing modalities, including structural vibration, radio frequency, computer vision and wearables, to enable real-time monitoring and early disease detection (Shulkin *et al*., 2025). Pervasive sensing systems can comprise static and animal-borne nodes to measure complex interactions between climate, soil, pasture and animals (Wark *et al*., 2007). Behavior tracking in small ruminants is crucial for understanding their welfare, social dynamics and grazing patterns. Sheep and goats exhibit various social behaviors through olfactory and vocal signals, which are essential for mother young relationships and sexual behavior (Flis and Molik, 2024). GPS tracking has revealed that these animals travel 6–9 km daily and stay within 0.6–1.1 km of water sources, with their movement patterns influenced by ambient temperature (Wade *et al*., 2024). Feeding behavior is affected by pasture structure, forage quality and animal selectivity, which varies with age (Silva and Filho, 2020).

Precision Livestock Farming (PLF) technologies offer promising solutions for monitoring and managing small ruminant welfare, addressing issues such as disease, nutrition, maternal behavior and environmental stressors (Morgan-Davies *et al*., 2024). These technologies can track body weight changes, behavioral patterns, milk yield, and environmental conditions, providing valuable insights for improved management and welfare of sheep and goats. Drivers and barriers for adoption of such technologies have been extensively studied. Key drivers include improved animal health, welfare and safety. However, barriers such as costs and lack of knowledge hinder widespread implementation (Buchan *et al.*, 2023). Improving animal welfare can contribute to sustainability and productivity, especially in low-productivity systems where welfare enhancements often lead to efficiency gains (Dwyer, 2020).

Role of Artificial Intelligence (AI) and advanced technologies is increasingly prominent in livestock systems. AI technologies are applied to enhance animal welfare, health monitoring and productivity across various species (Sztandarski *et al.*, 2025). They facilitate environmental monitoring, early disease detection, and behavioral analysis, optimizing production metrics and promoting better welfare practices. Despite these potential benefits, adoption rates of biosecurity measures remain low in some regions, highlighting the need for proactive engagement with farmers and supportive policies (Nyokabi *et al.*, 2023). Technological evolution in livestock monitoring has seen significant advancements, integrating intelligent systems, biosensors, and IoT devices to enhance productivity, welfare and sustainability. These technologies enable real-time monitoring of animal health, early disease detection and optimization of feeding efficiency (Vlaicu *et al.*, 2024). Biosensors offer specialized devices for measuring physiological, immunological, and behavioral parameters, contributing to improved disease management and reproductive cycle monitoring (Neethirajan *et al.*, 2017). IoT-based systems, coupled with machine learning algorithms, allow for continuous monitoring of various physiological parameters and behavioral patterns (Chaudhry *et al.*, 2020). The integration of PLF with AI and Machine Learning (ML) provides innovative methods for analyzing large datasets, addressing issues related to behavior, health, reproduction and production (Curti *et al.*, 2023). These advancements are driving the agricultural industry towards more efficient and sustainable farming practices.

Technologies for Pervasive Sensing

Wearable Sensors: Wearable sensors are transforming cattle monitoring within the framework of precision livestock farming. A range of devices such as GPS collars, ear tags, accelerometers and rumen boluses are now capable of providing real-time data on animal behavior and physiological status (Bailey *et al.*, 2017). These wearable wireless sensor systems (WWSS) have demonstrated strong performance in monitoring key activities such as eating, ruminating, lying and standing, although parameters like drinking time still require further refinement (Lee and Seo, 2021). The integration of GPS tracking with accelerometers has enabled researchers to analyze grazing patterns, identify genetic markers associated with spatial movement and detect potential health issues at an early stage. In parallel, rumen bolus sensors a rapidly advancing technology facilitate continuous measurement of physiological parameters, health status and estrus cycles (Vakulya *et al.*, 2024). Combining multiple sensor types and developing robust, online monitoring platforms are critical steps for enabling real-time cattle health management, early disease detection and improved animal welfare (Sharma, 2025).

Environmental Sensors: Proximal sensors present valuable opportunities for improving pasture quality assessment and livestock management across diverse ecosystems. Optical sensors are capable of evaluating vegetation characteristics such as pasture biomass and nutritive quality (Pullanagari *et al.*, 2011). In particular, multispectral and hyperspectral sensors have demonstrated strong potential for real-time pasture monitoring, showing high correlations between sensor-derived vegetation indices and field measurements of biomass and vegetation cover (Handcock *et al.*, 2016). In more complex environments, such as the Montado ecosystem, proximal sensors can be used to measure multiple variables including soil moisture, pasture biomass and feed nutritive value thereby supporting site-specific and adaptive management strategies (Serrano *et al.*, 2018). These technologies are especially relevant in precision farming systems, where they can aid in assessing grazing conditions, monitoring individual animal behavior and evaluating overall livestock health. While proximal sensing technologies offer significant advantages in terms of time efficiency and energy savings, they also present challenges related to measurement accuracy and data acquisition (Asmare, 2022). Nevertheless, these sensors provide an important set of tools for advancing livestock production efficiency and enhancing rangeland management.

Identification and Tracking: Ultra-wideband (UWB) technology is gaining attention as a promising advancement for next-generation RFID systems, offering enhanced localization accuracy, improved reliability and stronger security, all while maintaining low power consumption. UWB-RFID systems address key limitations of conventional narrow-bandwidth RFID, such as restricted coverage and insufficient ranging resolution (Dardari *et al.*, 2010). A notable development is the combination of UWB with UHF signals, which enables wake-up functionality for tags. This approach reduces energy consumption while ensuring compatibility with existing RFID infrastructures (D'Errico *et al.*, 2012). Such hybrid systems support high-accuracy indoor positioning and efficient asset tracking, making them highly suitable for Industry 4.0 environment. Looking ahead, UWB-RFID integration is expected to play a pivotal role in future Internet of Things (IoT) applications by enabling the precise detection and localization of tagged items using inexpensive, energy-autonomous and disposable tags (Dardari *et al.*, 2016). However, widespread adoption still faces challenges, particularly in developing low-cost, reliable solutions that can be feasibly implemented by small and medium-sized enterprises (Frankó *et al.*, 2020).

Behavior Tracking Parameters

Activity Monitoring: Recent research has advanced automated techniques for tracking behavior in small ruminants, with particular emphasis on grazing and rumination activities. Accelerometer-based sensors, mounted on collars, legs, or ears, have proven effective in classifying behaviors such as grazing, standing and walking with high accuracy (Barwick *et al.*, 2018). The RumiWatchSystem has shown reliable performance for measuring grazing behavior, rumination and general activity in pasture-based systems (Werner *et al.*, 2017). In addition, machine learning algorithms notably the Random Forest classifier have demonstrated strong capabilities in accurately identifying behavioral patterns using features derived from accelerometer and gyroscope data (Mansbridge *et al.*, 2018). Beyond movement tracking, energy expenditure during grazing can be estimated through heart rate monitoring, with measurable variations reported between different goat breeds and sheep (Beker *et al.*, 2010). Collectively, these technologies support continuous and automated behavior monitoring in small ruminants, offering significant potential to enhance the management of animal health, productivity and welfare.

Feeding and Drinking Behavior: Research on feeding and drinking behavior in small ruminants provides valuable insights for improving their management and welfare. In sheep, water intake patterns follow a distinct circadian rhythm, with an average of 2.4 visits to water troughs per day and peak drinking occurring between 8:00–10:00 AM (Abecia *et al.*, 2024). In feedlot environments, newly received calves display variable eating and drinking patterns; while eating duration tends to decrease over time, the frequency of feeding events remains relatively stable (Buhman *et al.*, 2000). Comparative studies indicate that goats generally spend more time eating than sheep, whereas sheep exhibit longer rumination periods (Khaskheli *et al.*, 2020). Feed conservation methods can also influence intake and water consumption animals fed fermented maniçoba consume less water compared to those provided with hay (Souza *et al.*, 2010). Furthermore, extensive feeding systems are often more beneficial for both sheep and goats, as they align with the animals' natural grazing behavior.

Social and Reproductive Behavior: Maternal behavior in small ruminants, particularly sheep and goats, is defined by the formation of a selective bond between the mother and her offspring during the early postpartum period. This behavior is influenced by both hormonal and sensory mechanisms, notably elevated estradiol concentrations and vaginocervical stimulation around parturition. Olfactory cues from the newborn are critical for sustaining maternal responsiveness and ensuring offspring recognition (Hernández *et al.*, 2011). Experimental studies have shown that hormonal treatments—such as progesterone and estradiol when combined with vaginocervical stimulation, can successfully induce maternal behavior in ewes and reduce behavioral signs of social isolation (Soto *et al.*, 2021). The underlying neural circuitry and neurotransmitter systems associated with maternal behavior and selective olfactory recognition of offspring have been well documented in sheep (Kendrick *et al.*, 1997). In addition to behavioral induction, several hormonal protocols have been developed to regulate reproduction in small ruminants. These include the administration of progesterone, prostaglandins and melatonin, which facilitate improved control of breeding cycles and enable more efficient artificial insemination management (Abecia *et al*., 2012).

Health and Welfare Indicators: Recent research has increasingly focused on identifying and developing indicators for assessing welfare in small ruminants, particularly sheep and goats. Key animal-based welfare indicators include lameness, body condition score, qualitative behavior assessment and human–animal relationship tests (Adrian Minnig *et al.*, 2021). In addition to these, positive welfare indicators such as the synchronization of lying and feeding behaviors have been recognized as valuable measures of good welfare states (S. Mattiello *et al.*, 2019). Major welfare challenges in small ruminant systems are often associated with disease, nutritional deficiencies and environmental stressors. The adoption of Precision Livestock Farming (PLF) technologies offers promising opportunities for monitoring these welfare indicators in real time, enabling early detection of problems and more targeted interventions (C. Morgan-Davies *et al*., 2024). On-farm welfare assessment should integrate multiple factors, including housing conditions, human–animal interactions, animal health status and overall management practices. However, further research is required to validate certain indicators particularly in the domains of nutrition and health and to develop comprehensive, standardized welfare assessment frameworks tailored for small ruminants (M. Caroprese *et al*., 2009).

Challenges and Limitations

Precision Livestock Farming (PLF) in small ruminants faces distinct challenges in extensive farming systems, where factors such as high animal mobility, harsh environmental conditions and limited energy availability can hinder technology deployment (Llaria *et al*., 2024). Despite these constraints, PLF presents significant opportunities for improving animal welfare, health and productivity (Caja *et al*., 2020). Key welfare concerns addressed through PLF include disease prevention, nutritional management, maternal behavior monitoring and mitigation of environmental stressors (Morgan-Davies *et al*., 2024). Among available tools, accelerometer-based sensors have shown particular promise for tracking livestock behavior. Their application generally follows a three-step methodology: (1) data collection, (2) data pre-processing and (3) model development. However, challenges remain in accurately predicting rare or transitional behaviors and ensuring that models are generalizable across different environments and animal populations. To overcome these issues, researchers emphasize the importance of maximizing data variability, selecting appropriate pre-processing techniques and employing classifiers that minimize overfitting (Riaboff *et al*., 2022). As PLF technologies continue to advance, their role in enhancing the efficiency and sustainability of small ruminant production systems is expected to grow substantially.

Conclusion

Pervasive sensing and behavior tracking in small ruminants signify a major advancement in modern livestock management, enabling continuous and real-time assessment of animal health, welfare and productivity. By integrating diverse sensing technologies including GPS tracking, computer vision, biosensors and Internet of Things (IoT) platforms farmers can obtain detailed insights into the behavioral ecology, feeding patterns and environmental interactions of sheep and goats. Within the framework of Precision Livestock Farming (PLF), these technologies, when combined with Artificial Intelligence (AI) and Machine Learning (ML), enable early disease detection, targeted management interventions and optimized use of resources. Such capabilities not only enhance production efficiency but also promote higher standards of animal welfare. Despite these benefits, adoption is often hindered by significant challenges, including high implementation costs, limited technical knowledge among farmers and uneven uptake across regions. Addressing these barriers requires coordinated efforts in farmer education, capacity building and the development of supportive policy frameworks to encourage widespread utilization.

References

1. Abecia, J. A., Erden, P. and Canto, F. (2024). Using proximity loggers in studies of sheep behavior: an estimation of the daily frequency of water consumption. *Animal Biotelemetry*. ***12***(1): 19.
2. Abecia, J. A., Forcada, F. and González-Bulnes, A. (2012). Hormonal control of reproduction in small ruminants. *Animal reproduction science*. ***130***(3-4): 173-179.
3. Asmare, B. (2022). A review of sensor technologies applicable for domestic livestock production and health management. *Advances in Agriculture*. ***2022***(1): 1599190.
4. Bailey, D. W., Trotter, M. G., Knight, C. W. and Thomas, M. G. (2018). Use of GPS tracking collars and accelerometers for rangeland livestock production research. *Translational Animal Science*. ***2***(1): 81-88.
5. Barwick, J., Lamb, D. W., Dobos, R., Welch, M. and Trotter, M. (2018). Categorising sheep activity using a tri-axial accelerometer. *Computers and Electronics in Agriculture*. *145*: 289-297.
6. Beker, A., Gipson, T. A., Puchala, R., Askar, A. R., Tesfai, K., Detweiler, G. D. and Goetsch, A. L. (2010). Energy expenditure and activity of different types of small ruminants grazing varying pastures in the summer. *Journal of Applied Animal Research*. ***37***(1): 1-14.
7. Buchan, M. S., Lhermie, G., Mijar, S., Pajor, E. and Orsel, K. (2023). Individual drivers and barriers to adoption of disease control and welfare practices in dairy and beef cattle production: a scoping review. *Frontiers in Veterinary Science*. *10*: 1104754.
8. Buhman, M. J., Perino, L. J., Galyean, M. L. and Swingle, R. S. (2000). Eating and drinking behaviors of newly received feedlot calves. *The Professional Animal Scientist*. ***16***(4): 241-246.
9. Caja, G., Castro-Costa, A., Salama, A. A., Oliver, J., Baratta, M., Ferrer, C. and Knight, C. H. (2020). Sensing solutions for improving the performance, health and wellbeing of small ruminants. *Journal of Dairy Research*. *87*(S1): 34-46.
10. Caroprese, M., Casamassima, D., Pier Giacomo Rassu, S., Napolitano, F. and Sevi, A. (2009). Monitoring the on-farm welfare of sheep and goats. *Italian Journal of Animal Science*. ***8***(sup1): 343-354.
11. Chaudhry, A. A., Mumtaz, R., Zaidi, S. M. H., Tahir, M. A. and School, S. H. M. (2020, December). Internet of Things (IoT) and machine learning (ML) enabled livestock monitoring. In *2020 IEEE 17th international conference on smart communities: improving quality of life using ICT, IoT and AI (HONET)* (151-155). IEEE.
12. Curti, P. D. F., Selli, A., Pinto, D. L., Merlos-Ruiz, A., Balieiro, J. C. D. C. and Ventura, R. V. (2023). Applications of livestock monitoring devices and machine learning algorithms in animal production and reproduction: an overview. *Animal reproduction*. ***20***(2): e20230077.
13. Dardari, D., Decarli, N., Guerra, A. and Guidi, F. (2016, May). The future of ultra-wideband localization in RFID. In *2016 IEEE International Conference on RFID (RFID)* (1-7). IEEE.
14. Dardari, D., d'Errico, R., Roblin, C., Sibille, A. and Win, M. Z. (2010). Ultrawide bandwidth RFID: The next generation?. *Proceedings of the IEEE*. ***98***(9): 1570-1582.
15. d'Errico, R., Bottazzi, M., Natali, F., Savioli, E., Bartoletti, S., Conti, A. and Sibille, A. (2012, November). An UWB-UHF semi-passive RFID system for localization and tracking applications. In *2012 IEEE International Conference on RFID-Technologies and Applications (RFID-TA)* (18-23). IEEE.
16. Dias-Silva, T. P. and Abdalla Filho, A. L. (2020). Sheep and goat feeding behavior profile in grazing systems. *Acta Scientiarum. Animal Sciences*. **43**: e51265.

17. Dwyer, C. M. (2020). Can improving animal welfare contribute to sustainability and productivity?. *Black Sea Journal of Agriculture*. **3**(1): 61-65.
18. Flis, Z. and Molik, E. (2024). Characteristics of selected behavioural patterns in sheep and goats. *Animal Science and Genetics*. **20**(3).
19. Frankó, A., Vida, G. and Varga, P. (2020). Reliable identification schemes for asset and production tracking in industry 4.0. *Sensors*. ***20***(13): 3709.
20. Handcock, R. N., Gobbett, D. L., González, L. A., Bishop-Hurley, G. J. and McGavin, S. L. (2016). A pilot project combining multispectral proximal sensors and digital cameras for monitoring tropical pastures. *Biogeosciences*. ***13***(16): 4673-4695.
21. Kendrick, K. M., Da Costa, A. P., Broad, K. D., Ohkura, S., Guevara, R., Lévy, F. and Keverne, E. B. (1997). Neural control of maternal behaviour and olfactory recognition of offspring. *Brain research bulletin*. ***44***(4): 383-395.
22. Khaskheli, A. A., Khaskheli, M. I., Khaskheli, A. J. and Khaskheli, A. A. (2020). Significance of feeding practices for small ruminants: A reveiw. *Agricultural Reviews*. *41*(3): 285-290.
23. Lee, M. and Seo, S. (2021). Wearable wireless biosensor technology for monitoring cattle: A review. *Animals*. ***11***(10): 2779.
24. Llaria, A., Menassol, J. B., Terrasson, G., Jouven, M. and Rezzouki, M. (2024, July). Embedded systems for small ruminants behavior identification: Application to pastoral farms in mountain and mediterranean areas. In *2024 IEEE Sensors Applications Symposium (SAS)* (1-6).
25. Mansbridge, N., Mitsch, J., Bollard, N., Ellis, K., Miguel-Pacheco, G. G., Dottorini, T. and Kaler, J. (2018). Feature selection and comparison of machine learning algorithms in classification of grazing and rumination behaviour in sheep. *Sensors*. ***18***(10): 3532.
26. Mattiello, S., Battini, M., De Rosa, G., Napolitano, F. and Dwyer, C. (2019). How can we assess positive welfare in ruminants? *Animals*. ***9***(10): 758.
27. Minnig, A., Zufferey, R., Thomann, B., Zwygart, S., Keil, N., Schüpbach-Regula, G. and Zanolari, P. (2021). Animal-based indicators for on-farm welfare assessment in goats. *Animals*. ***11***(11): 3138.
28. Morgan-Davies, C., Tesnière, G., Gautier, J. M., Jørgensen, G. H. M., González-García, E., Patsios, S. I. and Dwyer, C. M. (2024). Exploring the use of precision livestock farming for small ruminant welfare management. *Animal*. **18**: 101233.
29. Morgan-Davies, C., Tesnière, G., Gautier, J. M., Jørgensen, G. H. M., González-García, E., Patsios, S. I. and Dwyer, C. M. (2024). Exploring the use of precision livestock farming for small ruminant welfare management. *Animal*. *18*: 101233.
30. Morgan-Davies, C., Tesnière, G., Gautier, J. M., Jørgensen, G. H. M., González-García, E., Patsios, S. I. and Dwyer, C. M. (2024). Exploring the use of precision livestock farming for small ruminant welfare management. *Animal*. *18*: 101233.
31. Neethirajan, S., Tuteja, S. K., Huang, S. T. and Kelton, D. (2017). Recent advancement in biosensors technology for animal and livestock health management. *Biosensors and Bioelectronics*. *98*: 398-407.
32. Nyokabi, N. S., Berg, S., Mihret, A., Almaw, G., Worku, G. G., Lindahl, J. F. and Moore, H. L. (2023). Adoption of biosecurity practices in smallholder dairy farms in Ethiopia. *Transboundary and Emerging Diseases*. ***2023***(1): 2277409.
33. Poindron, P., RamÃrez-Vera, S., Vielma, J., Duarte, G., Fitz-RodrÃguez, G., Retana-MÃ, S., ... & SerafÃn, N. (2011). SENSORIAL AND PHYSIOLOGICAL CONTROL OF MATERNAL BEHAVIOR IN SMALL RUMINANTS: SHEEP AND GOATS. *Tropical and Subtropical Agroecosystems*. ***15***(S1):
34. Pullanagari, R. R., Yule, I., King, W., Dalley, D. and Dynes, R. (2011). The use of optical sensors to estimate pasture quality. *International Journal on Smart Sensing and Intelligent Systems*. ***4***(1): 125-137.
35. Riaboff, L., Shalloo, L., Smeaton, A. F., Couvreur, S., Madouasse, A. and Keane, M. T. (2022). Predicting livestock behaviour using accelerometers: A systematic review of

processing techniques for ruminant behaviour prediction from raw accelerometer data. *Computers and Electronics in Agriculture*. *192*: 106610.
36. Serrano, J., Shahidian, S., Marques da Silva, J. and De Carvalho, M. (2018). A holistic approach to the evaluation of the montado ecosystem using proximal sensors. *Sensors*. ***18***(2): 570.
37. Sharma, R. (2025). Wearable biosensors: an aid for cattle well-being. *Sensor Review*.
38. Shulkin, J. D., Vibhatasilpin, A. and Adhana, V. (2025). Pervasive Sensing for Livestock Health and Activity Monitoring: Current Methods and Techniques. *arXiv preprint arXiv:2503.15674*.
39. Soto, R., Terrazas, A., Poindron, P. and González-Mariscal, G. (2021). Regulation of maternal behavior, social isolation responses, and postpartum estrus by steroid hormones and vaginocervical stimulation in sheep. *Hormones and Behavior*. *136*: 105061.
40. Souza, E., Guim, A., Batista, Â., Albuquerque, D., Monteiro, C., Zumba, E. and Torres, T. (2010). Comportamento ingestivo e ingestão de água em caprinos e ovinos alimentados com feno e silagem de Maniçoba. *Revista Brasileira de Saúde e Produção Animal*. ***11***(4).
41. Sztandarski, P., Marchewka, J., Jaszczyk, A., Solka, M., Michnowska, H., Pogorzelski, G. and Horbańczuk, J. O. (2025). Scientific literature on AI technologies to enhance animal welfare, health and productivity. *Animal Science Papers and Reports*. **43**(2).
42. Vakulya, G., Hajnal, É., Udvardy, P. and Simon, G. (2024). In-depth development of a versatile rumen bolus sensor for dairy cattle. *Sensors (Basel, Switzerland)*. ***24***(21): 6976.
43. Vlaicu, P. A., Gras, M. A., Untea, A. E., Lefter, N. A. and Rotar, M. C. (2024). Advancing livestock technology: intelligent systemization for enhanced productivity, welfare, and sustainability. *AgriEngineering*. ***6***(2): 1479-1496.
44. Wade, C., Trotter, M., Chang, A., Steele, C., Prihodko, L. and Bailey, D. W. (2024). Use of Global Positioning System Tracking to Assess Landscape Distribution in Extensive Small Ruminant Operations☆. *Rangeland Ecology and Management*. **94**(1): 29-37.
45. Wark, T., Corke, P., Sikka, P., Klingbeil, L., Guo, Y., Crossman, C. and Bishop-Hurley, G. (2007). Transforming agriculture through pervasive wireless sensor networks. *IEEE Pervasive Computing*. ***6***(2): 50-57.
46. Werner, J., Leso, L., Umstatter, C., Niederhauser, J., Kennedy, E., Geoghegan, A. and O'Brien, B. (2018). Evaluation of the RumiWatchSystem for measuring grazing behaviour of cows. *Journal of neuroscience methods*. *300*: 138-146.