Livestock and Virtual Fencing: Foundations of Conditioning for Animal Welfare

Authors: B. Mayer, A. Dalke, A. Antaya, J. Beard, S. Noelle & A. Lien

Virtual Fencing

In Arizona and other western states, ranchers and land managers rely on thousands of miles of permanent wire fencing to manage livestock on extensive rangelands (Hayter 1939). This type of fencing has led to improved rangeland conditions in many places by aiding in the application of grazing systems. However, wire fencing can fragment landscape connectivity, pose a risk to wildlife, is a major financial investment, and provides little to no flexibility to rapidly change pasture size, manipulate grazing distribution, or avoid areas of high use or sensitive habitat within a pasture (Holecheck et al. 2011; Jakes et al. 2018). As a result, there are constraints on the use of permanent fences as a tool for managing riparian health, post-fire vegetation recovery, or improving livestock distribution. Virtual fencing (VF) is an emerging precision livestock management technology used to address these limitations and increase management flexibility and adaptive capacity to respond to changing environmental conditions as part of a larger grazing management system (di Virgilio et al. 2018; Lima et al. 2018; Trotter 2010). As a management tool, VF uses invisible barriers, established by global positioning system (GPS) coordinates, that influence livestock movement with a combination of auditory and electrical cues. Primary elements are shown in Figure 1 and include: (1) a software interface to draw virtual fence lines and the boundary zone on a digital map, which defines the allowable grazing area and exclusion zone; (2) GPS-enabled collars fitted around the circumference of an animals' neck that contain technology to track livestock movement and deliver auditory and electrical cues to influence livestock distribution; and (3) base stations and/or cellular towers to transmit and receive communication between the software and collars (for more information see Rangelands Gateway: https://rangelandsgateway.org/virtual-fence). Virtual fencing relies on livestock successfully recognizing an association between two cues originating from collars when the animal enters a boundary zone: an auditory cue, or beeping sound, and an electrical cue, or a slight electrical pulse. Recognition of these cues is learned through training with classical conditioning and negative enforcement. After training, livestock should respond to the auditory cue by changing direction away from the exclusion zone (Figure 1). If the association between cues is continuous, predictable, and controllable, a collar can influence livestock movement. Understanding how livestock recognize and interpret this association can limit potential risks for animal health and welfare.

Virtual Fencing Glossary

virtual fence: a line drawn on a digital map.
boundary zone: a defined amount of space that extends from where the virtual fence is drawn on the map and acts as a buffer to alert livestock when they are approaching a virtual fence.
allowable grazing area: the area enclosed by the virtual fence available for livestock grazing.
exclusion zone: the area outside the virtual fence line where animals should not enter.
auditory cue: beeping sound originating from collars.
electrical cue: slight electrical pulse originating from collars.
classical conditioning: an involuntary learning process where a novel stimulus is paired with a naturally occurring response and, over time, the novel stimulus can independently trigger the response.
negative reinforcement: a learning process where an unpleasant stimulus is removed to increase the likelihood of a desired behavior.

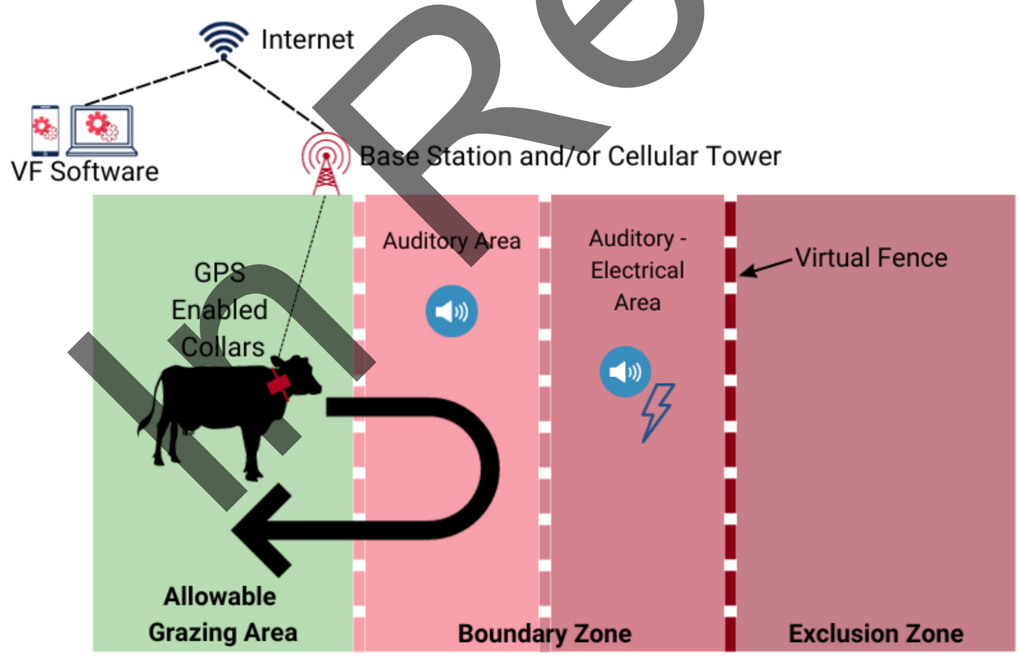

Figure 1: Conceptual model of virtual fencing (VF) components and livestock behavior in response to the auditory cue after training.

Training with Classical Conditioning

A VF system is designed to influence livestock movement with a combination of auditory and electrical cues. This influence starts by building an association between cues using classical conditioning. Classical conditioning is an involuntary learning process where a novel stimulus is paired with a naturally occurring response and, over time, the novel stimulus can independently trigger the response (Domjan 2014). For example, in Pavlov's dog training, a novel stimulus (ringing bell) was introduced with food, which naturally caused the dog to salivate, and, with repeated exposure, the dog involuntarily salivated to the ringing bell alone (Figure 2a). In VF classical conditioning, when an animal enters the boundary zone, the unfamiliar auditory cue (beeping sound) is introduced prior to the electrical cue (slight electrical pulse), which results in the animal naturally moving away from the location where the electrical cue was received (Figure 2b). With repeated exposure to this combination, livestock will involuntarily change directions and avoid the boundary zone in response to the auditory cue alone. After training, the association between auditory and electrical cues is predictable to livestock. Training with classical conditioning allows livestock to develop strategies to avoid and control whether they receive an electrical cue. The learned association can be used to influence livestock movement and is the cornerstone of virtual fencing.

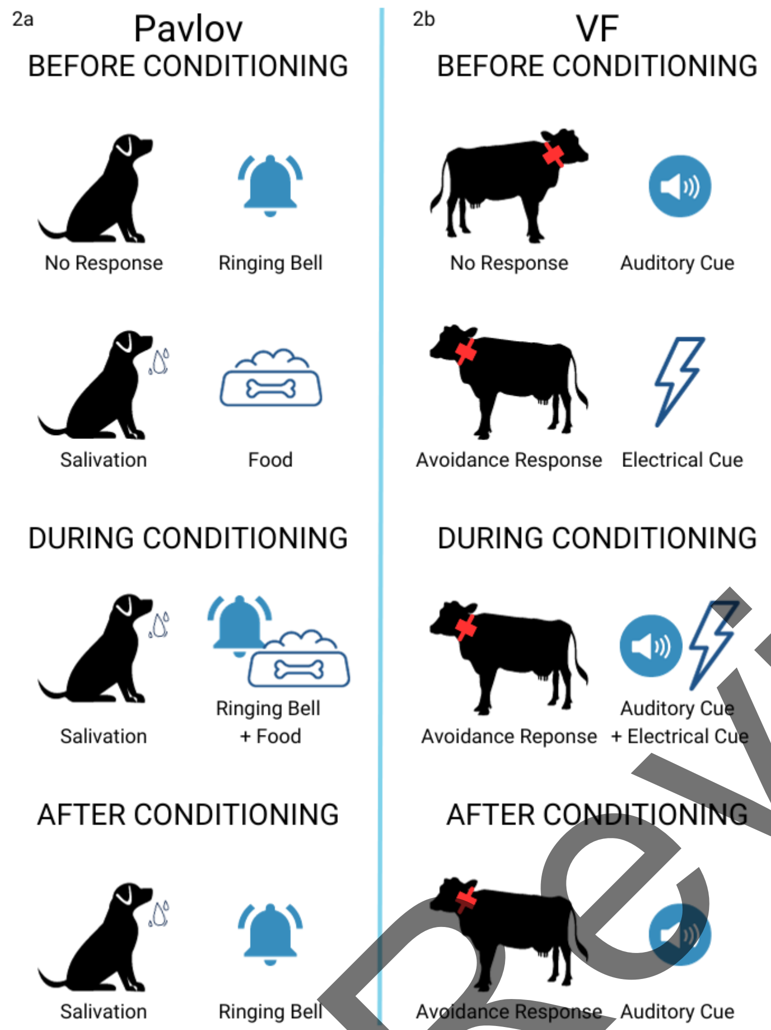

Figure 2: Classical conditioning in (a) Pavlov's dog experiment and (b) a VF system.

Modifications and Maintenance with Negative Reinforcement

Classical conditioning informs livestock that an electrical cue is imminent after an auditory cue is heard, triggering an avoidance response. Once this relationship is established, a VF system primarily uses negative reinforcement to maintain and modify this response. Negative reinforcement aids learning by removing an unpleasant stimulus when a desired behavior occurs, which ultimately increases the likelihood of a desired behavior in the future (Domjan 2014). For example, a horse learns to turn towards the direction that reins are pulled to relieve the uncomfortable pressure created by the tugging. In a VF system, the removal of the unpleasant auditory cue, associated with electrical cue, indicates livestock have successfully performed the desired avoidance behavior and returned to the allowable grazing area (Figure 3). During training, every interaction with the virtual fence should result in the desired behavior (returning to the allowable grazing area). For this reason, during training virtual fences are ideally placed along physical fence lines. Introducing virtual fences with physical fences limits an animal's ability to move through the boundary zone after receiving an auditory cue. Repeated exposure to negative reinforcement helps livestock learn the desired avoidance behavior in response to sound alone. Training with physical fences builds a foundation for the desired behavior to occur once the physical fence is removed, as it maximizes virtual fence compliance, or the amount of time an animal stays within the allowable grazing area.

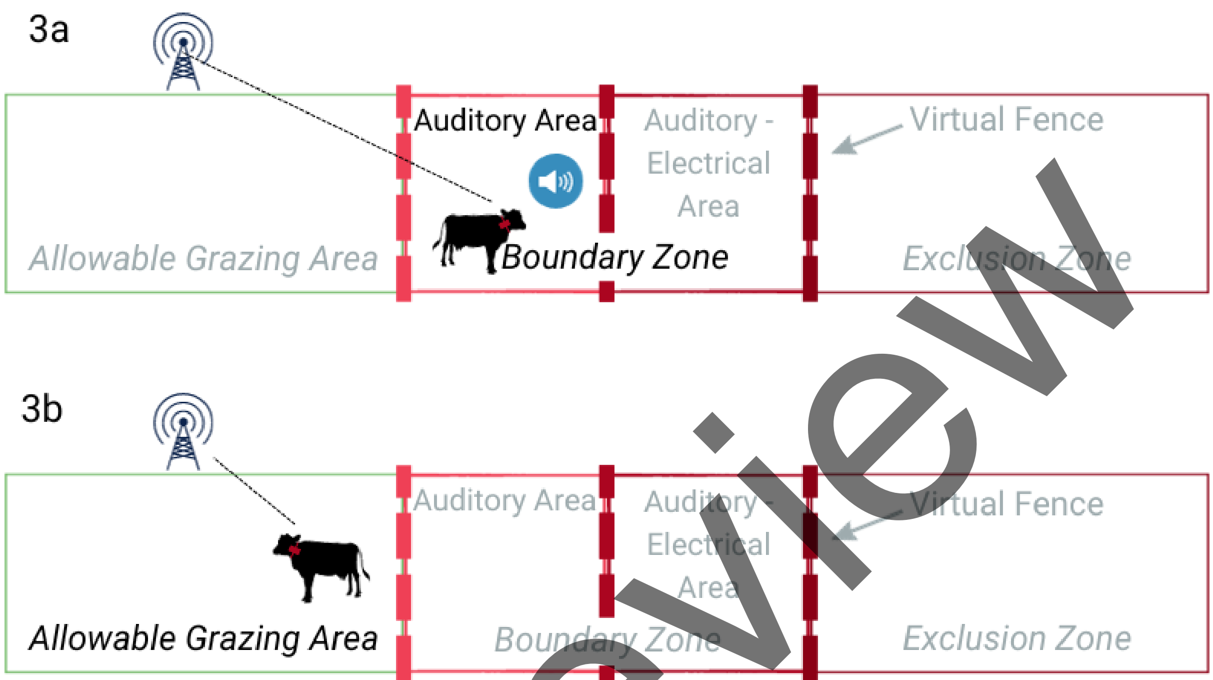

Figure 3: Conceptual model of negative reinforcement in a VF system where (a) the auditory cue, associated with electrical cue, is heard in the boundary zone triggering livestock to change directions and (b) the removal of auditory cue indicates a successful avoidance behavior.

Animal Welfare Considerations

In a VF system, classical conditioning and negative reinforcement shape how livestock recognize a virtual fence line, respond, and move across a landscape. After successful training, the auditory cue is the only information that livestock have to identify and avoid an electrical cue. Predictability between cues is vital for livestock to maintain the auditory cue as a reliable indicator of an impending electrical cue. In some situations, the electrical cue can be disabled manually or as part of a safety protocol. If disabled for an extended period, predictability is reduced because animals do not encounter electrical cues when they otherwise would have expected too based on conditioning. Without being able to predict that the auditory cue is followed ban an electrical cue, livestock may forget to avoid the electrical cue and stop listening for the sound all together. In this situation, the system is not able to control livestock movement.

When the association between cues and behavior is predictable and continuous, livestock can control or influence the results of their actions (i.e., controllability). An animal may understand the association between auditory cue and the impending electrical cue, but without the ability to locate the allowable grazing area and escape the boundary zone, the animal has no control over its response. Without controllability, livestock may be unable to locate the allowable grazing area and are more likely to attempt unpredictable movements to escape the boundary zone (e.g., enter the exclusion zone). Animals could also endure the electrical cue rather than escaping it. If this occurs over an extended period, animals may develop learned helplessness, a condition where an animal perceives no relationship between their behavior and receiving an electrical cue (Moberg 1985; Domjan 2014). Learned helplessness is more likely to occur when virtual fences are complex (e.g., sharp angles/corners or overlapping fences). With complex fence designs, livestock struggle to avoid or escape auditory or electric cues in the boundary zone (Figure 4). Virtual fences should be designed with wider angles (>90 degrees) to lessen the likelihood of repeated cues, which may cause chronic stress and have long term consequences for production and animal welfare.

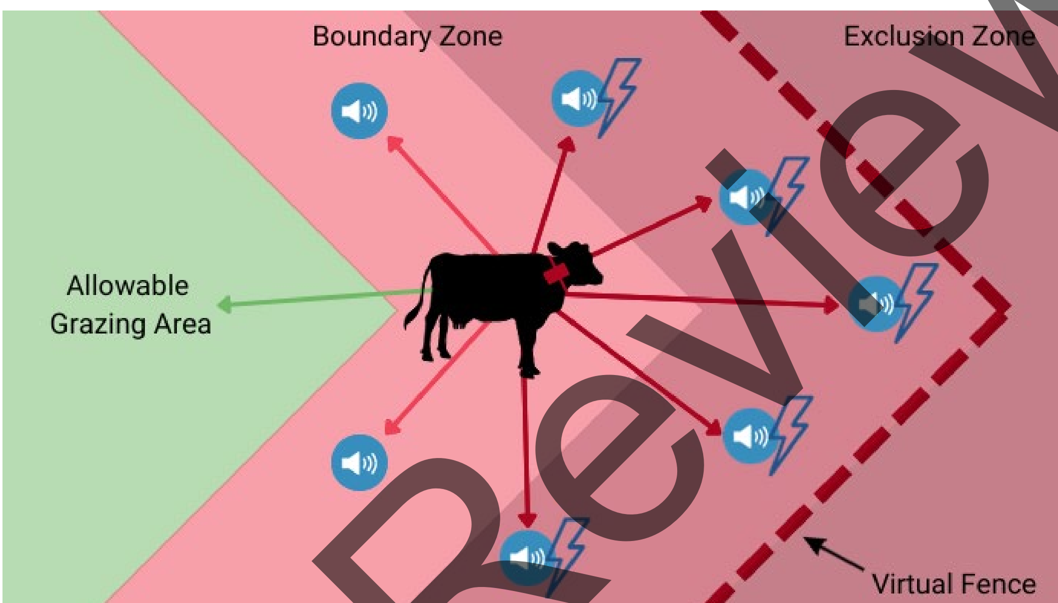

Figure 4: Conceptual model of complex virtual fence design where animals may have difficulty avoiding or escaping cues.

The electrical cue has been the major concern for animal welfare (Campbell et al. 2019). However, it is likely that this is only an acute livestock stressor, or short-term stress response. Short-term stress is common (e.g., minor injuries, interactions with unfamiliar animals or people) and has limited long term consequences as animals are able to cope or return to normal levels of stress on their own (Lee et al. 2018). The greatest hazard in a VF system may be related to possible chronic stress, which could occur when an animal is unable to successfully navigate a boundary zone. Stress responses are more likely to occur if the association between the auditory and electrical cues breaks down or if fences are overly complex. Chronic stress occurs when an animal is unable to cope with the new stress load and cannot return to their normal stress level (Seyle 1976; Moberg 1985). Chronic stress affects livestock operations by negatively impacting livestock health (Moberg 1985; Chen et al. 2015; Brown and Vosloo 2017), weight gain (Cooke 2014; Fernandez-Novo et al. 2020), and reproduction (Dobson and Smith 2000, Dobson et al. 2001; Von Borell et al 2007; Café et al. 2011; Kumar et al. 2012; Fernandez-Novo et al. 2020). Predictability and controllability limit both chronic and acute stress in livestock (Lee et al. 2018). In a VF system, ensuring livestock are properly trained and the association is predictable, controllable, and consistent is important to limiting the production and animal welfare consequences due to chronic stress.

Conclusion

Virtual fencing relies on a combination of auditory and electrical cues to influence livestock movement. Classical conditioning and negative reinforcement are vital to build and maintain the association between cues. Classical conditioning is the process where livestock associate an auditory cue with an impending electrical cue. Through repeated experience, animals respond to the auditory cue alone and should avoid an electrical cue. Negative reinforcement strengthens the avoidance behavior (Bishop-Hurley et al. 2007; Lee et al. 2009; Umstatter 2011; Umstatter et al. 2015). When an animal performs the desired avoidance behavior, they experience positive outcomes (e.g., removal of cues). This enhances the learning process and encourages future compliance.

Using a physical fence during training provides opportunities for animals to successfully interact with the boundary zone. This successful rehearsal improves the association between the cues, which results in the desired avoidance behavior. It also limits the possibility of livestock correlating the electrical cue with other aspects of the landscape or ranching infrastructure, rather than a virtual fence line. Successful training may support coping, reduce overall stress in the individual, and promote animal welfare. After training, a collar can influence livestock movement if the association between the cues is continuous, predictable, and controllable. When the association breaks down, livestock cannot predict and/or control their ability to avoid a cue. This has repercussions for animal welfare and VF effectiveness. While VF research has shown promise in small pasture dairy animals (Langworthy et al. 2021; Verdon et al. 2021), more VF research is needed on animal welfare on extensive and complex rangelands. Understanding the animal's ability to recognize potential hazards and respond to cues is vital to applying a landscape-scale VF system. Building and strengthening the association with training increases the probability of successful VF use while maintaining livestock welfare.

Disclaimer

There are several companies that manufacture hardware and software for commercial use including Corral Technologies™, eShepherd™, NoFence™, and Vence™. Virtual fencing components from different manufacturers are generally not interoperable or interchangeable. Specific components, GIS data needs, software protocol, software training, frequency and duration of the cues, GPS error, livestock collaring, and livestock training protocols may vary depending on the manufacturer. Follow the manufacturer's recommendations and guidelines. The University of Arizona does not endorse a specific product.

Acknowledgements

This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2021-38640-34695 through the Western Sustainable Agriculture Research and Education program under project number WPDP22-016. USDA is an equal opportunity employer and service provider. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

This work is supported by the AFRI Foundational and Applied Science Program: Inter-Disciplinary Engagement in Animal Systems (IDEAS) [award no. 2022-10726] from the USDA National Institute of Food and Agriculture.

Additional funding for the University of Arizona's Virtual Fence program was provided by Arizona Experiment Station, the Marley Endowment for Sustainable Rangeland Stewardship, and Arizona Cooperative Extension.

For additional information about virtual fencing, visit: https://rangelandsgateway.org/virtual-fence

Reference

Bishop-Hurley, G.J., Swain, D.L., Anderson, D.M., Sikka, P., Crossman, C., Corke, P., 2007. Virtual fencing applications: Implementing and testing an automated cattle control system. Computers and Electronics in Agriculture 56, 14–22. *https://doi.org/10.1016/j.compag.2006.12.003*

Brown, E.J., Vosloo, A., 2017. The involvement of the hypothalamopituitary-adrenocortical axis in stress physiology and its significance in the assessment of animal welfare in cattle. Onderstepoort Journal of Veterinary Research 84, 9. *https://doi.org/10.4102/ojvr.v84i1.1398*

Cafe, L.M., Robinson, D.L., Ferguson, D.M., McIntyre, B.L., Geesink, G.H., Greenwood, P.L., 2011. Cattle temperament: Persistence of assessments and associations with productivity, efficiency, carcass and meat quality traits1. Journal of Animal Science 89, 1452–1465. *https://doi.org/10.2527/jas.2010-3304*

Campbell, D.L.M., Lea, J.M., Keshavarzi, H., Lee, C., 2019. Virtual Fencing Is Comparable to Electric Tape Fencing for Cattle Behavior and Welfare. Frontiers in Veterinary Science 6.

Chen, Y., Arsenault, R., Napper, S., Griebel, P., 2015. Models and methods to investigate acute stress responses in cattle. Animals 5, 1268–1295.

Cooke, R.F., 2014. Bill E. Kunkle Interdisciplinary Beef Symposium: Temperament and acclimation to human handling influence growth, health, and reproductive responses in Bos taurus and Bos indicus cattle1. Journal of Animal Science 92, 5325–5333. *https://doi.org/10.2527/jas.2014-8017*

di Virgilio, A., Morales, J.M., Lambertucci, S.A., Shepard, E.L., Wilson, R.P., 2018. Multi-dimensional Precision Livestock Farming: A potential toolbox for sustainable rangeland management. PeerJ 6, e4867.

Dobson, H., Smith, R.F., 2000. What is stress, and how does it affect reproduction? Animal reproduction science 60, 743–752.

Dobson, H., Tebble, J.E., Smith, R.F., Ward, W.R., 2001. Is stress really all that important? Theriogenology 55, 65–73.

Domjan, M.P., 2014. The principles of learning and behavior. Cengage Learning.

Fernandez-Novo, A., Pérez-Garnelo, S.S., Villagrá, A., Pérez-Villalobos, N., Astiz, S., 2020. The effect of stress on reproduction and reproductive technologies in beef cattle—A review. Animals 10, 2096.

Hayter, E.W., 1939. Barbed Wire Fencing: A Prairie Invention: Its Rise and Influence in the Western States. Agricultural History 13, 189–207.

Holechek, J., Pieper, R.D., Herbel, C.H., 2011. Range management: principles and practices. Prentice Hall,.

Jakes, A.F., Jones, P.F., Paige, L.C., Seidler, R.G., Huijser, M.P., 2018. A fence runs through it: A call for greater attention to the influence of fences on wildlife and ecosystems. Biological Conservation 227, 310–318. *https://doi.org/10.1016/j.biocon.2018.09.026*

Kumar, B., Manuja, A., Aich, P., 2012. Stress and its impact on farm animals. FBE 4, 1759–1767. *https://doi.org/10.2741/e496*

Langworthy, A.D., Verdon, M., Freeman, M.J., Corkrey, R., Hills, J.L., Rawnsley, R.P., 2021. Virtual fencing technology to intensively graze lactating dairy cattle. I: Technology efficacy and pasture utilization. Journal of Dairy Science 104, 7071–7083. *https://doi.org/10.3168/jds.2020-19796*

Lee, C., Colditz, I.G., Campbell, D.L.M., 2018. A Framework to Assess the Impact of New Animal Management Technologies on Welfare: A Case Study of Virtual Fencing. Frontiers in Veterinary Science 5.

Lee, C., Henshall, J.M., Wark, T.J., Crossman, C.C., Reed, M.T., Brewer, H.G., O'Grady, J., Fisher, A.D., 2009. Associative learning by cattle to enable effective and ethical virtual fences. Applied Animal Behaviour Science 119, 15–22. *https://doi.org/10.1016/j.applanim.2009.03.010*

Lima, E., Hopkins, T., Gurney, E., Shortall, O., Lovatt, F., Davies, P., Williamson, G., Kaler, J., 2018. Drivers for precision livestock technology adoption: A study of factors associated with adoption of electronic identification technology by commercial sheep farmers in England and Wales. PloS one 13, e0190489.

Moberg, G.P., 1985. Influence of Stress on Reproduction: Measure of Well-being, in: Moberg, G.P. (Ed.), Animal Stress. Springer, New York, NY, pp. 245–267. *https://doi.org/10.1007/978-1-4614-7544-6_14*

Ray, E., Schamel, W., 1997. Glidden's Patent Application for Barbed Wire. Social Education 61, 53–56.

Selye, H., 1976. Stress without Distress, in: Serban, G. (Ed.), Psychopathology of Human Adaptation. Springer US, Boston, MA, pp. 137–146. *https://doi.org/10.1007/978-1-4684-2238-2_9*

Trotter, M., 2010. Precision agriculture for pasture, rangeland and livestock systems, in: Food Security from Sustainable Agriculture 15th Australian Agronomy Conference, Lincoln, New Zealand.

Umstatter, C., 2011. The evolution of virtual fences: A review. Computers and Electronics in Agriculture 75, 10–22. *https://doi.org/10.1016/j.compag.2010.10.005*

Umstatter, C., Morgan-Davies, J., Waterhouse, T., 2015. Cattle Responses to a Type of Virtual Fence. Rangeland Ecology & Management 68, 100–107. *https://doi.org/10.1016/j.rama.2014.12.004*

Verdon, M., Langworthy, A., Rawnsley, R., 2021. Virtual fencing technology to intensively graze lactating dairy cattle. II: Effects on cow welfare and behavior. Journal of Dairy Science 104, 7084–7094. *https://doi.org/10.3168/jds.2020-19797*

von Borell, E., Dobson, H., Prunier, A., 2007. Stress, behaviour and reproductive performance in female cattle and pigs. Hormones and Behavior, Reproductive Behavior in Farm and Laboratory Animals 52, 130–138. *https://doi.org/10.1016/j.yhbeh.2007.03.014*