



Foundations of Virtual Fencing: Training and Animal Welfare

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Virtual Fence

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; Netz 2004). This type of fencing has improved rangeland conditions in many places by aiding in the application of grazing systems (Holecheck et al. 2011). However, wire fencing can fragment landscape connectivity, pose a risk to wildlife, and is a major financial investment. Moreover, it offers limited flexibility in adjusting pasture size, actively manipulating grazing distribution, or avoiding high-use areas or sensitive habitats within a pasture (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 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, a virtual fence (VF) system uses invisible barriers, established by Global Positioning System (GPS) coordinates, that influence livestock movement with a combination of auditory and electrical cues (Ehlert et al. 2024; Antaya et al. 2024). 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 grazing area and exclusion zone; (2) a GPS-enabled collar fitted around the circumference of an animal's

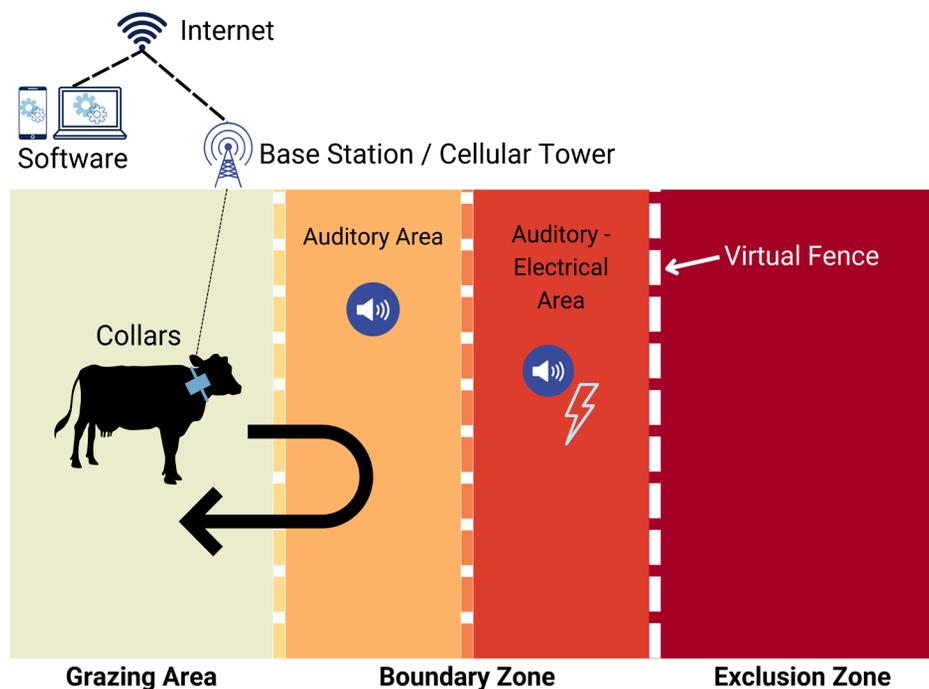


Figure 1: Conceptual model of VF components (VF software, base station and/or cellular tower, and GPS-enabled collars), which are used to define the grazing area, boundary zone, and exclusion zone. Livestock learn to associate two cues originating from collars when the animal enters a boundary zone: an auditory cue (beeping sound) and an electrical cue (electrical pulse). After training, livestock should respond to the auditory cue by changing direction away from the exclusion zone.

neck or other wearable device that contains 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 please see Rangelands Gateway: <https://rangelandsgateway.org/virtual-fence>). A VF system relies on livestock successfully recognizing an association between two cues – an auditory cue (beeping sound) and an electrical cue (electrical pulse) – originating from the GPS-enabled collars when the animal enters a boundary zone. Recognition of these cues is learned through training with classical conditioning and negative reinforcement. 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. This factsheet provides an overview of the underlying learning methods (i.e., classical conditioning and negative reinforcement) used to train livestock.

Glossary

Virtual fencing: a precision livestock management tool that uses invisible barriers, established by Global Positioning System (GPS) coordinates, to influence livestock movement with a combination of auditory and electrical cues

Virtual fence (VF): a line drawn on a digital map that can include a boundary zone

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

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

Collar: a wearable device fitted around an animal’s neck that contains the technology for tracking locations and delivering auditory and electrical cues

Auditory cue: beeping sound originating from the collars when livestock enter a boundary zone

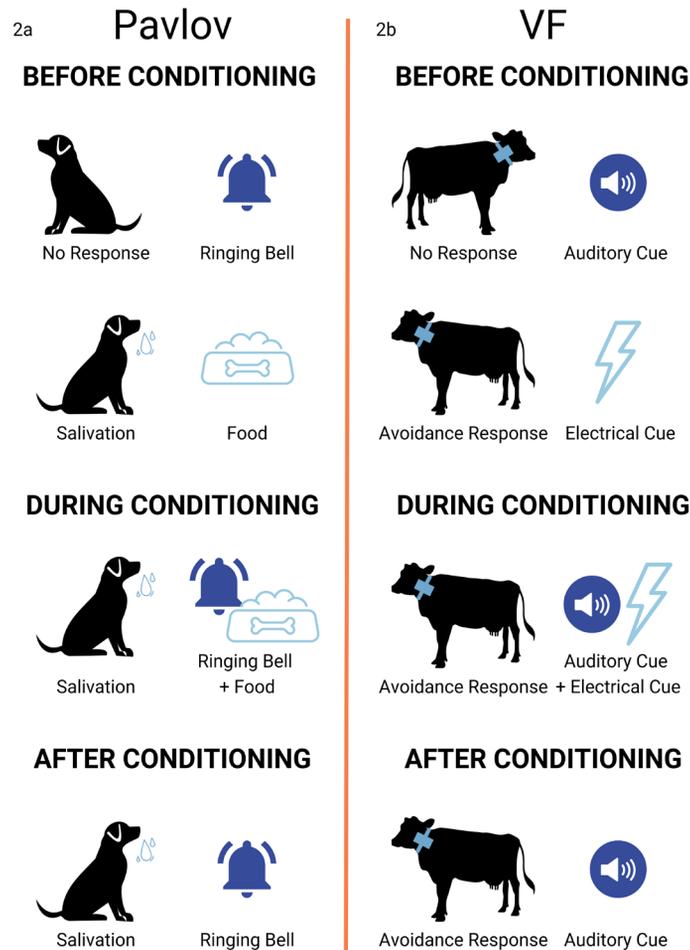


Figure 2: Classical conditioning in (a) Pavlov's dog experiment and (b) a VF system.

Electrical cue: electrical pulse originating from collars when livestock approach a virtual fence

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

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 (electrical pulse), resulting 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 direction 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.

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 pressure from the bit created by the reins. In a VF system, the removal of the unpleasant auditory cue and its associated electrical cue, indicates to the livestock that they have successfully performed the desired avoidance behavior and returned to the grazing area (Figure 3). During training, every interaction with the active VF should result in the desired behavior (returning to the grazing area). For this reason, during training, VFs are ideally placed along physical fence lines. Introducing VFs with physical fences

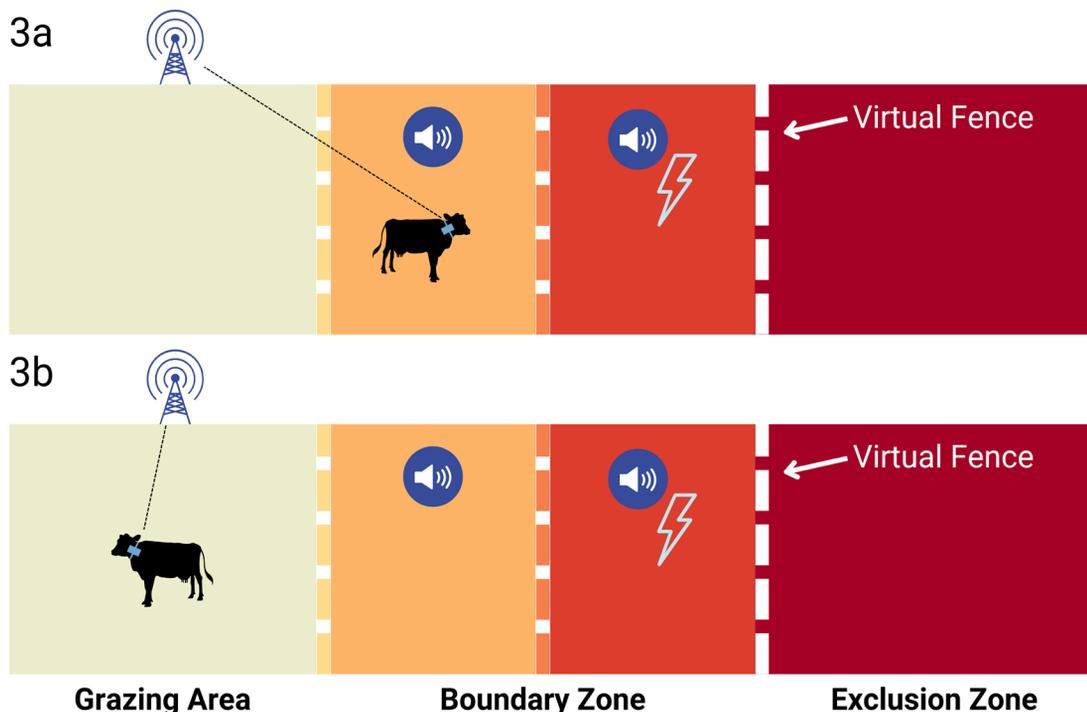


Figure 3: Conceptual model of negative reinforcement in a VF system where (a) the auditory cue, associated with electrical cue, is heard in the boundary zone triggering livestock to change directions and (b) the removal of auditory cue indicates a successful avoidance behavior.

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 establishes a foundation for the desired behavior, which enhances VF compliance and improves the effectiveness of animal containment within the grazing area once the physical barriers are removed.

Animal Welfare Considerations

Classical conditioning and negative reinforcement shape how livestock recognize a VF line, respond, and move across a landscape. After successful training, the auditory cue is the only information that livestock can identify to 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 to, based on conditioning. Livestock may fail to anticipate the electrical cue if the sequence of cues is unpredictable, potentially leading them to disregard the auditory cue altogether. 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 grazing area and escape the boundary zone, the animal has no control over its response. Without this perceived control, livestock may struggle to locate the 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 VFs are complex (e.g., sharp angles/corners or overlapping fences). With complex fence designs, livestock struggle to avoid or escape auditory or electrical cues in the boundary zone (Figure 4). Virtual fences should be designed with wider angles ($>90^\circ$) to lessen the likelihood of repeated cues, which may cause chronic stress and have long term consequences for production and animal welfare.

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

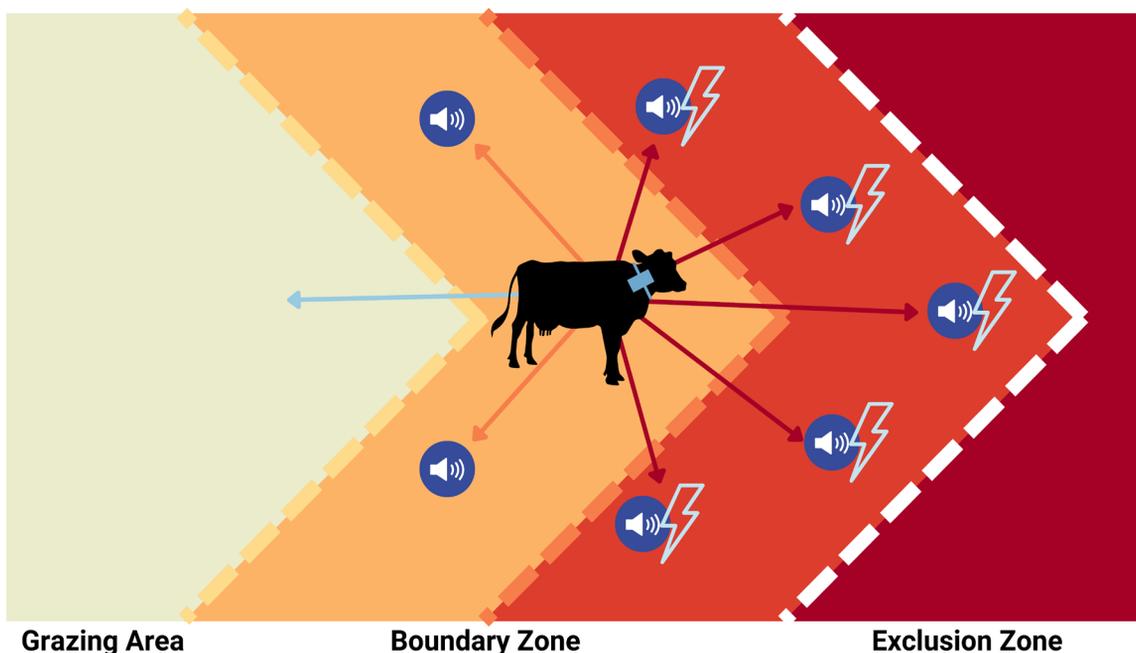


Figure 4: Conceptual model of a complex VF design where animals may have difficulty avoiding or escaping cues.

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 health¹, weight gain², and reproduction³ (Moberg 1985¹; Chen et al. 2015¹; Brown and Vosloo 2017¹; Cooke 2014²; Fernandez-Novo et al. 2020²; Dobson and Smith 2000³, Dobson et al. 2001³; Von Borell et al. 2007³; Café et al. 2011³; Kumar et al. 2012³; Fernandez-Novo et al. 2020³). 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 limit the 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 be able to 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, it experiences 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 VF line. Successful training can lower initial stress levels in animals, facilitate coping, and enhance their overall 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 successfully controlled livestock 99% of the time in small pasture systems (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 including Corral Technologies™, eShepherd™ from Gallagher™, Halter™, 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.

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

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