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Virtual fencing applications: Implementing and testing an automated cattle control system

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Abstract

Managing livestock movement in extensive systems has environmental and production benefits. Currently permanent wire fencing is used to control cattle; this is both expensive and inflexible. Cattle are known to respond to auditory and visual cues and we investigated whether these can be used to manipulate their behaviour. Twenty-five Belmont Red steers with a mean live weight of 270 kg were each randomly assigned to one of five treatments. Treatments consisted of a combination of cues (audio, tactile and visual stimuli) and consequence (electrical stimulation). The treatments were electrical stimulation alone, audio plus electrical stimulation, vibration plus electrical stimulation, light plus electrical stimulation and electrified electric fence (6 kV) plus electrical stimulation. Cue stimuli were administered for 3 s followed immediately by electrical stimulation (consequence) of 1 kV for 1 s. The experiment tested the operational efficacy of an on-animal control or virtual fencing system. A collar–halter device was designed to carry the electronics, batteries and equipment providing the stimuli, including audio, vibration, light and electrical of a prototype virtual fencing device. Cattle were allowed to travel along a 40 m alley to a group of peers and feed while their rate of travel and response to the stimuli were recorded. The prototype virtual fencing system was successful in modifying the behaviour of the cattle. The rate of travel of cattle along the alley demonstrated the large variability in behavioural response associated with tactile, visual and audible cues. The experiment demonstrated virtual fencing has potential for controlling cattle in extensive grazing systems. However, larger numbers of cattle need to be tested to derive a better understanding of the behavioural variance. Further controlled experimental work is also necessary to quantify the interaction between cues, consequences and cattle learning.

Keywords: Animal behaviour; Free-ranging cattle; Sensory stimuli; Fencing; Prototype virtual fencing device; Wireless sensor network

1. Introduction

Fossilised records provide evidence of livestock domestication, which occurred between 8000 and 10,000 years before present (YBP). Animals were contained by tethering or by building an impenetrable boundary. The simplest and earliest forms of nomadic domestication allowed livestock to forage in open areas during the day; however, at night animals were corralled in pens to contain and protect them (Holl, 1998). In modern agricultural systems, hedges, stone

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walls or wire and timber fences are used to contain or manage livestock. Containment of cattle in large scale grazing systems, using either barbed wire or electric fencing, is time consuming and expensive. However, managing livestock movement has significant environmental and productivity benefits (McKeon et al., 1990; Ash et al., 1995, 1997; Ash and Smith, 1996; McIntyre et al., 2003).

Cattle are known to respond to auditory and visual cues and these can be used to manipulate their behaviour (Howery et al., 2000; Wredle et al., 2004). Animals learn to respond to visual and/or auditory cues associated with food and can be trained to approach feed troughs (Hagen and Broom, 2004). Electric fences provide both a visual and a sensory cue. When an animal touches an electric fence it receives a mild electric shock. Barbed wire fencing provides a physical barrier to restrict livestock movement; however, electric fencing relies on the livestock associating a negative sensation with the visual cue of the fence. Common brushtail possums (*Trichosorus vulpecula*) learnt to avoid electric fences within 7 h following their initial exposure (Clapperton and Matthews, 1996). Dairy farmers routinely use a single strand electric fence to control cattle within a paddock; cows quickly learn to avoid the fence as they associate it with an unpleasant electric shock.

Although electric fences provide a flexible low cost solution for controlling cattle, their use is limited to relatively small-scale intensive livestock production systems. Controlling livestock in extensive grazing systems currently involves the use of permanent barbed-wire fencing that is expensive and inflexible. There is a need to develop livestock control systems that are not only flexible but can also be deployed in extensive grazing systems. On-animal control devices have been used to control dogs (Andelt et al., 1999); these systems involve the dog wearing a collar that emits a combination of audible and electrical stimulation. Dogs can be trained to respond to these controls and they are used for containment and training. Cattle have been trained to respond to audioelectrical stimulation (Quigley et al., 1990). Goats learned to remain within a pre-defined area when equipped with electric stimulation collars (Fay et al., 1989).

The aim of this study was to determine (using a replicated controlled experimental design) whether a virtual fencing cue and consequence device fitted to cattle was able to alter their behaviour when travelling along an alley. The experiment carried out in this study tested the operational efficacy of an on-animal control device or prototype virtual fencing system. Observational data were used to categorise individual animal responses to a range of cue and/or consequence combinations.

2. Methods

2.1. Experimental site

The experiment was conducted at the Belmont Research Station (150°13′E, 23°8′S), located 20 km NW of Rockhampton in Queensland, Australia between 23rd August and 22nd September 2005. An alley that was devoid of vegetation, adjacent to the main yards and approximately 42 m long, 6 m wide with a 2 m high fence along its length was used for the experiment (Fig. 1).

2.2. Preparation of cattle

Twenty-five Belmont Red steers between 22 and 24 months of age with a mean live weight (LW) of 270 kg were randomly assigned to one of five treatments. Treatments consisted of a combination of cues (audio, vibration and visual stimuli) and consequence (electrical stimulation). The treatments were electrical stimulation alone, audio plus electrical stimulation, vibration plus electrical stimulation, light plus electrical stimulation and electrified electric fence (6 kV) plus electrical stimulation. For the electric fence treatment, a two-wire, three step-in post-energized electric fence was erected across the alley. Cues were administered for 3 s followed immediately by the electrical stimulation (consequence) for 1 s at 1 kV. The electrical stimulation treatment was 1 s long compared with a total cue and consequence package of 4 s for the remaining treatments. Treatments were applied at the same physical location along the alley (line B in Fig. 2), however, if the cattle did not cross the virtual fence line (line C in Fig. 2) then no stimulus was applied. Cattle were familiar with wearing neck collars, being mustered and handled in association with having collars attached and removed. This experiment was approved by the Rockhampton Animal Experimentation Ethics Committee (Application number RH205-05).

In preparation for the experiment, the steers were removed from pasture approximately 12 h prior to a run; they were fasted but had access to *ad libitum* water. On the day of a test, five non-experimental cattle from the herd were

Fig. 1. Photo of the alley used in the experiment showing the condition and construction of the experimental site.

placed as an attractant at the end of the alley (G in Fig. 2). A 3 m long feed bunker (F in Fig. 2) with good quality lucerne hay was also located at the end of alley to provide an additional attractant. As the test cattle reached the end of the alley they were given access to a mouthful of forage from the feed bunker. While the cattle were not involved in a run they were kept in an 8 ha paddock approximately 500 m from the yards with *ad libitum* access to forage and water.

The equipment was fitted to the cattle while they stood in a race located 25 m before the release gate (A in Fig. 2). An animal was only released from the race (A in Fig. 2) when it was standing quietly and looking straight ahead. Cattle only received one cue and/or consequence package each time they travelled along the alley. An animal was allowed to spend a maximum of 180 s in the alley. When an animal had completed its run, it was removed from the vicinity of the alley to avoid it interfering with the next animal. A run finished when the animal passed the virtual fence line E (Fig. 2). Prior to testing, the cattle were familiarised to the alley with five runs being completed without wearing equipment. The animals wore neck collars during run six and neck-collars and head-halters during run seven but treatments were not applied. Treatments were applied during runs eight, nine and ten; although for run ten, treatments were applied without a consequence.

2.3. Interfacing the electronic equipment with the cattle

A neck-collar and combined head-halter (collar–halter) device was designed to carry the electronics, batteries and equipment providing the stimuli, including audio, vibration, light and electrical stimulation. The collar–halter device consisted of a neck collar and a modified horse halter. The neck-collar was made from 100 mm wide nylon webbing with compartments for the box containing the electronics, the global positioning system (GPS) and radio antennae and two batteries (Fig. 3). Wiring for the radio and GPS antennae were routed through pockets in the collar to the top of the animal's neck; this configuration ensured the collars GPS and radio transceiver achieved the best possible reception. The batteries and electronics were housed at the bottom of the animal's neck. The weight of the batteries placed on either side of the box containing the electronics balanced the neck-collar and helped to stop the collar rotating around the animal's neck. External wires were routed from the box containing the electronics to be connected to the head-halter once both neck-collar and head-halter had been fitted to the animal.

Devices capable of delivering sound to the animal's ear, vibration to its forehead, light to the animal's eye and electrical stimulation to the back of the animal's neck were attached to a modified horse-halter (Fig. 3). A brow band was added to the halter to attach a generic vibrating cell-phone battery (3.6 V Lithium ion, 1100 mA h) to provide a tactile stimulus. Piezos (AVX, Piezoelectric Acoustic Generators, 4–25 V, 87 dB) were attached to the brow band

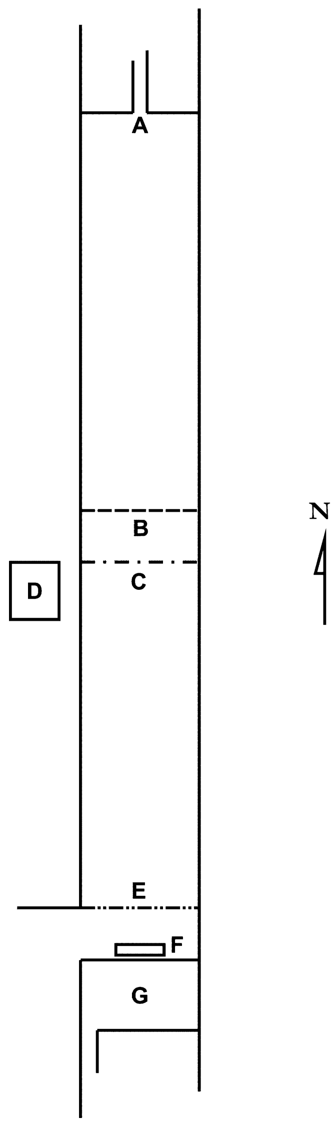

Fig. 2. Schematic of a 42.2 m × 5.9 m alley in which the responses of individual steers to cue and/or consequence packages were observed and their progress timed as they moved along a 39.6 m long section (A–E) of the alley to two attractants (F and G). A, release gate (start time); B, line at which cues and/or controls were initiated; C, line not to pass (location of temporary fence); D, observation tower with platform at 3.5 m; E, line at which timing stops; F, feed bunker filled with lucerne hay; G, pen of five non-experimental steers from the herd.

adjacent to the opening of each ear canal to deliver sound. Two red LED's (5 mm diameter clear lens, 14,000 mcd from Jaycar Electronics) were attached using flexible steel tube to the halter. This configuration allowed the LED's to be positioned in front of the steers head approximately 50 mm from each eye. Electrical stimulation was delivered by two 20 mm stainless steel electrodes set approximately 60 mm apart located behind the animal's pole on the halter strap used to secure the halter to the animal's head. Wires for the audio, vibration, light and electrical stimulation devices were routed along the halter to connect with the appropriate wire from the box housed on the collar.

2.4. Electronics

The electronics that monitored the animal and administered the cue and consequence combinations used the Fleck2 wireless sensor network (WSN) device (Sikka et al., 2004) combined with a daughterboard (control board), capable of

Fig. 3. A Belmont Red steer equipped with a neck collar head halter device for administering audio, vibration and electrical stimulation stimuli.

producing an electrical pulse. A cordless phone battery (Generic Ni-MH, 3.6 V, 600 mA h) was used to store the energy for the control board. The Fleck2 was charged by two 6 V, 4.2 A h Panasonic lead-acid batteries housed in compartments on the neck collar. These batteries were connected in parallel and also powered the Fleck2. Radio communications were transmitted and received through a 433 MHz 1/4 wave flex whip antenna supplied by Rojone, Australia. The GPS signal was received by an uBlox GPS antenna (ANN-MS-0-005).

A laptop running Suse 9.3 Linux was used to manually control the electronics located on the animal collar. A transceiver was attached to the laptop to receive and transmit wireless signals to and from the electronics on the collar. A Java-based user interface was developed to allow the user to control the duration and intensity of all stimuli. Sliders were coded into the interface to give stimuli a linear range of 1–10 s duration and 600–4000 V. The laptop was positioned on a 3.5 m high platform located adjacent to the alley (D in Fig. 2). The height of the platform enabled the operator to monitor the exact location and behaviour of the cattle as they moved along the alley.

2.5. Data recorded

Cattle were videotaped from the observation platform located adjacent to the alley (D in Fig. 2). Videotapes provided a backup to the timing and observation data collected and were reviewed as necessary. The time taken for an individual animal to move from the release gate (A in Fig. 2) and from the point of control (B in Fig. 2) to a pre-defined point at the end of the alley (E in Fig. 2) was recorded. How each animal responded to the cue and/or control package was recorded as stop, turn, reverse, walk, run, etc. (Table 1). To check that the animals had received the cue and/or consequence package, the Fleck2 recorded the GPS time when a command was received by the collar and the duration and intensity of the stimuli delivered.

2.6. Statistical analysis

Observational and video records of the animal's activity were used to code the animal's response to the stimuli. Chi-square analysis determined the effectiveness of the stimuli in modifying the animal's behaviour. If the stimuli had no effect, the expected behavioural response for cattle travelling along the alley would be to cross the virtual fence line without stopping, reversing or turning.

Table 1
Responses of cattle within treatments to stimuli delivered using a prototype virtual fencing system

Run	Electrical stimulation	Audio plus electrical stimulation	Vibration plus electrical stimulation	Light plus electrical stimulation	Electric fence plus electrical stimulation
Treatment (naïve)					
Did not stop	0	3	0	0	0
Stop and run through	0	0	0	1	0
Stop, reverse and run through	1	0	0	0	0
Stop, reverse/turn and run through	4	2	4	4	0
Stop and reverse/turn	0	0	1	0	5
Treatment					
Did not stop	0	1	1	2	0
Stop and run through	0	0	0	0	0
Stop, reverse and run through	0	0	0	0	0
Stop, reverse/turn and run through	4	1	1	1	0
Stop and reverse/turn	1	3	3	2	5
Treatment without electrical stimulation					
Did not stop	0	0	0	1	0
Stop and run through	1	0	1	0	0
Stop, reverse and run through	0	0	0	0	0
Stop, reverse/turn and run through	1	1	0	1	0
Stop and reverse/turn	3	4	4	3	5

3. Results

Fig. 4 shows the results from eight runs within the current experiment. The first group of bars is the mean from five runs which make up a pre-test baseline value with no collar (labelled no device). The second group of bars is from the first run where the cue and/or consequence combinations were applied to naïve cattle (labelled treatment (naïve)). The third group of bars is from the second cue and/or consequence combination (labelled treatment) and the fourth group is cue only (visual, audio and tactile), that is, no electrical stimulation followed the cue (labelled treatment w/o electrical stimulation).

The mean travel time along the alley varied among individual steers, treatments and runs (Fig. 4). The mean baseline time for non-instrumented cattle to travel through the alley was 19.6 s and was similar for all cattle within and among treatment groups. The energized electric fence cue plus electrical stimulation treatment stopped all cattle for 180 s; the

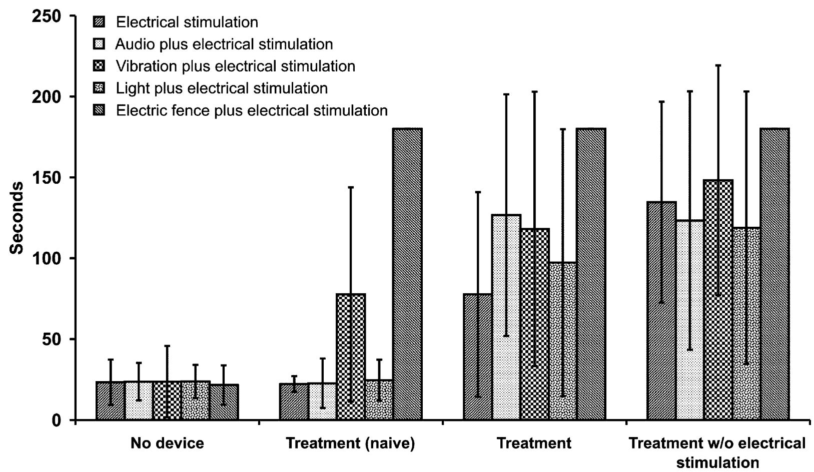

Fig. 4. Mean and standard deviation time taken for five Belmont Red steers per treatment to travel 39.6 m (over five non-consecutive days between 23 August and 22 September 2005). The no device data are from the second of five baseline replicates.

Table 2
Responses of steers during three runs to cue and/or control packages delivered using a prototype virtual fencing system

Response	Run			
	Treatment (naïve)	Treatment	Treatment without electrical stimulation	Pooled
Did not stop	3	4	1	8
Stop and run through	1	0	2	3
Stop, reverse and run through	1	0	0	1
Stop, reverse and/or turn and run through	14	7	3	24
Stop and reverse and/or turn	6	14	19	39
Probability	<0.001	<0.001	<0.001	<0.001
Test value	39.29	36.21	46.15	67.68

The column labelled pooled represents the combined data from the previous three runs. A chi-square test has been used to test the hypothesis that the equipment successfully modified the behaviour of the cattle moving along an alley.

maximum time any steer was allowed to take to move along the alley. During the fourth run when treatments were applied without the electrical stimulation the electric fence plus electrical stimulation treatment stopped 100% of the cattle. The tactile cue in the second run was the most effective in slowing the animal's rate of travel along the alley, although there is a large amount of variability within this treatment group (Fig. 4). The second time the treatments were applied (third run) the rate of travel of all treatment groups was reduced compared to the first time the treatments were applied. As the number of times the cattle were exposed to the treatments increased, the slower their rate of travel along the alley. However, there was considerable variation among animals.

The data in Table 2 have been pooled across treatments to determine the overall effectiveness of the prototype virtual fencing system. Some cattle failed to stop when the stimuli were applied; however, the behaviour of approximately 90% of the cattle was modified during runs eight, nine and ten. The device altered the behaviour of 88% of naïve cattle and 95% of cattle using only the cue after the treatment had been applied twice.

4. Discussion

Virtual fencing has the potential to flexibly manage livestock in extensive grazing systems. This study adds to previous research that used electrical stimulation collars (Fay et al., 1989; Quigley et al., 1990; Andelt et al., 1999) by implementing a replicated experimental design to test the basic assumptions regarding cues and consequences. An operational virtual fencing system will need to include a monitoring component, a control component based on varying combinations of audio, tactile and electrical stimulation, a control algorithm, which administers an appropriate level of stimulation, and finally a mechanism for attaching the device to the animal. Although the concept of virtual fencing has been explored the reality of a reliable application has not been realised (Wredle et al., 2004). With the advent of smaller more efficient electronic monitoring and control systems the opportunity to provide a robust control platform is now much closer (Sikka et al., 2004). There are still significant technological challenges; this study was designed to test whether the animal responded to a collection of cues and/or consequence generated by a prototype virtual fencing device. In particular, the experimental design provided a replicated data set with pre-defined treatments that were consistent throughout the trial.

There was a large degree of variability among the virtual fencing treatment run times. The small number of animals (reps) in each treatment and the large variability in the time taken to travel along the alley precludes any statistically significant interpretations from the timed data. However, these data do provide an indication of learning and suggest some general differences in the behavioural response to individual cues. Although the electric fence was energized, the animals never touched it and this is consistent with other studies that have demonstrated restricted movement of animals using electric fencing (Clapperton and Matthews, 1996). Although the cattle in this study had prior exposure to electric fences there was no detailed information on the duration, frequency or associative learning response for the individual animals. However, electric fences are widely used by livestock producers to successfully contain cattle. The electric fence provided a baseline comparison for the automated animal control treatments. In all cases the cattle did not attempt to touch or push through the electric fence treatment. This experiment demonstrated that the strong visual cue of a conventional electric fence is an important component for successfully controlling cattle. Visual cues are important for modifying behaviour in cattle (Howery et al., 2000). The vibration plus electrical stimulation was the most effective virtual fencing treatment for stopping the cattle. Previous studies have demonstrated that skin defence systems help protect animals from aggressions inflicted by predators (Cibils et al., 2004). The positive response to the vibration cue may be linked to skin defence mechanisms. The audio cue was initially less effective than the vibration cue at eliciting a behavioural response; however, as the cattle had repeated exposure to the audio cue there was a stronger behavioural response. The light plus electrical stimulation treatment was the least effective virtual fencing control; however, this lack of success may be in part due to ineffective LED lighting. Further work is required to establish an effective lighting system that provides a reliable visual cue. Visual cues appear to be important and the lighting system aimed to exploit the association between a visual cue and an electrical stimulation consequence.

The behavioural observation and classification data demonstrated a range of responses to the virtual fencing application. Had the devices failed to alter the animal's behaviour the time taken for cattle to move along the alley would have been similar to the baseline values. The majority of cattle showed some response to the virtual fencing treatments. However, the responses were varied both among cattle and among runs. Throughout all of the runs the cattle made some attempt to stop, with approximately 90% of all cattle stopping. Within an individual run the highest no-stop response was 20% of the cattle. As the cattle gained experience moving along the alley their responses changed. In particular there were an increasing number of cattle that stopped and reversed or turned around at the virtual fence line. In earlier runs the cattle had stopped, reversed and/or turned but very quickly ran through the virtual fence line. These results provide evidence that the cattle showed early signs of associative learning to the virtual fencing controls. The treatments were always applied at the same location in the alley and although there was no obvious visual cues the cattle may have developed some form of spatial awareness and were responding to a location-based cue.

The data collected in this experiment demonstrated that cattle did respond to virtual fencing treatments. The virtual fencing treatments only applied a single 3 s cue followed immediately by a 1 s consequence (a total of 4 s); therefore, it is not surprising that the cattle could not be held behind the virtual fence line for the maximum time of 180 s. By ensuring the treatments remained the same, it was possible to quantify how successful the prototype virtual fencing system was in inducing an initial behavioural response. Testing the treatments on individual animals in a standard alley ensured external variables, for example, interference from other animals, could be controlled. The information gained from this alley-based experiment needs to be validated in a paddock, with larger numbers of animals. The effect of herding interactions on an individual animal's reaction (behaviour) will also need to be quantified.

5. Conclusions

The prototype virtual fencing system was successful in eliciting a behavioural response from the cattle with all cue consequence combinations. The observational data suggest that most cattle responded immediately after the cues and/or consequences were administered. The strong visual association of a conventional electric fence was the most successful in stopping the cattle and demonstrated the association of visual cues with consequences is important in controlling cattle. However, the rate of travel along the alley demonstrated the large variability in behavioural responses between individual animals to tactile, visual and audible cues. The experiment demonstrated that sensory cues used within the context of virtual fencing have potential for controlling cattle in extensive grazing systems. However, larger numbers of cattle need to be tested to derive a better understanding of the behavioural variance. Further controlled experimental work is also necessary to quantify the interaction between cues, consequences and cattle learning. Finally, the detailed work from the alley will need to be compared to similarly detailed work in the paddock to ensure that the knowledge acquired in the alley is applicable to the grazing situation.

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