Influence of virtual fence on heart rate response in beef cattle

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On the Ground

- Virtual fence (VF) technologies can aid cattle producers in applying grazing management for land resource objectives.
- Acute stress and animal welfare are important factors to consider when adopting VF on rangelands.
- VF did not cause increased heart rate (HR) to mature, lactating beef cows when receiving audio or electric cues during a 30-minute period.
- Increased HR was observed when cattle interacted with the electric cue boundary, but HR typically returned to levels observed during a control period within 30 seconds to 4 minutes.
- Overall, VF caused minimal acute stress to the mature cows with calves and cattle learned to respond to audio cue warnings and avoid electric cues after being trained.

Keywords: cow behavior, grazing management, heart rate, virtual fence.

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Introduction

Innovative precision livestock management (PLM) technologies can aid cattle producers in applying grazing management practices for key grazing land resource objectives.[1] Virtual fencing (VF) is a relatively new PLM tool that creates an invisible boundary by emitting sensory cues via audio and electric stimuli to on-animal collars.[2,3] This technology provides opportunities for livestock managers to create flexible grazing management boundaries, potentially reducing required time, labor, and physical fencing material and improving grazing practices that benefit cattle utilization efficiency and natural resource conservation.

A factor to consider when adopting new PLM technologies, such as VF, on rangelands is the potential impact on animal welfare.[4] A cow's ability to adapt to novel situations and surrounding environments has been linked to responses of stress and overall individual welfare.[5,6] The influence of audio and electric cues used in VF systems to manage where cattle graze raises concerns about potential increases to cattle stress and an animal's ability to adapt to this new management. Training cattle to understand the association between the designated fencing area and the cues they receive is important in minimizing their stress response.[7] VF systems function on an animal's cognitive abilities of avoidance learning. Through proper conditioning, an animal learns how to avoid the VF electric cue by appropriately responding to the VF audio cue.[6] The potential stress exhibited by cattle with VF could be related to the amount of time a cow has had to adapt to VF. Assessing the impact of VF on livestock requires an assessment of multiple variables, such as acute and chronic stress, behavior responses associated with audio and electrical cues, livestock cognition, and social learning abilities.[5]

Acute stress in cattle is associated with a relatively short (e.g., seconds to minutes) response to a stress-inducing situation. Typically cattle exhibit a biological response to stress (e.g., running away) followed by a recovery to a normal state.[8-10] Direct physiological measures such as concentrations of the plasma cortisol and β-endorphins, body temperature, and heart rate (HR) can been used to assess acute stress in cattle.[5] Whereas, field-based measures, such as cortisol metabolite levels in fecal material and hair, are often used to examine chronic stress levels.[5] Evaluating animal cortisol levels to measure chronic stress over extended periods (e.g., weeks to months) minimizes the fluctuation effects from seasonal changes, circadian rhythm changes, and animal handling.[11] More research has used chronic stress measures to assess the response of cattle to VF compared to acute stress measures. Hamidi et al.[12] used fecal cortisol metabolites to examine stress of heifers managed with VF compared with heifers managed with traditional fencing methods. They observed no differences in cortisol concentration between the treatments.[12] Other research has also found cortisol levels not increasing in beef cattle with the use of VF.[13]

By focusing on acute stress response of cattle to VF cues, we can better understand the short-term effect of VF on individual animal welfare. The use of HR to measure acute stress of cattle managed with VF has not been extensively studied compared to chronic measures of stress (e.g., fecal cortisol) because of the challenge of attaching HR monitoring devices to cattle.[5] Anderson[14] reported using a HR monitor on a single beef cow managed with a VF system. Cow HR spiked during an electric cueing event to 94 beats per minute (BPM) with the animal returning to an 8-hour average (56 BPM) in approximately 13 minutes. However, minimal research has evaluated cattle HR response to VF on multiple individuals or responses before and after cattle have been trained to VF over longer periods (e.g., months). Our study objectives were to better understand the acute stress response of cattle to audio and electric cues by monitoring HR, movement, and behavior of individuals within groups during defined 30-minute control and VF periods. Based on minimal chronic stress responses observed in studies evaluating cortisol metabolites and observed behaviors,[12,13] we hypothesized cattle stress would be short-term and that cattle would return to a normal state quickly following interactions with VF cues.

Methods

Our study was conducted in 2023 at the University of Nebraska - Lincoln Gudmundsen Sandhills Research Laboratory near Whitman, Nebraska. This research facility covers approximately 5,280 ha (12,800 acres), with 4,694 ha (11,600 acres) being upland range ecological sites and 486 ha (1,200 acres) of subirrigated and wetland meadows. Twenty mature (mean age of 6 years) Red Angus and Simmental crossbred cows were used for our study. All cows had calves born in March 2023 by their side throughout the study. Because of cattle availability at the research center, cows in the study were a mixture of individuals used for a short preliminary test (~ 2 months) of the VF system in 2022 and cows with no experience with VF. Before the start of the 2023 trials, cows that had experienced VF in the previous year did not have the collars on for approximately 7 months. Of the 20 cows, nine had experienced VF in the previous year and 11 with no experience (i.e., naïve) with VF were added to the herd in 2023. To account for individual cow difference in VF experience, five cows were randomly chosen from both the experienced and naïve individuals to be equipped with both VF collars and a HR monitor. The remaining 10 cows were only fitted with VF collars. The University of Nebraska - Lincoln Institutional Animal Care and Use Committee (IACUC) approved protocols and work conducted for our project.

The VF system used for our study was designed and manufactured by Vence (Merck Animal Health, Rahway, NJ). This VF system has been used in other research exploring the use and efficacy of VF on beef cattle.[15-17] We used the Vence Herd Manager software to create VF boundaries with on a map with customizable audio and electric cueing region widths. The VF boundaries can be edited, which gives users flexibility on the design and location of their VF. The collars are powered by a lithium battery and produce audio and electric cues when cattle move within designated VF boundaries. The collars are designed to deliver an audio cue to the cow when they approach the designated audio boundary, signaling them to turn away from the boundary. If a cow continues into the electric boundary, the collar delivers an electric cue. The audio cue follows a pattern of delivering cues at a volume of 75 decibels, which lasts for 0.5 seconds followed by a 1.5 second pause and then another cue until the animal leaves the audio boundary. The electrical cue (0.33 Joules) lasts approximately 0.5 seconds followed by a 3.5 second pause. If the animal does not leave the electric cue boundary this pattern repeats until the collar has reached 20 applied events. The collar will pause for 3 minutes and repeat the pattern over 4 cycles. If the cow remains in the electric boundary zone after 4 cycles, the collar becomes disabled until it is reactivated manually in the VF herd manager software.[15,18]

The HR monitoring system consisted of a 2.75 m (9 feet) customized polyester band equipped with a Polar Pacer H10 watch connected via Bluetooth to a Polar Equine H10 HR monitor (Polar Electro OY, Kempele, Finland) with two electrodes providing a HR measure each second. The band was wrapped behind the shoulders of the cow, with an electrode placed behind the front left leg and another electrode placed midway up the left shoulder (see Peterson et al.[19]; Fig. 1). The precision, accuracy, and reliability of using a girth band and a HR monitor has been validated by Hopster and Blokhuis.[20] Hair clippers were used to create a skin-to-electrode contact point behind the front left leg and ultrasound gel was applied to both electrodes to give better contact and increase likelihood of accurate HR readings. A buckle fastened the belt around the cow's girth and Durvet Livestock Identification Tag Cement (Durvet Inc., Blue Springs, MO) secured the belt to the cow near the electrode contact points. The HR monitor and the GPS enabled watch collected HR (measured as beats/minute [BPM]), GPS locations, and the travel distance (feet) of the cattle between GPS locations each second.

We collected data during two trial periods in the summer of 2023 to evaluate the effect of VF on HR, movement, and other behavioral responses of cattle. The first trial (i.e., pregraze trial date) occurred on June 15 at the start of the summer grazing season. The second trial (i.e., postgraze trial date) occurred on August 14 at the end of a grazing period where cattle were exposed to VF on pastures for approximately 60 days. During the pregraze trial in June, HR monitoring systems with GPS enabled watches were placed on 10 randomly selected individuals and cows were given 15 to 60 minutes to become accustomed to the HR monitors in a holding pen. All 20 cows and calves in the herd were moved into a 0.9 ha (2.2 acre) study pen for 30 minutes for a control period to measure HR and movement of cattle in the pen without VF. After the control period, all cows were fitted with VF collars and randomly sorted into five groups. Each group consisted of four cows with calves, two with HR monitors and two without HR monitors. Each group was randomly assigned naïve or experienced cows (Table 1). We analyzed the cattle within smaller groups to allow for better visual observation of

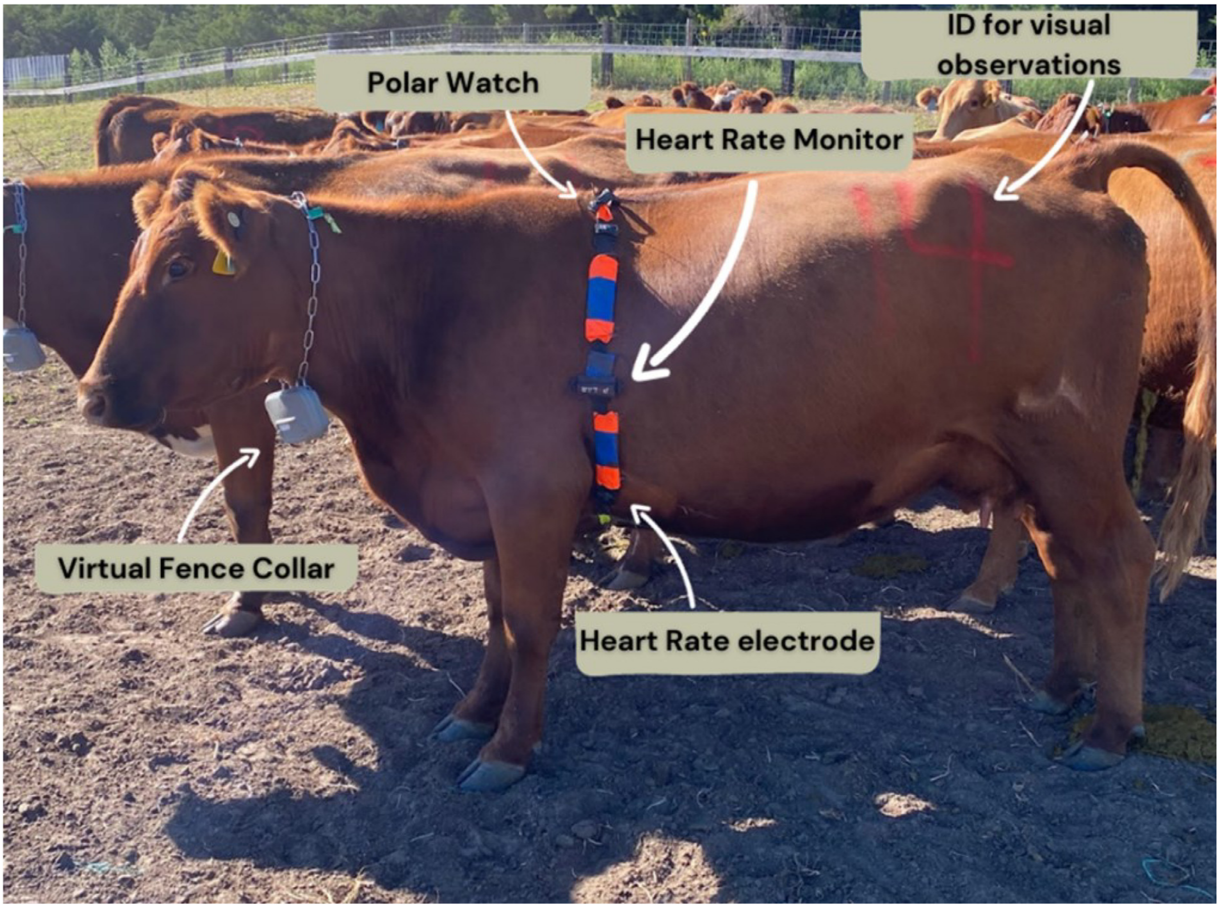

Figure 1. A cow fitted with a virtual fence (VF) collar and heart rate (HR) monitor used to evaluate HR and movement during 30-minute control and VF periods at the University of Nebraska –Lincoln Gudmundsen Sandhills Lab near Whitman, Nebraska in 2023.

individuals and because cattle may react to the response of other cow interactions with VF in the same group.[21]

Within the same pen used for the control, a VF boundary with a 3-m (10 ft) audio cue width and a 15-m (49 ft) electric cue width was designated around the perimeter of the pen (Fig. 2A). We selected this width for the audio and electric cue boundary to fit the smaller study pen (0.9 ha) compared with the larger pastures (11-15 ha [27-37 acres]) where cows grazed during the summer and to increase the likelihood cows would encounter both audio and electric cues during the VF period. Each group, one at a time, was released into the same study pen used during the control, but with the VF boundaries, for a 30-minute VF period. Cattle groups were held in holding pens where a building blocked their view of the study pen. Three or four trained technicians visually observed and recorded the number of cues received, behaviors of the cows, and physical responses of cows when contact was made with the VF boundary. Cows were assigned an individual observation number with spray paint on their hip so observers could record physical observation for that individual (Fig. 1). All observed behaviors were recorded and results were summarized into general themes of behaviors occurring most often during the trials. Examples of behaviors observed included cattle returning to the inclusion zone, head throwing, running, and jumping. After completion of the VF period, cows were moved into a separate holding pen. We repeated this process for each of the five groups in a random order.

After the pregraze trial, HR monitors were removed, and cows were moved to a 26 ha (64 acre) subirrigated meadow pasture bounded with a barbed wire fence. Based on the typical pasture management at the ranch, the pasture was subdivided into north and south sections (11-15 ha [27-37 acres]) with a single-wire electric fence (Fig. 2). Cows were rotated between the two sections approximately every 2 weeks. During the first week on pasture (June 20 to June 27), an audio cue boundary of 15 m (49 feet) and electric cue boundary of 25 m (82 feet) was designated around the physical fences to train the cows to the VF boundaries. After the training, cows were exposed to a variety of VF pasture arrangements during the remaining 60-day grazing season (examples shown in Fig. 2). Boundary widths remained the same for all VF designed exclusion and inclusion zones. Cattle GPS locations were taken every 30 minutes with the VF collars, and we used the Vence Herd Manager software to determine if cattle went outside of the VF boundaries during each VF arrangement. While cattle were on pasture, a single collar fell off and another stopped working after the case was broken. These collars were replaced before data were collected during the postgrazing trial. After the grazing season, we conducted the postgraze trial in August, where individuals underwent the same control

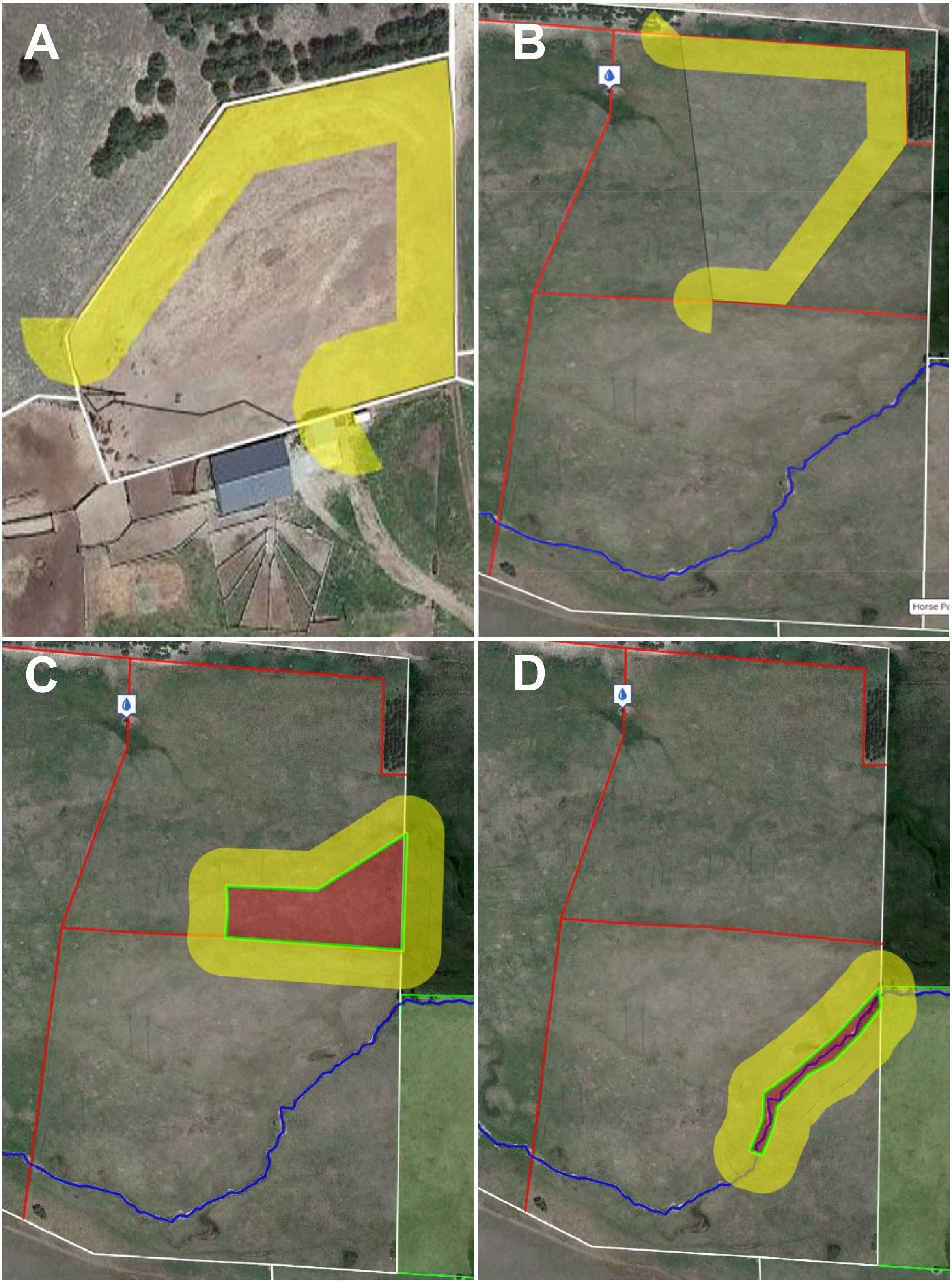

Figure 2. Virtual fence (VF) boundaries (yellow zones) within study trial pen (A) used during the pre- and postgraze trials at the University of Nebraska–Lincoln Gudmundsen Sandhills Lab near Whitman, Nebraska in 2023. Examples of VF boundaries on the larger subirrigated meadow pastures for inclusion (B), exclusion of a sub-section of the physically fenced pasture (C), and exclusion of a riparian stream areas (D). Red and white lines represent the physical boundary fences within the study pastures. Images were taken from Vence herd manager (Merck Animal Health, Rahway, NJ).

Table 1
Count of audio and electric cues cattle received during a 30-minute pregraze trial in June and postgraze trial in August after ~60 days grazing with VF on pasture at the Gudmundsen Sandhills Lab near Whitman, Nebraska.

Cattle groups	Pregraze trial		Postgraze trial	
	Audio cues	Electric cues	Audio cues	Electric cues
Group 1				
8184 (HR)	3	0	2	0
6001 (HR)	1	2	2	1
9196*	2	9	1	2
7226	0	0	1	0
Group total	6	11	6	3
Group 2				
8158 (HR)*	0	1	3	1
6224 (HR)	6	4	1	3
8147*	0	1	7	1
7106	2	1	3	0
Group total	8	7	14	5
Group 3				
8108 (HR)*	3	0	1	3
4203 (HR)*	2	3	1	0
5201*	2	6	0	0
7143	1	1	0	0
Group total	8	10	2	3
Group 4				
8250 (HR)	1	2	1	1
9173 (HR)*	9	8	4	3
9206*	2	0	1	0
6058	3	6	0	0
Group total	15	16	6	4
Group 5				
6260 (HR)	0	0	2	1
5106 (HR)*	5	0	2	1
9323*	0	3	1	1
9252*	0	5	4	1
Group total	5	8	9	4
Trial total	42	52	37	19

* Represents cows that were naïve to VF before the pregraze trial.

and VF periods as during the pregraze trial. The only difference from the pregraze trial was that VF collars were not removed during the control period, but VF boundaries were not active.

Data analysis

At the conclusion of both the pre- and post-graze trials, all HR and movement data from each of the 10 cows with HR monitors were individually uploaded from the watches and transferred to the Polar flow activity analyzer (https://flow.polar.com/diary). Polar flow activity analyzer creates CSV files with cow HR (BPM) and movement distance based on GPS locations (feet/second) at 1-second time stamped intervals. The time stamp allowed us to line up each cow's HR reading and movement with technician observations of behavior and responses to VF cues. Time stamped data were also compared with a report provided by Vence of audio and electric cue times during the 30-minute VF period.

Data from the HR monitors were organized by trial date (i.e., pregraze vs. postgraze trial). Data from individual cows within each trial date were separated by the 30-minute control and VF periods within each trial date. HR data from each cow were graphed over the treatment periods to visually assess data quality and completeness. Cows having inconsistent data with multiple missed HR readings were excluded from the comparison of the control and VF periods. During the pregraze trial, complete HR and movement data were collected from seven of the 10 cows fitted with HR monitors over the 30-minute control and VF periods (cows 6001, 6224, and 9173 were removed; Table 1). Three of the seven cows with HR monitors received at least one electric cue during the pregraze trial. During the postgraze trial, complete HR and movement data were collected from nine of the 10 cows (cow 8108 was removed; Table 1). Seven of these cows received at least one electric cue. Cow group ($n = 5$) was treated as the experimental unit to avoid a potential lack of independence for stress responses associated with reactions to other cow interactions with VF cues in the same group. Cow group composition remained the same for both the pre- and postgraze trials.

We analyzed mean HR and cattle movement, which was summed to the minute and converted from feet/minute to meters/minute, during the 30-minute control and VF periods using a mixed-model analysis of variance with trial date and period (i.e., control vs. VF period) as the fixed effects and cow group as the random variable. We then compared HR and movement over 5-minute time intervals during the 30-minute control and VF periods within each trial date. Treatment and 5-minute time interval were considered fixed effects and cow group within time was a random variable to account for the repeated data collected from individual cow groups. All main effects and interactions were evaluated in these analyses. Count of technician observed and Vence recorded VF cue events (e.g., number of audio and electric cues) for all cattle (i.e., with and without HR monitors) within groups were analyzed using a mixed model with trial date as the fixed effect and group as the random variable. We organized and graphically visualized HR response for each of the HR monitored cows that received an electric cue 1 minute before the cue (-60 to -1 seconds), during the cue (0 seconds), and 5 minutes after the cue (1-300 seconds) to assess variability of HR changes during an electric cueing event and the length of time it took the cow to return to their control period HR. Lastly, observed behavioral responses to audio and electric cueing events were averaged across all cattle and reported as the percent of the total responses observed.

We conducted our analyses using the "lmer" function from the lme4 package[22] in R statistical environment (Version 4.3.2, R Core Team 2022). The "emmeans" function was used for post hoc pairwise comparisons. Assumptions of normality were visualized graphically using qqplots and analyzed with the Shapiro-Wilks test in R. Data not normally distributed were transformed using the log function to meet normality assumptions. Differences were considered significant at $P < 0.05$.

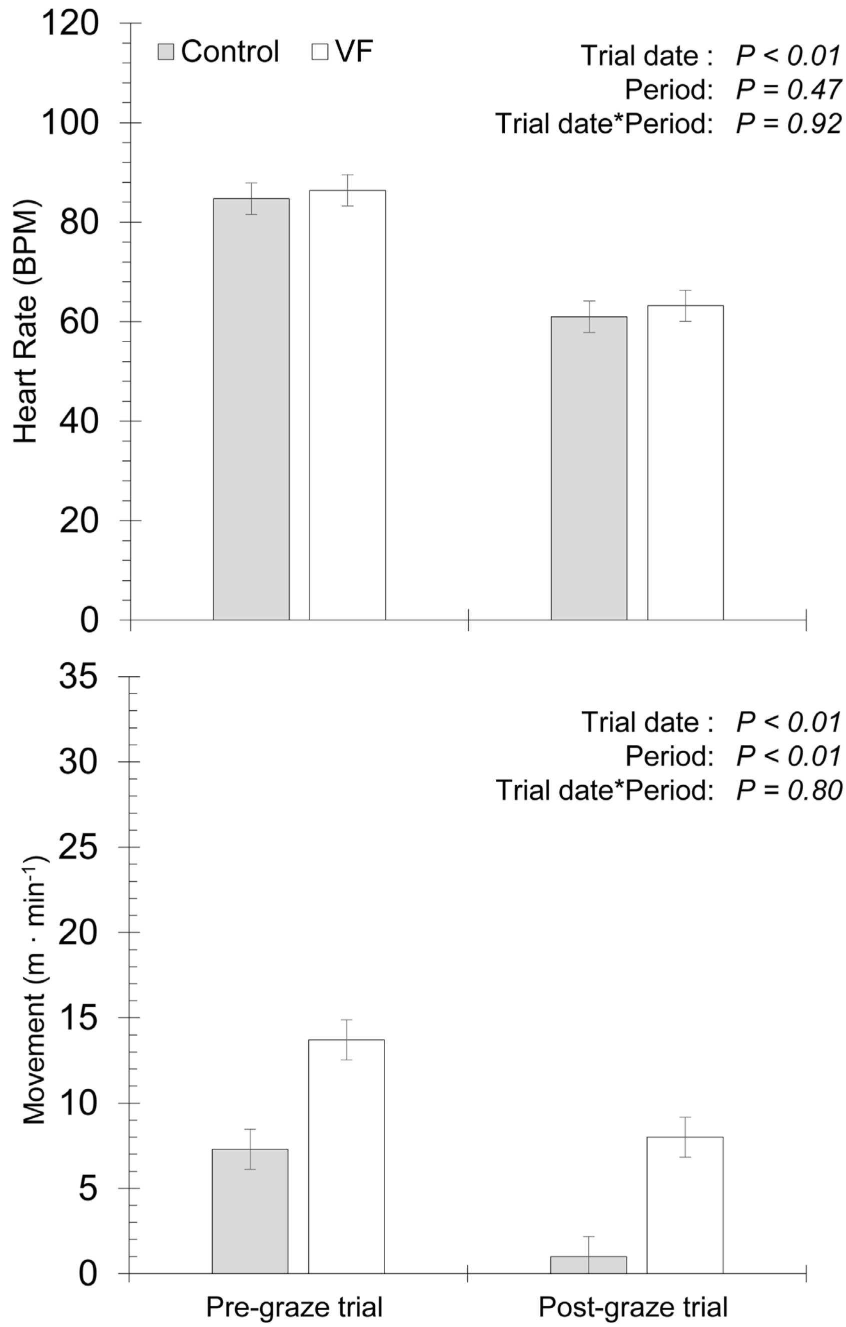

Figure 3. Mean heart rate (top graph, BPM) and movement (bottom graph, m min^{-1}) of cows with calves during 30-minute control and virtual fence (VF) periods conducted during different trial dates (i.e., pregraze in mid-June before cattle were turned out to pasture with VF and postgraze in mid-August after cows were exposed to VF for approximately 60 days) at the Gudmundsen Sandhills Lab near Whitman, Nebraska in 2023.

Results

HR and movement response to VF

No statistical difference in the average HR of cows was observed ($P = 0.47$) between the 30-minute control and VF periods during both the pre- and postgraze trial dates (Fig. 3). However, cow HR averaged across the VF and control periods was 27% lower ($P < 0.01$) during the postgraze trial date in August (62 BPM) compared with HR during the pregraze trial date in June (85 BPM). While average HR was not different between the entire 30-minute VF and control periods, HR during the VF period was higher ($P < 0.01$) during the first 5-minute interval of the postgraze trial (Fig. 4). During the pregraze trial, mean HR was numerically higher during the first 5-minute interval of the VF period, but this was not statistically different ($P = 0.23$; Fig. 4). HR during both trials did not differ during 5-minute intervals later in the VF and control periods. Cattle HR response immediately after an electrical cue was individually variable in both the increase of the HR response and the duration of the elevated HR compared with the control period mean (Fig. 5). Cow HR typically returned to levels near or

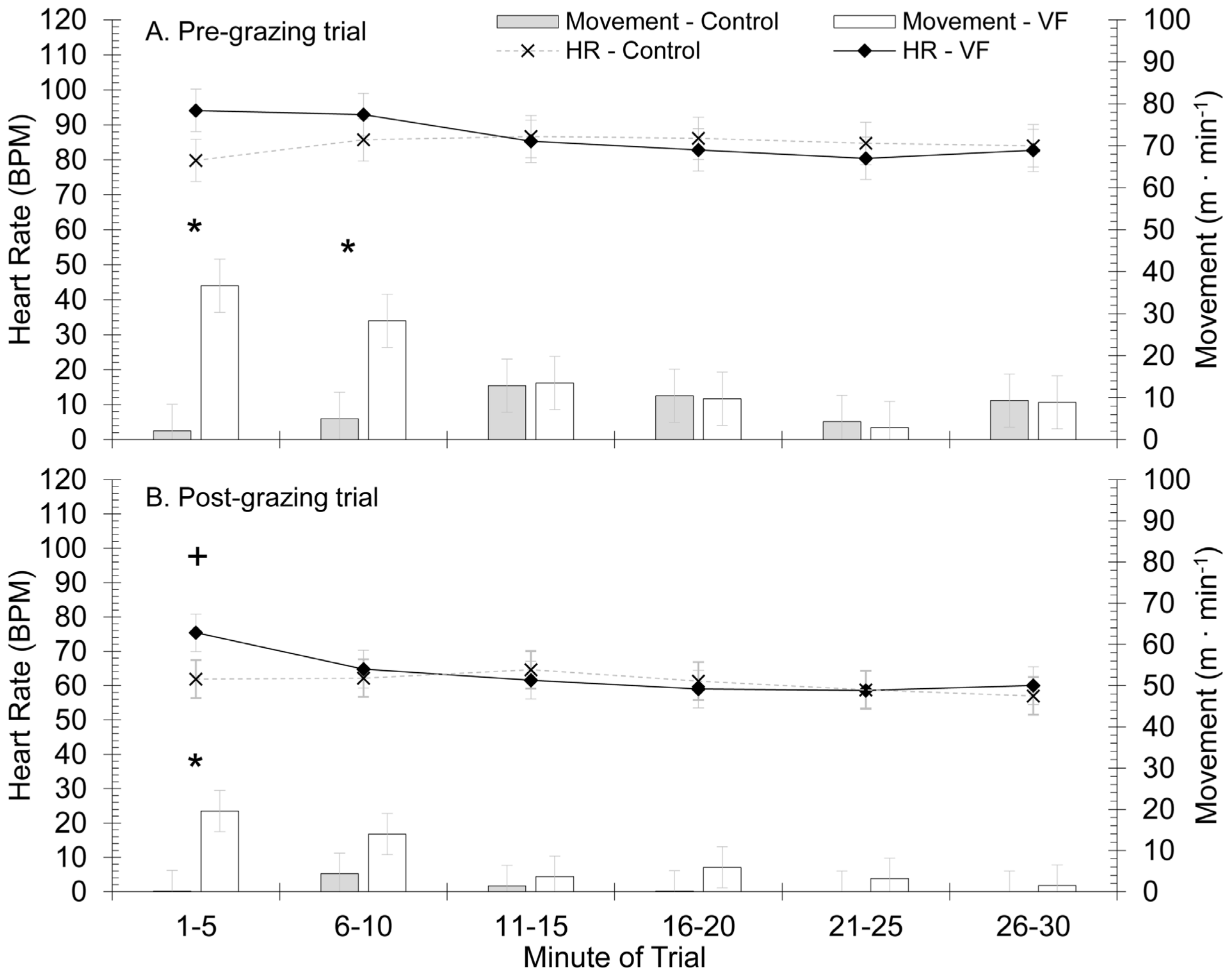

Figure 4. Mean heart rate (HR; line graphs, primary axis) and movement (m · min^{-1}; bar graphs, secondary axis) of cows wearing HR monitors and GPS watches during the 30-minute control and virtual fence (VF) periods of the (A) pre- and (B) postgrazing trial dates. A plus sign (+) represents a significant difference (P < 0.01) in mean HR and an asterisk (*) represents a significant difference (P < 0.01) in movement between control and VF periods for HR and movement, respectively. Data were collected at the Gudmundsen Sandhills Lab near Whitman, Nebraska in 2023.

below the mean HR during the control period within 30 seconds (postgraze trial cow 8158) to 238 seconds (postgraze trial cow 6224) after an electric cue event. One cow (pregraze trial cow 8158) did not show an increased HR response over the control period level following the electric cue.

We observed significant ($P < 0.01$) trial date and treatment main effects for cow movement (Fig. 3). Mean cow movement was 2.6 times greater during the 30-minute VF period compared with the control period across the trial dates (Fig. 3). Movement of cows averaged across the control and VF periods was 57% less ($P < 0.01$) during the postgraze trial in August compared with the pregraze trial in June. We observed a significant treatment by 5-minute interval time of trial interaction ($P < 0.01$) during both the pre- and postgraze trials (Fig. 4). Movement of cows was greater ($P < 0.01$) in the first 5- and 10-minute intervals of the pregraze trial and in the first 5-minute interval of the postgraze trial during the VF period compared with the control period (Fig. 4). No differences in cow movement were observed later during the control and VF periods.

Observations of response to VF

The number of audio and electric cue events for cow groups during the pregraze and postgraze trials differed by event type (Fig. 6). The overall number of audio cues individual cow groups experienced did not differ ($P = 0.67$) between the pregraze and postgraze trials. However, cow groups received 66% fewer ($P = 0.01$) electric cues during the postgraze trial compared with the pregraze trial (Fig. 6).

Cows exhibited an array of observed physical responses to the audio and electric cues during the VF period (Fig. 7). Some behaviors (e.g., full body twitch, running, and jumping) were more frequently observed reactions during the pregraze trial compared with the postgraze trial (Fig. 7). Visual observations indicated that after the initial interaction to the VF audio and electric cues, cows appeared to learn the location of the boundary and individuals were frequently observed standing or resting near the VF barrier during the latter half of the VF period.

When cows were turned out to pasture after the pregraze trial, 85% to 95% of cows remained within VF boundaries

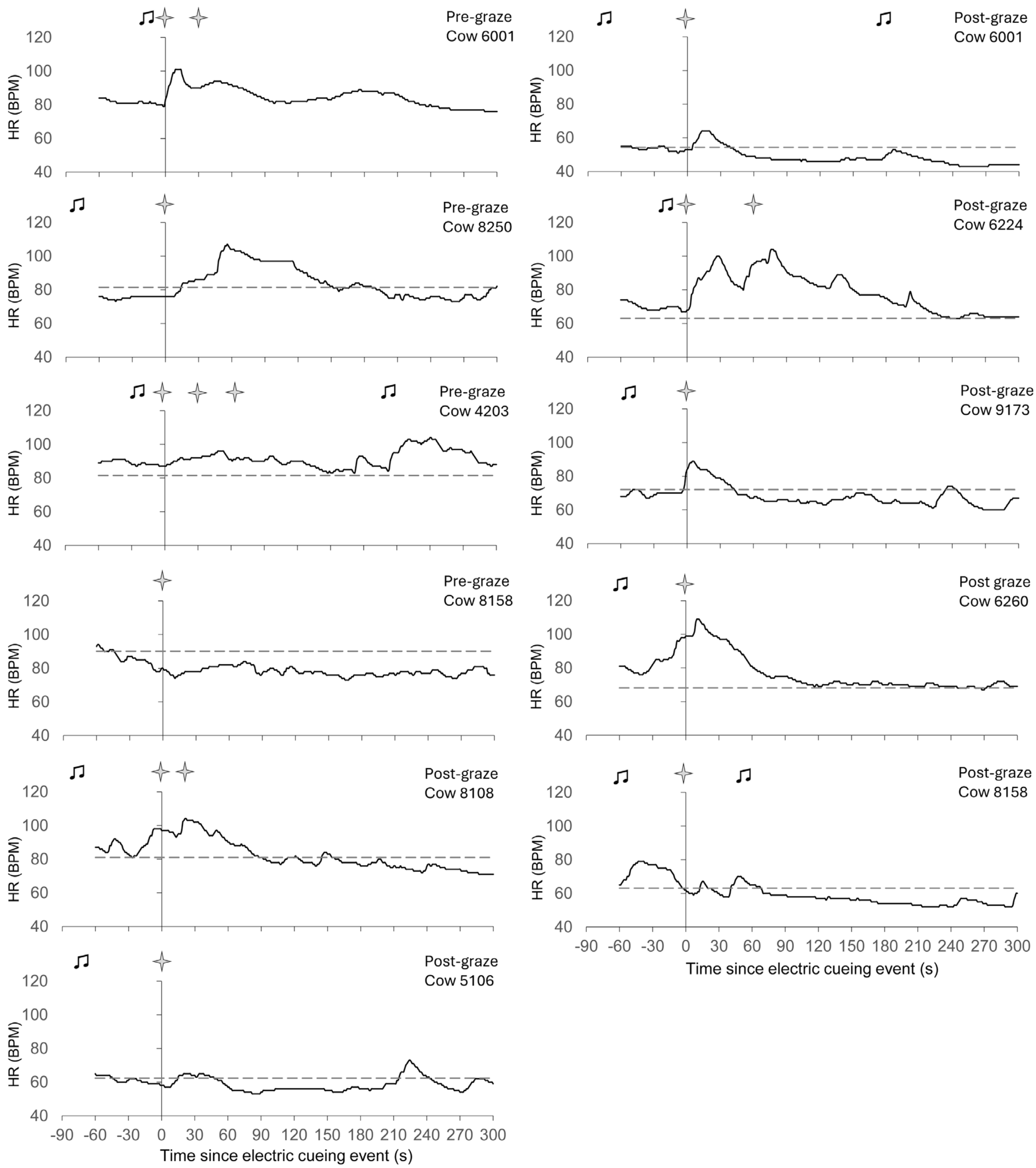

Figure 5. Heart rate (HR) response of cows 1 minute before (-60 to -1 seconds), during an electric cueing event (0), and 5 minutes after (1-300 seconds) during the pre-and postgraze trials. Dashed lines represent mean HR for cows during the control period, audio cues are presented by ♫ and electric cues are represented by ✧. Pregraze Cow 6001 did not record HR data during the control period. Data were collected at the Gudmundsen Sandhills Lab near Whitman, Nebraska in 2023.

(17-19 out of 20 cows) for each of the different VF arrangements during the 60-day grazing period. The one to three cows breaching the boundary typically returned within 1 to 2 hours.

Discussion

With recent technological advances allowing for VF to be used at commercial scales, there are increasing opportunities for VF to be applied to grazing management under different scenarios. Evaluating short-term stress response of grazing beef cows to VF provides better understanding of how cows learn and adapt to experiences associated with PLM technologies.[5,6] Our study supports a growing number of studies showing VF can be used on cattle without causing significant added stress.[12,13,23]

We observed no differences in mean HR among cow groups during the 30-minute control and VF periods during both the pre- and postgraze trial dates. We believe this

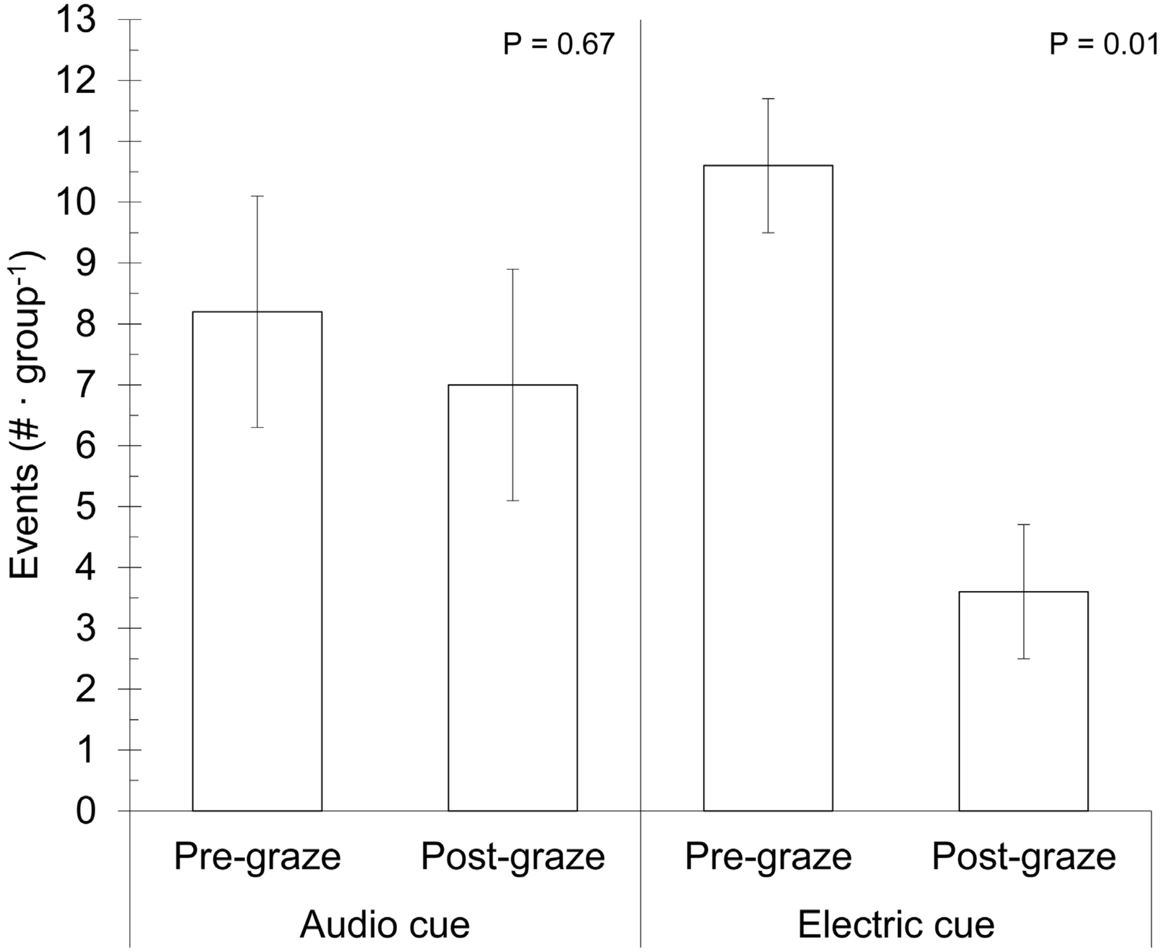

Figure 6. Comparison of the number of audio and electric cues cow groups received during the 30-minute virtual fence (VF) period during pregraze trial in mid-June and the postgraze trial in mid-August at the Gudmundsen Sandhills Lab near Whitman, Nebraska in 2023.

indicates cows learned to adapt to the VF relatively quickly because the HR of cows normalized to a level observed during the control period within the 30-minute VF period. Acute stress responses in cows are challenging to assess, but external HR monitors have been used to evaluate how cows respond to potentially stressful events.[20,24] Mean HR has been used to evaluate stress in cattle experiencing novel cues, such as opening and closing an umbrella in front of cattle,[25] blindfolding cattle,[26] and administering electrical cues to cattle in a chute.[27] Generally, the normal HR of beef cattle is 40 to 70 BPM,[28] but research has documented a range of 80 to 97 BPM for yearling cattle contained within a chute,[12] and an average HR of 83 BPM for lactating compared with 74 BPM for nonlactating beef cows.[24] The 30-minute mean HR of individual cows averaged across the control and VF periods in our study ranged from a low of 71 BPM to a high of 113 BPM (overall mean 85 BPM) during the pregraze trial and a low of 50 BPM to high of 75 BPM (overall mean 62 BPM) later in the growing season during the postgraze trial.

Several physical responses were visually observed (e.g., running and jumping) when cows received electric cues during the 30-minute VF period, especially during the pregraze trial periods. However, these responses did not substantially elevate the mean HR over the whole duration of the 30-minute VF period when compared with HR of the same cow groups, in the same pen, during the 30-minute control period. However, HR was greater during the first 5-minutes of the postgraze trial, and several cows exhibited elevated HR directly after an electric cueing event. This suggests that short-term increases in stress may result when cattle interact with the electric cue boundary, but HR generally returned to levels observed during the control period relatively quickly (i.e., within 30 seconds to 238 seconds) after an electric cuing event (Fig. 5). Our observed HR return interval was much shorter than that reported by Anderson[14] (i.e., 13 minutes). However, their measurement to HR return was the 8-hour mean, which likely would have been lower if the cow had been resting during that period. Lee et al.[27] reported increases in HR of cattle exposed to electric shocks and increased flight times when leaving a chute but concluded that stress responses of animals to low-energy electric shock were minimal.

The lower average HR during the postgraze compared with the pregraze trial may be associated with cattle becoming comfortable with HR monitors or with the changing availability and quality of forage the cattle consumed on native rangelands between June (pregraze trial) and August

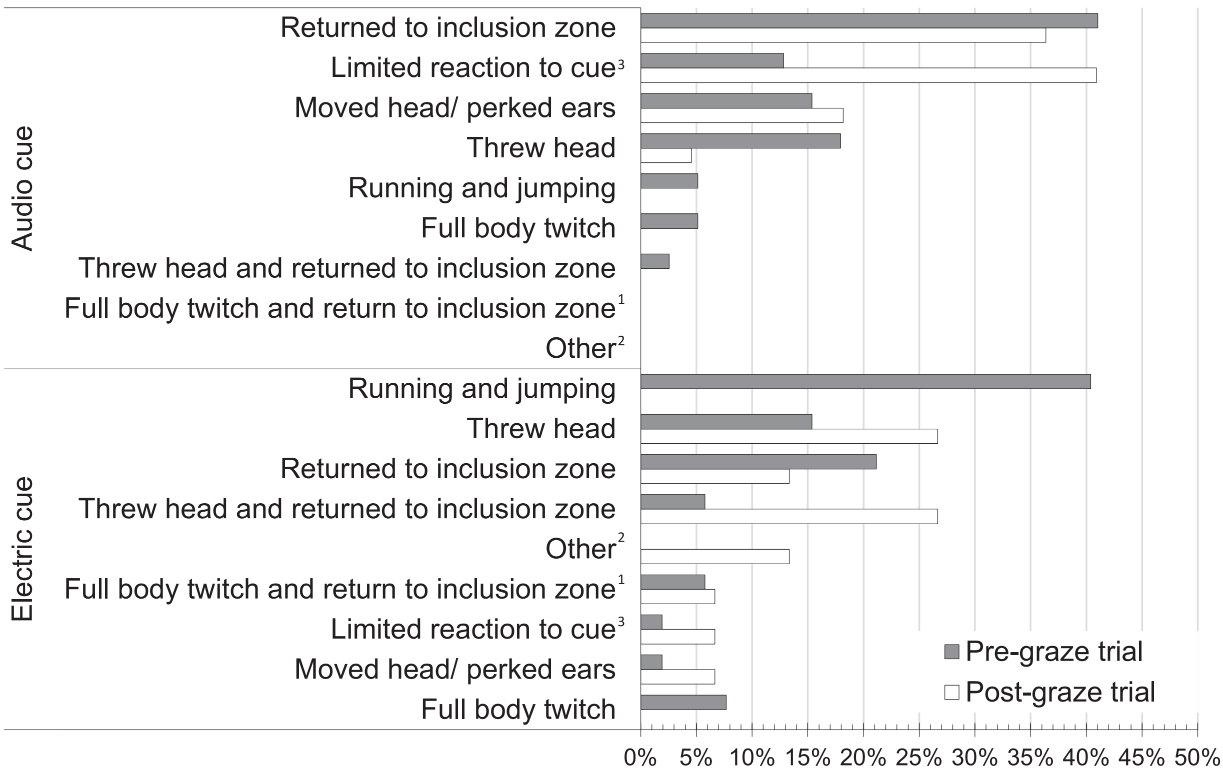

Figure 7. Percent of cow physical responses to audio and electric cues during the pre- and postgraze trial times.[1] Full body twitch is when the cow flinches its body following a VF cue.[2] Other describes actions with one observation as a reaction in the VF treatment periods (e.g., cow swished tail).[3] Limited reactions occurred when an audio or electric cue was observed but the cow did not show a distinctive response and continued with the same action before the cue. Data were collected at the Gudmundsen Sandhills Lab near Whitman, Nebraska in 2023.

(postgraze trial). Brosh et al.[29] indicated that higher HR for cows occurred earlier in the growing season when forage quality was higher and daily grazing energy expenditures were greater compared with later in the growing season when forage quality decreased. Beef cattle also have higher HRs during peak lactation, which would have been near our pregraze trial date in June (~75-100 days from calving date in March) for cattle used in our study.[24] Greater movement of cows during the pregraze trial also likely contributed to the increased HR compared with the lower movement occurring during the postgraze trial.[5] Increased movement, especially early (i.e., first 5-10 minutes) in the VF periods (Fig. 4), also may have contributed to higher HR early in the VF period as cattle moved around the study pen searching out the VF boundaries. Cows also exhibited generally greater HR immediately after an electric cueing event, but, over the longer 30-minute period, HR was not different between the control and VF periods, which suggests that cattle HR response to VF was for only a short period (e.g., seconds to minutes). While more data are needed to explore potential variability among individuals, our study provides a measure of the acute stress of mature cows with calves to VF using HR response, movement, and behavior, which supports other research showing VF does not increase individual animal stress compared with when cows are managed with only physical fence boundaries.[12]

Greater movement during the VF period in the pre- and postgraze trials indicated cows moved more within the study pen because of the VF. Visual observations recorded that as cows contacted the VF boundary they returned to areas along the physical fence near the gate where they were turned into the study pen. When cows experienced either an audio or electric cue, they moved around the pen until they appeared to learn where the VF boundary was located. This increased movement tended to decrease in cow groups as the 30-minute VF period progressed and cows became accustomed to the location of the VF boundary (Fig. 4). By the end of the 30-minute VF period, several cow groups were observed loafing near the audio boundary with some lying down and chewing their cud. Campbell et al.[30] reported yearling cattle having less lying time with VF compared with electric fence but did not observe any additional stress between groups based on fecal cortisol levels. In contrast, Hamidi et al.[12] observed greater lying time on some days when cattle were managed with VF compared with physical electric fences.

Cattle have an innate ability to learn from different external pressures, especially when they are trained to avoid, or find release, from the pressure.[6] Our results support previous research in which cattle were observed learning what the audio cue represented and how to avoid the electric cue after being trained to VF.[31,32] During the postgraze trial in our study, the number of audio cues did not change compared with the pregraze trial, but the number of electric cues cow groups experienced decreased significantly, suggesting cows were more responsive to the audio cue and avoided repeated electric cues.

Additionally, the percentage of cows reacting to electric cues with running and jumping decreased from 40% of the behavioral responses during the pregraze trial to 0% during the postgraze trial. Other research evaluating the effect of VF on lactating cows indicated that individuals learned how to respond to VF, which reduced total cueing events and increased cattle reliance on audio cues rather than electric cues.[32] Thus, in most VF situations, lactating beef cows with calves are likely to learn what cues mean and how to respond appropriately to minimize potential stress associated with audio and electric cues from the VF collars.

While efficacy of VF with trained cattle is typically high, studies have shown that a proportion of animals may move beyond the VF boundaries.[10,16,32,33] In our study, the efficacy of VF on pasture was high (17-19 out of 20 cows did not cross the VF boundary depending on the pasture arrangements), but setting physical fences in critical areas (e.g., along roads) would still be important if cattle could not be managed with 100% certainty. Additionally, battery life, retention of collars on cattle (a collar fell off a single cow during our study), and other technical difficulties (e.g., broken collars) might provide logistical constraints to adopting VF in certain situations. Overall, training appears to be an important factor in cattle positively responding to cues and should be a focus of management when beginning to use VF.

Conclusions

The recent development of VF at commercial scales provides the agriculture and natural resources community with a new tool and opportunity to strategically manage cattle grazing on extensive rangelands. Animal welfare is an essential factor to consider when implementing PLM technologies like VF. Within our study, VF caused minimal acute stress to mature, lactating beef cows when receiving audio or electric cues during a 30-minute period. Additionally, cows learned to adapt to audio cues and avoid electric cues when trained to the VF. Additional research is needed to assess how cow HR and HR variability, a more in-depth measure of acute stress,[34] respond to VF cues over more classes of cattle, in different scenarios (including open pasture), and over more cueing events. However, VF provides a promising tool for optimizing grazing management, reducing labor input, and potentially increasing opportunities for ranchers to manage their grazing land proactively without significantly contributing to increased acute stress of grazing animals.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The authors certify that they have no financial interest in the subject matter discussed in the manuscript. M.S. is a current member of the Rangelands Steering Committee but was not involved in the review or decision process for this manuscript.

CRediT authorship contribution statement

Kaitlyn Dozler: Conceptualization, Writing – original draft, Data curation. **Yijie Xiong:** Conceptualization, Writing – review & editing. **Travis Mulliniks:** Conceptualization, Writing – review & editing. **Andrew Little:** Supervision, Writing – review & editing. **Mitchell Stephenson:** Conceptualization, Funding acquisition, Project administration, Writing – review & editing.

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