Comparison of Dairy Cow Aversion to Continuous and Intermittent Current

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Abstract. *The results of studies comparing dairy cow response to steady−continuous, pulsed−continuous, pulsed−intermittent, and single−exposure current applied to water bowls are presented. Aversion studies were performed in which the magnitude of applied current was set at a level having a fixed relationship to the sensitivity of individual animals. In the first experiment, response to a steady 60 Hz stimulus continuously applied to a water bowl (steady−continuous) was compared with response to a 10−cycle 60 Hz stimulus pulsed once per second (pulsed−continuous). No differences between responses to these two treatments were evident. In the second experiment, responses to pulsed−continuous stimulus, to a 10−cycle 60 Hz stimulus applied to the water bowls once every 10 min (pulsed−intermittent), and to a single event of pulsed current (single−pulse) were compared to a control group receiving no current. Only the pulsed−continuous treatment produced a response significantly different from the control. The pulsed−continuous treatment increased the delay to drink and inhibited water consumption over both 4 and 8 h intervals for current exposures ranging from 6 to 15 mA peak. These effects were not observed for the pulsed−intermittent or single−pulse treatments.*

Keywords. *Dairy cows, Electrical exposure, Stray voltage.*

In prior aversion studies, current and voltage exposure has generally been applied continuously as steady 60 Hz stimuli. Several studies have, however, examined responses to intermittently applied currents. Gorewit et al. (1985) reported that 4 mA of current applied semi−randomly in a non−avoidance environment across subdermal electrodes on cows' spines for four continuous 24 h intervals did not alter milk yield, milk composition, or intake of feed and water. Aneshansley et al. (1988) reported no significant change in water intake, milk production, milk quality, or somatic cell count in cows exposed to 8 V (60 Hz, rms) in a regular, pulsed pattern and in a random pattern. In a study by Currence et al. (1990), a 10−cycle 60 Hz pulse applied repeatedly produced reaction at the same peak current level as steady 60 Hz stimuli, while a single−cycle 60 Hz stimulus required more current to elicit a behavioral reaction. Aneshansley and Gorewit (1999) reported that a 6−cycle 60 Hz pulsed stimulus required somewhat more current than steady 60 Hz current to stop cows from drinking.

Aversion studies performed at the University of Wisconsin applied pulsed currents of 60 Hz and 6000 Hz to water bowls once every second (Reinemann et al., 1995, 1996, 1999). This routine can be characterized as continuous exposure to a pulsed stimulus, as cows could not drink without being exposed to current, even though the current was applied in a pulsed manner. These are worst−case scenarios, as voltage and current exposures in the field tend to be intermittent. For example, current and voltage transients produced by motors starting will occur only when the motor is started. This may occur from several times per day up to several times per hour. Steady−state voltage and current levels generally vary throughout the day, depending on the relative magnitude of sources and the use patterns of these sources.

This study had two objectives, the first of which was to compare aversive responses to steady versus pulsed stimuli applied to pathways typical of those encountered in the field. The second objective was to compare the relative effects of current pulses applied once per second with those applied less frequently.

Materials and Methods

The test stalls, electrical apparatus, and sensitivity measurement methods described previously (Reinemann et al., 1999) were used to determine the sensitivity of each cow to a pulsed−continuous current applied via the muzzle to all hooves pathway prior to all aversion tests. Prior to participation in an experiment, each cow's behavioral response threshold to applied current was determined. Pulsed−continuous current was applied via the muzzle to all hooves pathway and increased in increments of about 1 mA until trained observers noted a behavioral response. The current exposure levels reported in this article are specified by the zero−to−peak value of the 60 Hz sinusoidal waveforms applied. The behavioral response threshold levels of the cows used in these experiments are listed in table 1. Note that the behavioral response levels are given as the measured current

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Table 1. Behavioral reaction thresholds of cows used in these experiments reported as zero−to−peak mA of a 10−cycle series of a 60 Hz waveform applied once per second.

Experiment	Group	Cow Number	Lactation Number	Days in Milk	Behavioral Reaction Threshold (Peak mA)
A	1	4049	2	40	14.9
A	1	3810	4	50	11.2
A	1	4052	2	57	13.8
A	1	3864	4	45	12.5
A	1	3995	2	153	8.1
A	1	3895	3	160	8.9
A	1	3996	2	224	7.9
A	1	3804	4	228	8.9
A	2	3964	2	55	7.2
A	2	3965	3	57	8.1
A	2	3894	3	51	9.1
A	2	936	4	62	8.1
A	2	3985	3	10	7.0
A	2	4061	2	16	7.0
A	2	3732	5	67	8.8
A	2	3967	3	48	9.9
B	1	4080	2	50	6.0
B	1	3925	3	127	5.0
B	1	3872	4	88	7.9
B	1	3730	5	124	7.7
B	1	3862	4	63	6.7
B	1	3744	5	30	5.7
B	1	3851	4	133	5.9
B	1	3978	3	41	4.0
B	2	3780	4	239	9.2
B	2	4151	1	244	8.2
B	2	4084	2	69	7.2
B	2	4050	2	192	5.1
B	2	3813	4	281	7.2
B	2	3827	4	249	7.1
B	2	3717	5	257	5.1
B	2	3884	3	286	8.0

at which the response was noted. Because the increment in current application was about 1 mA, the actual response threshold may have been up to 1 mA below the cited level.

Cows received no current exposure for a minimum of three days between behavior threshold testing and subsequent aversion studies. The water supply to all water bowls was turned off 3 h prior to the start of treatment exposures (5:00 a.m.). This was done to reduce variability by ensuring that all cows had a desire to drink upon returning from the morning milking. It is estimated that a cow was deprived of approximately 20% of her normal daily water intake during this time. The cows were released from their stalls for milking at about 7:00 a.m. Cows were then sent to an outside yard after milking. During this time, the experimental stalls were prepared by turning on the water supply and applying the specified voltage/current to each water bowl. Cows were returned to the test stalls at about 8:00 a.m.

Experiment A: Comparison of Steady−Continuous with Pulsed−Continuous Stimulation

Experiment A was designed to compare responses to steady−continuous (SC) and pulsed−continuous (PC) stimuli of the same current level. The SC treatment was a steady 60 Hz stimulus continuously applied to each individual cow's water bowl. The PC treatment used 10 cycles of 60 Hz stimulus applied to each individual cow's water bowl once per second. The duration of each current exposure was 24 h. No water sources were made available to cows other than their individual water bowls. The current levels applied to the water bowl of each cow corresponded to the current level required to produce an observable behavioral response for that cow using a PC stimulus applied from muzzle to all hooves. These current thresholds were determined for each cow a minimum of three days before beginning each experiment. A crossover design was used, with a total of 16 cows in two replicates of 8 cows each. Hourly total water consumption and quarter−hour totals for the first hour of exposure were recorded for each cow on four consecutive days of the experiment for each replicate as follows:

- Day 1: Control day with no treatment placed on the water bowls.
- Day 2: Sub−reaction current on the water bowl. The voltage levels were set at 1.4 V peak, so that 1 mA rms of current would pass through a 500 Ω shunt resistor used in the manner recommended for making field measurements of stray voltage. These current levels were well below the reaction level of all cows. Data from this day were used for a study of cow drinking behavior reported by LeMire et al. (1997).
- Day 3: Treatment day with four cows (group 1) exposed to SC stimulus and four cows (group 2) exposed to PC stimulus.
- Day 7: No treatment was applied for three days. Treatments were again applied on day 7 with four cows (group 1) exposed to PC stimulus and four cows (group 2) exposed to SC stimulus (treatments applied in reverse order for each cow).

Experiment A Results

The effects of treatment (SC vs. PC), group, and group−by−treatment interaction were tested using an SAS mixed model with repeated measures (response = treatment + group + group × treatment; repeated/subject = cow). The effects of group and of group−by−treatment interaction were not significant for any of the response measures, indicating that the order of treatment had no significant effect (table 2).

The model was then refined by removing the group and interactive terms. The results of this refined model are presented in table 3. One cow (No. 4052) developed a displaced abomasum after day 3 and was not used on day 4. This cow had experienced a displaced abomasum about one month earlier while on another research trial.

Drinking behaviors did not differ between the control and the 1 mA treatments. Likewise, drinking behaviors did not differ between the SC and PC treatments. However, the SC and PC treatments both differed from the control and 1 mA treatments. Cows exposed to the SC and PC treatments showed an increased delay to drink and reduced water consumed in 4 and 8 h. These differences were largely due to

Table 2. Results of significance test of treatment, group, and group × treatment effects for experiment A.

	Delay	4 h Water	8 h Water
Treatment	p = 0.78	p = 0.63h	p = 0.96
Group	p = 0.98	p = 0.26	p = 0.18
Group × Treatment	p = 0.36	p = 0.15	p = 0.59

Table 3. Least squares means of delay to drink first 3.8 L (1 gal.) of water, water consumed in 4 h, and water consumed in 8 h for experiment A.

	Delay (h)	Water in 4 h, L (gal.)	Water in 8 h, L (gal.)
Control (C)	0.8 a	25 (6.6) a	45 (12.0) a
1 mA	0.4 a	28 (7.3) a	46 (12.1) a
Steady−continuous (SC)	5.2 b**	14 (3.8) b***	32 (8.5) b*
Pulsed−continuous (PC)	6.0 b**	13 (3.4) b***	33 (8.7) b*
Standard error	1.5	2.9 (0.77)	4.1 (1.1)

Note: Least square means followed by the same letter are not different at the 95% confidence level.
* Indicates $p < 0.05$.
** Indicates $p < 0.01$.
*** Indicates $p < 0.001$.

three of the 16 cows. This experiment had in excess of 80% power (Lachin, 1981; Cohen, 1988) to find a 0.7 h, 11 L (2.8 gal.), and 13 L (3.4 gal.) difference in delay and water consumed in 4 and 8 h, respectively, between the control and the 1 mA exposures and a 8.7 h, 12 L (3.1 gal.), and 20 L (5.3 gal.) difference in delay and water consumed in 4 and 8 h, respectively, between the PC and SC treatments.

Experiment B: Comparison of Pulsed−Continuous with Intermittent and Single−Pulse Stimulation

Experiment B was designed to compare responses to PC stimuli with responses to intermittently applied (I) and single−exposure (S) stimuli of the same current level. The PC treatment used 10 cycles of 60 Hz current applied to the water bowl once every second. Treatment I used the same level and type of stimulus and was applied once every 10 min. The S treatment was applied as follows. A cow was placed in a treatment stall under observation. A PC current was applied to the water bowl. The first time she attempted to drink, she was exposed to the PC stimulus. Immediately following this drink or attempt to drink, the PC stimulus was removed from the water bowl for the remainder of the treatment period. The current levels applied to the individual water bowl of each cow for all treatments was 150% of the current required to produce an observable behavioral response for that cow using a PC stimulus applied from muzzle to all hooves.

A total of 16 cows were used in two replicates of eight cows each. The duration of exposure was 8 h. Within each replicate, a crossover design was used with each group of eight cows divided into four subgroups: one control group receiving no stimulus, and three treatment groups. Each subgroup received all three treatments according to the schedule indicated in table 4. A period of at least three days,

Table 4. Sequence of treatments for experiment B (C = control, PC = pulsed−continuous, I = intermittent, S = single exposure).

		Stall			
Group	Day	1 and 2	3 and 4	5 and 6	7 and 8
1	1	C	PC	S	I
1	2	I	C	PC	S
1	3	S	I	C	PC
1	4	PC	S	I	C
2	1	C	PC	S	I
2	2	I	C	PC	S
2	3	S	I	C	PC
2	4	PC	S	I	C

Table 5. Results of significance test of treatment, day, and day × treatment effects for experiment B.

	Delay	4 h Water	8 h Water
Treatment	$p < 0.0001$	$p < 0.0001$	$p < 0.001$
Day	$p = 0.79$	$p = 0.35$	$p = 0.80$
Day × Treatment	$p = 0.76$	$p = 0.69$	$p = 0.99$

during which cows received no current, was allowed between treatment days.

Experiment B Results

As with experiment A, a mixed model with repeated measures analysis was used (response = treatment + day + day × treatment; repeated/subject = cow). The interaction of treatment with day was not significant (table 5), indicating that, although the sequence of treatments for each cow was not randomized, the effects of treatment were not due to the order in which treatments were applied.

The model was then refined by removing the day and interactive terms. A summary of the results of the final model is presented in table 6. None of the drinking behaviors differed between the control, intermittent, and single−exposure treatments. This experiment had in excess of 80% power to find a 0.5 h, 5.7 L (1.5 gal.), and 6.8 L (1.8 gal.) difference in delay and water consumed in 4 and 8 h, respectively, between the control, S, and I treatments. The pulsed−continuous treatment was significantly different from all other treatments ($p < 0.0001$).

Behavioral responses in this study were noted for 60 Hz current exposures ranging from 4.0 to 15 mA peak (2.8 to 11 mA rms) for short−term exposures using the muzzle (nose ring) to all hooves pathway. Changes in drinking behaviors were observed for current exposures ranging from 6.0 to 15 mA peak (4.2 to 11 mA rms) using pathways typical of cow housing (water bowl to floor). These values compare well with previous studies in which short−term 60 Hz exposures of 2.2 to 5.4 mA rms produced behavioral responses when applied from one front to one rear hoof of 24 cows (Currence et al., 1990) and steady 60 Hz currents from 3.3 to 18 mA rms applied to water bowls caused cows to stop drinking (Aneshansley and Gorewit, 1999).

Conclusions

Cows exposed to 1 mA of steady 60 Hz current on their water bowls showed no changes in drinking behavior as compared to the previous day when no current was applied. Some cows exhibited moderate changes in drinking behaviors when exposed to 60 Hz current at a level sufficient to

Table 6. Least squares means of delay to drink first 3.8 L (1 gal.) of water, water consumed in 4 h, and water consumed in 8 h for experiment B.

	Delay (h)	Water in 4 h, L (gal.)	Water in 8 h, L (gal.)
Control (C)	0.8 a	31 (8.1) a	55 (14.4) a
Single exposure (S)	0.4 a	33 (8.7) a	55 (14.4) a
Intermittent (I)	0.4 a	31 (8.1) a	55 (14.6) a
Pulsed−continuous (PC)	6.4 b***	3.4 (0.9) b***	22 (5.6) b***
Standard error	0.37	0.51	0.90

Note: Least square means followed by the same letter are not different at the 95% confidence level.
*** Indicates $p < 0.0001$.

produce a behavioral response. Drinking behaviors did not differ, however, between 60 Hz current pulses applied once per second and continuously applied 60 Hz stimuli with the same peak current. Experiments performed with pulsed−continuous current exposures can therefore be compared to those performed with steady 60 Hz current exposures.

In a second experiment, a significant difference was observed in the drinking behavior of cows exposed to 60 Hz current at 150% of their behavioral threshold applied to water bowls in a pulsed−continuous manner (10 cycles of 60 Hz current applied once per second). However, no significant difference in drinking behavior was observed for cows exposed to the same level of current applied in an intermittent manner (10 cycles of 60 Hz current applied to water bowls once every 10 min) or those exposed once (10 cycles of 60 Hz current applied to water bowls at cow's first attempt to drink). This result indicates that if the exposure conditions were such that cows had sufficient time to drink after or between current pulses, they consumed water at the same rate as cows receiving no current stimulus.

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