compared to those at 0.25 mA and above. However, when no alternative source existed, greater than 3.0 mA was needed to affect drinking time and 4.0 mA to affect consumption.

Robert (1991) examined the effects stray voltage on 72 growing/finishing pigs by applying treatments of 0, 2 V or 5 V between the feeder or drinker and the metallic floor. During daytime, the applied potential difference of 5 V decreased the eating frequency in both feeding groups and the drinking frequency in restricted-fed pigs. Daily feed intake and average daily gain were lower in the 5 V group than in the 2 V and the control groups from 17 to 21 weeks of age. Gastric lesions, hematological and biochemical variables were not affected by either voltage level.

Matte (1992) measured the total body impedance (TBI) of 12 pigs between the ages of 9 and 22 weeks exposed to 2 V or 5 V of 60 Hz AC and flooring conditions of woven wire covered with water (WW) or dry (WD). TBI was higher at 2 V (1300 Ohms) than at 5 V (1091 Ohms) while the effect of age on TBI also depended on the age of pig and the wetness of the floor with values ranging from 3041 Ohms (WD) to 1031 Ohms (WW) at 10 weeks of age to 1036 Ohms (WD) to 778 (WW) at 18 weeks of age. The reduction in TBI with age could be explained by the increase of the contact area and of the pressure exerted by hooves on the floor, which are major factors influencing the quality of floor-hooves contact. In a second trial, TBI was measured for two 15 week-old pigs with 1 V and 2 V of current at frequencies of 60 Hz, 1000 Hz, 3000 Hz and 10,000 Hz on flooring surfaces WW, WD, and a copper plate covered with water (CW). No difference in TBI was found between the 1 V and the 2 V treatments while TBI at 60 Hz on CW was lower than on WD but similar to that measured on WW. As current frequency increased, the differences among surfaces disappeared. These results indicate that a greater amount of current could pass through the body of growing-finishing pigs as they get older and/or heavier. Among the studied factors affecting TBI, wetness of the floor and current frequency appeared to be the most important.

Robert (1992) evaluated the effects of 0 V, 5 V or 8 V applied between feeder or drinker and the metallic floor on 72 growing-finishing pigs. The total drinking time and the number of drinking bouts were lower in the 8 V group than in the 0 V group. The percentage of time spent drinking during light hours was reduced in the 5 V and 8 V groups at 18 and 20 wk. However, it was only between 14 and 16 weeks of age that water intake was lower in the voltage groups. There was no effect of voltage on mean daily feed intake and average daily gain over the whole fattening period. Behaviors were modified in the 8 V and 5 V groups while the metabolic profile, the frequency and the severity of gastric ulcerative lesions and the meat color were similar among the treatments.

Goodcharles (1993) subjected 72 pigs to 0 V plus 2 V pulses, 2 V plus 3 V pulses, 5 V plus 8 V applied between feeder or drinker and metal floor and a control with no voltage. Pulses were of 3 second duration. No major impact voltage exposure on health, growth or welfare of fattening pigs was observed. Some behavior changes were noted, however.

Kambic (1993) evaluated the effects of electrical stimulation on the mechanical properties of healing skin of 20 Hanford mini-pigs. Wounds were stimulated 2 hours per day, 5 days per week for 30 days. The stiffness values for skin samples oriented parallel to the current flow were reduced by nearly half the values obtained for normal controls (a desirable condition). No adverse effects were reported.

Robert (1994) conducted an experiment to determine the current through pigs housed on different types of floor (woven wire, concrete, molded plastic, or plastic-coated metal) and under different flooring conditions (dry or wetted with urine). Current flow was higher in wet than in dry conditions and increased with age on the 4 floor types, as did the hoof contact area with floor and hoof pressure of pigs. In dry conditions, there was no measurable current flow on the 2 plastic floors. On all floor types, except dry plastic, the current flow increased with frequency of current, the highest values being on the woven wire floor. These data show how the contact impedance between the floor and the hooves varies as a function of floor conditions and can influence the amount of current through young and adult pigs.

Heyde (1995) measured galvanic DC voltages of 400 mV to 600 mV between the floor and farrowing crates, water bowls, and feed troughs. No link between voltage, behavior, and production was reported.

Kennedy (1995) measured heart rate and behaviors of gilts released into a field surrounded by an electric fence for the first time. Most contacts with the fence occurred in the first 10 minutes of the first day after which the pigs avoided the fence. The magnitude of the heart rate response did not diminish with subsequent shocks but increased with increasing gestation. The authors suggest that contact with an electric fence for the first time during pregnancy could contribute to reproductive upset.

Robert (1996) randomly assigned 120 gilts to three voltage treatments; 2 V steady with 5 V pulses, 5 V steady with 8 V pulses, and a control treatment. The steady voltage was applied 24 h/day while pulses of 3 sec duration were applied at irregular intervals. Gilts showed some behavioral response to voltage while the behavior of sows and suckling pigs was not affected. Water and feed intakes were similar among treatments, except during week 1 of lactation where feed intake was lower in the control group. It was concluded that exposures up to 8 V did not impair the welfare, reproductive performance, or health of sows and suckling pigs.

3.18.2. Sheep[11]

Duvaux-Ponter (2005) performed an avoidance test to determine the threshold level at which sheep perceive the electric shock, and their behavioral responses. Ewes had free choice to eat from one of two metallic feeders. A voltage was then applied from to the feeder in which the ewe initially started to eat to a metal floor-plate on which the ewe stood. This allowed the ewe to change to the non-electrified feeder if it wanted to. The voltage was increased daily in steps of 0.5 V from 1 V up to 8 V. At 5.5 V and above, the ewes tended to spend more time eating and to eat more from the non-electrified feeder

[11] *The two studies reported here are the only published works in which sheep were exposed to voltage and current levels typical of stray or tingle voltage. There have been other studies on sheep with extremely high level of current exposure used for electro-immobilization during shearing (Rushen, 1986; Kuchel, 1990) intentionally stressful foot-shocking. (Domanski, 1986, 1989, 1992; Morris, 1997; Prsekop, 1984, 1985, 1986, 1990) electric fences for training (Cavani, 1994) and electro-acupuncture for analgesia (Bossut, 1986). These exposures generally produced pronounced behaviors and some produced hormonal responses.*

compared with the electrified feeder. The number of ewes which suddenly removed their heads while eating in the electrified feeder was higher at 4 V and 5 V compared to no voltage. The authors concluded that a voltage of 5.5 V appears to be the threshold at which avoidance behavior starts for a large number of the ewes, but that there were differences in the responsiveness of animals. Further research on resistance values was recommended to account for some of this variability. In a second study with the same methodology but using lambs, Duvaux-Ponter (2006) reported that they avoided feed bowls starting at a threshold of 5 V.

3.18.3. Poultry

Wilcox (1986) reported on a field study in a laying facility in which egg production and feed consumption were reduced by about 1/3 in the span of 1 week. Potentials of 0.8 to 0.9 V between the metal cage and water in the plastic cups and a 1.3 V to 1.5 V potential between the cage and a driven ground rod were measured. Reduction of voltage potentials was associated with water and feed consumption and egg production returning to normal levels. It was speculated that electrical disturbances could be a source of production loss in cage layers.

McFarlane (1988; 1989) studied the effects of electric shock on health, behavior, and performance of chicks. Chicks were exposed to currents increasing from 2.9 mA on Day 1 to 8.7 mA on Day 7, applied from one point on a foot to another. When exposed to this between 10 and 17 days of age, chicks' weight gain was reduced by 12%, feed intake by 5% and gain:feed by 8%. Chicks were reported to habituate to the shock over time. Effects of multiple concurrent stressors chicks was also studied using intermittent electric shock between 2.9 and 8.7 mA, ammonia, beak trimming, coccidiosis, heat stress and continuous noise as stressors. All stressors, except noise, decreased weight gain, feed intake and feed conversion efficiency. Performance results indicated that chicks responded to each stressor in the same fashion regardless of whether a stressor occurred singly or concurrently with up to five others.

Halvorsen (1989) reported on a field investigation of turkeys poults that experienced increased mortality. Alternating current voltage potentials of up to 2.5 V was detected between waterers and the floor. Reduction of voltage potentials was associated with resolution of the mortality problem. A series of experiments was subsequently conducted to determine the sensitivity of turkey poults to alternating current. It was concluded based on these experiments that the voltage levels measured at the farm did not cause the mortality experienced.

Villeneuve (1990) investigated the effects of both continuously applied voltages from 1 V to 9V in three separate experiments and randomly applied voltages from 3 V to 9 V in a fourth experiment. voltages were applied between the nipple drinker and the metallic cage on 30 hens laying hens per treatment. Each experiment lasted from 2 to 4 weeks. Up to 3 V of continuous exposure had no effect on laying rate, daily feed intake, or daily water intake. Exposures of up to 6 V also had no effect on laying rate but did influence feed and water behaviors at times but these differences were inconsistent and overall there was no effect of treatment. Randomly applied voltage of up to 9 V had no influence on laying rate, daily feed intake or daily water intake. The authors concluded that up to 9 V of continuous or randomly applied voltage does not impair egg production, and that the electrical resistance of hens from beak to foot was much higher than that of dairy cattle and pigs.

Vidali (1995; 1996) studied the effects of sinusoidal voltages applied between metallic nipple drinker and the metallic cage on 120 laying hens in 7 different experiments and chopped sinusoidal voltages an another group of 120 laying hens in 5 additional experiments. Neither sinusoidal nor chopped sinusoidal voltage differences as high as 18 V had an effect on the hens' production and behavior. The electrical resistance of 23- and 40-week-old hens was measured and found to vary between 350,000 and 544,000 Ohms.

Worley (2000a; 2000b; 2001) investigated concerns of poultry producers that the number of eggs that end up on floors and between slats rather than in nests may be related to voltage exposures. A field survey was done on 15 farms and reported that it was difficult to gauge the extent of the exposure problems because of the fluctuation in voltage levels. While there was no correlation between percent of floor eggs and the amount of voltage found, the author speculated that voltage may be a contributing factor to floor and slat egg problems. Subsequent experiments were performed in which mature and young hens were subjected to 0, 3, 6 or 9 V between slats and laying nests. These data indicated no difference in laying habits between any of the treatments and control pens, however all of the groups of hens (including the control groups) had a high incidence of laying eggs in locations other than the nest, indicating that factors other than the applied voltage may have been causing a floor egg problem.

3.19. Summary and Synthesis of Research

3.19.1. Compilation of Dairy Cow Reponses to Current Dose

Figure 5 illustrates the combined results of studies on dairy cows in which an ascending series of 60 Hz current was applied through various body pathways until a behavioral response threshold was observed. These data were compiled from the following studies: Aneshansley, 1997, 1999; Craine, 1975; Currence, 1990; Gorewit, 1984; Lefcourt, 1982, 1986; Norell, 1985; Reinemann, 1995, 1996, 1999b, 2003b, 2003c; Whttlestone, 1975; Woolford, 1972; and represent 355 cows, in 15 separate experiments, by 9 research groups, across 31 years and two continents. The studies summarized in Figure 5 all verified that current flowing through an individual cow during the course of a series of tests in which the current dose was gradually increased until a pre-defined behavioral response was observed. These tests allow for the specification of response thresholds for individual animals. All of the response levels have been converted into equivalent 60 Hz rms steady state levels using relationships from measurement practice (e.g. 1 milliamp measured from zero-to-peak for a sinusoidal waveform = 0.707 mA rms) and from neuro-electric models with experimental verification (e.g. the response to a single cycle sinusoidal stimuli is equivalent to about 80% of the same waveform applied in a continuous or multiple cycle manner).

The green line in Figure 5 indicates a mild behavioral response noted by the researchers in those studies that were designed to determine this type of behavioral response threshold. The majority of these (from 10% to 90% of cows) fall between 3 and 8 mA of 60 Hz rms current with the 50th percentile just below 5 mA.

In some of these experiments, researchers increased the current exposures above the level required to achieve the first, mild behavioral response and recorded current level that produce stronger or more pronounced behavioral responses. Many of the research groups noted rapid acclimation to the current levels just sufficient to produce subtle behavioral responses and increased current exposure levels in order to obtain a more repeatable (stronger or more pronounced behavioral) response. One study represented in this pronounced behavior group (Reinemann, 2003b) used involuntary muscle contraction was used as the response threshold when an ascending series of current was applied between muzzle and all hooves. The threshold of involuntary muscle contraction would be expected to occur at higher current does levels than the threshold of sensory stimulation. This threshold was chosen as being a more repeatable metric that the sensory response threshold for purposes of comparing responses to different current waveforms but was not judged to be painful to cows by trained observers. The sample of 125 cows represented by a discomfort behavioral response is indicated by the yellow line in Figure 5 with the 10% to 90% values spanning 4 mA to 9 mA and the 50th percentile at 6.5 mA.

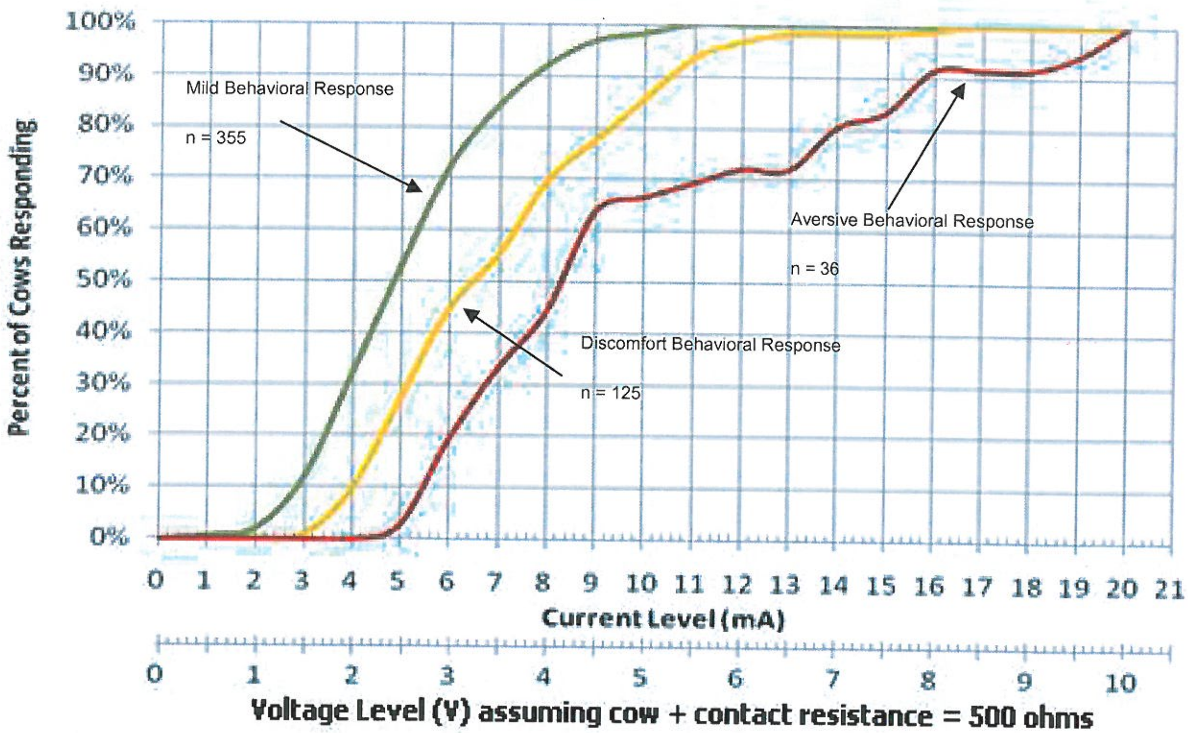

Figure 5. Summary of Behavioral Response thresholds for Dairy Cows exposed to ascending series of 60 Hz current exposures. Current is expressed in equivalent 60 Hz rms values.

Aversive response thresholds (stop drinking) and those studies in which researchers identified thresholds at which cows appeared to be in pain are indicated by the red line in Figure 5. This threshold has been documented by the least number of studies (36 cows) and fall in the range from about 5 mA up to 16 mA of current dose, with the 50th percentile just above 8 mA. The comparison of the 50th percentile values for these three response types give a good indication of the general relationship between sensation, motor response and annoyance, as is predicted by neuro-electric theory: first behavior 5 mA, pronounced behavior 6.5 mA (or 1.3 times first behavior), aversion 8 mA (or 1.6 times first behavior).

Table 2. summarizes the experiments in which groups of cows were exposed to a constant current when attempting to eat or drink or during milking (depending on the specific experiment). The cows in these studies are not included in the summary presented in Figure 5 because an ascending series of current was not used to determine a response threshold. The individual responses of cows was also not generally reported in these studies, however, the researchers often noted the general pattern of responses (e.g. "some cows showed behavioral changes"). The experiments summarized in Table 2 represent over 260 cow tests (some cows were used in multiple experiments).

Table 2. Summary of experiments in which groups of cows were exposed to constant current stimulus when attempting to eat or drink, or during milking.

mA	Author	Year	# Cows	Exposure Pathway	Responses
1.0	Gustafson	1985	6	FH-RH on wet expanded metal plates	NC in hoof lifting (31% compared to 27% for control)
1.0	Gustafson	1985	6	Metallic mouth bit – AH on wet metal plates	NC in mouth Opening (7% compared to 8% for control)
1.0	Norell	1983	7	FH-RH on metal plates in water filled containers	NC in Hoof lifting (23% compared to 18% for control)
1.0	Norell	1983	7	Metallic mouth bit – AH on wet metal plates	Increased mouth opening (14% compared to 0% for control)
1.5	Gustafson	1985	6	Body (metal plate with gel) to AH on wet expanded metal plates	NC in behaviors (30% compared to 26% for control)
2.0	Gustafson	1985	6	FH-RH on wet expanded metal plates	NC in hoof lifting (24% compared to 27% for control)
2.0	Gustafson	1985	6	Metallic bit in mouth to AH on wet expanded metal plates	NC in mouth opening (18% compared to 8% for control)
2.0	Norell	1983	7	FH-RH on metal plates in water filled containers	NC in hoof lifting (25% compared to 18% for control)
2.0	Norell	1983	7	Metallic mouth bit – AH on wet metal plates	Increased mouth opening (30% compared to 0% for control)
2.5	Lefcourt	1986	7	Hock - Hock EKG patches	Mild Behaviors 2 of 7 cows. NC in heart rate, prolactin, glucocorticoids, epinephrine
3.0	Gustafson	1985	6	FH-RH on wet expanded metal plates	Increased hoof lifting (62% compared to 27% for control)
3.0	Gustafson	1985	6	Body (metal plate with gel) – AH on wet expanded metal plates	NC Behaviors (43% compared to 26% for control)
3.0	Gustafson	1985	6	Metallic mouth bit-AH on wet metal plates	Mouth Opening increased (42% compared to 8% for control)
3.0	Norell	1983	7	FH-RH on metal plates in water filled containers	Increased Hoof lifting (43% , compared to 18% for control)
3.0	Norell	1983	7	Metallic mouth bit – AH on wet metal plates	Increased mouth opening (69% compared to 0% for control)
3.6	Lefcourt	1985	7	Hock-Hock EKG Patch, 5s on 25 s off during milking, 7 days	Some behavior change; NC in MY, milking time, or WMT; Oxytocin and Prolactin release delayed in some cows
4.0	Gorewit	1984	6	Udder-AH, during milking for 7 days	Some Behavior change; NC in MY or composition, peak milk flow, milking time, residual milk or SCC

4.0	Gorewit	1984	8	Sub-dermal spinal Electrode for 5 min. 6 times/day	Some Behaviors with acclimation, NC in MY, Milk composition, SCC, water or feed intake
4.0	Gorewit	1984	6	Sub-dermal Spinal Electrode before and during milking every other morning milking for 6 days	Increased heart rate and blood flow before milking but no effect on Heart rate and blood flow during milking
4.0	Gustafson	1985	6	FH-RH on wet expanded metal plates	Increased hoof lifting (66% compared to 27% for control)
4.0	Gustafson	1985	6	Metallic mouth bit-AH on wet metal plates	Increased mouth opening (60% compared to 8% for control)
4.0	Norell	1983	7	FH-RH on metal plates in water filled containers	Increased Hoof lifting (72%, compared to 18% for control, $p<0.01$)
4.0	Norell	1983	7	Metallic mouth bit-AH, wet metal plates	Increased mouth opening (92% compared to 0% for control)
4.5	Gustafson	1985	6	Body (metal plate with gel) to 4 Hooves, wet expanded metal plates	NC in behavior (39% compared to 26% for control)
5.0	Aneshansley	1992	8	Copper Electrodes in teat cups to rear hooves on metal plate, During milking (L1 cows)	Behavioral Responses, NC in MY, composition or SCC; Reduced milking time
5.0	Gustafson	1985	6	FH-RH, wet expanded metal plates	Increased hoof lifting (84% compared to 27% for control)
5.0	Gustafson	1985	6	Metallic mouth bit-AH, wet metal plates	Increased mouth opening (74% compared to 8% for control)
5.0	Lefcourt	1982	5	Hock-Hock EKG Patch, before, during and after Milking	MY and milking time decreased with intermittent voltage, but not continuous voltage; NC in Oxytocin or catecholamine
5.0	Lefcourt	1986	7	Hock-Hock EKG Patch	7 of 7 cows show mild behaviors, NC in heart rate, prolactin, glucocorticoids, epinephrine
5.0	Norell	1983	7	FH-RH, on metal plates in water filled containers	Increased hoof lifting (97%, compared to 18% for control, $p<0.01$)
5.0	Norell	1983	7	Metallic mouth bit – AH on wet metal plates	Increased mouth opening (98% compared to 0% for control)
5.0	Norell	1985	7	Muzzle pressing a metal plate - AH	Changes in Learned Behavior
6.0	Gustafson	1985	6	Body (metal plate with gel)- AH on wet expanded metal plates	Behavioral Change (49% compared to 26% for control)
6.0	Lefcourt	1985	6	Hock-Hock EKG Patch, 5s on 25 s off during milking, 7 days	1 cow could not be milked, behaviors in others; NC in; MY, Milking Time, or WMT; Oxytocin and Prolactin release delayed in some cows
7.5	Gustafson	1985	6	Body (metal plate with gel) – AH on wet expanded metal plates	Behavioral Change (64% compared to 26% for control)
7.5	Lefcourt	1986	7	Hock-Hock EKG Patch,	7 of 7 cows show pronounced behaviors, NC in heart rate, prolactin, glucocorticoids, or epinephrine
8.0	Aneshansley	1992	8	Copper Electrodes in teat cups - RH on metal plate, During milking (ML)	Behavioral Responses, NC in MY, composition, SCC, or milking time
8.0	Gorewit	1984	6	Udder-AH, during milking for 7 days	Behavioral Responses, Slight increase in Cortisol and Oxytocin, NC in MY, Milking Time, Peak Milk Flow, Residual Milk, Protein, Fat, SCC
10.0	Lefcourt	1986	7	Hock-Hock EKG Patch,	2 of 7 cows show extreme behaviors, increased heart rate, epinephrine increased in 2 cows, NC in prolactin or glucocorticoids
12.0	Lefcourt	1985	3	Hock-Hock EKG Patch,, 5s on 25 s off during milking, 7 days	Extreme Behaviors in 3 cows, experiment stopped
12.5	Lefcourt	1986	7	Hock-Hock EKG Patch,	5 of 5 cows show strong behaviors,

					increased heart rate, 2 of 2 cows increased epinephrine and glucocorticoids.

Notes: shading code: **None** = no change in behavior in any cows, **Green** = mild behaviors in some cows, **Yellow** = discomfort behavior in some cows, **Red** = aversion in some cows. **NC** = No Change, **FH**= Front Hooves, **RH** =Rear Hooves , **AH** = All Hooves, **L1** = 1st Lactation, **ML** = multiple Lactation, **SCC** = Somatic Cell Count, **WMT** = Wisconsin Mastitis Test. **Prolactin** is a hormone associated with lactation. **Oxytocin**, a similar hormone that triggers milk let-down. **Glucocorticoids** are hormones produced in the adrenal glands. **Cortisol** is the most important glucocorticoid that regulates a variety of important cardiovascular, metabolic, immunologic, and homeostatic functions. **Catecholamines** are hormones released by the adrenal glands in situations of stress, the most abundant of these are **Epinephrine (Adrenaline), Norepinephrine** and dopamine.

It is instructive to examine the group of behavioral responses that occurred below 2 mA of current dose. In an experiment by Lefcourt (1982) one cow showed a mild behavioral response to 0.7 mA of current applied to EKG patches from front to rear hocks on shaved areas of skin. It is possible that shaving of the contact areas resulted in a cut in the skin which would produce a current concentration and increased sensitivity. In one of the Norell (1983) experiments three of six cows changed plate pressing behaviors (muzzle to metal plate to receive feed) with an application of 1 mA on their first exposure to current applied in an ascending series of 0.25 mA increments (represented in Figure 5). In two subsequent exposures these cows did not change behaviors until currents of 2 to 3.5 mA were applied to the metal plate. In a second experiment by Norell (1983) cows were fitted with bits in their mouths and mouth opening was observed for 14% of the 50 exposures of 1 mA of current applied to 7 cows (Table 2). One cow out of a sample size of over 300 cows tested at the University of Wisconsin showed mild behavioral response to 1.4 mA of current applied to a metal clip in the cows' muzzle (represented in Figure 5). This study used subtle behaviors (eye blink, facial twitch) as a response threshold for current applied through a non-piercing nose clip. None of these were typical farm exposure condition. It is also possible that that a concentration of current may have occurred for these cows due to a small contact area on the muzzle plate, mouth bit or nose clip.

In summary, there may have been very few behavioral responses noted at levels between 1 mA and 2 mA of current dose, these have been for unusual exposure pathways, not typical of those occurring on farms. The vast majority of behavioral response thresholds have been documented to occur between current levels of 3 mA to 8 mA. The current levels at which the first subtle behaviors can be observed are unique to each animal and range by a factor of about 4:1 from the most sensitive to the least sensitive animal.

As the current flowing through an animal is gradually increased there is initially no response because the current density is insufficient to cause nerve stimulation. At some current threshold the action potential of sensory nerves is exceeded and mild behavioral responses can be documented by careful observation and comparison to control conditions. These mild behavioral responses would be difficult to detect in a farm setting as they would be exhibited by only a part any group of animals and would likely be lost in the normal behavioral modification from the many other stresses and group activities of farm animals. These mild behavioral reactions are not associated with changes in the physiological status of the animal (hormonal responses), do not produce aversive behaviors such as avoidance of water or feed consumption nor are they likely painful to the animal, but merely novel stimuli such as a tingling sensation.

As the current flowing through an animal is increased above the sensory nerve stimulation threshold the sensations produced by this externally applied electrical current increase in intensity and motor neurons begin to activate, resulting in involuntary muscle contraction (twitches). It is clear from the many studies done on cows and several studies done on swine and sheep that farm animals will develop adaptive strategies to deal with these stimuli which are likely experienced as moderately annoying at lower current levels and painful at higher current levels. For each individual cow the severity of behavioral response has been shown to increase as the current exposure is increased above this first response threshold and aversive behaviors occurring at levels about 1.5 to 1.6 times higher than this mild behavioral response threshold.

When animals are exposed to current levels that are capable of producing annoyance and aversion the resulting effects on farm operations depend upon the specific exposure locations and the time history of exposures. For example if the offending currents can only be accessed at locations that are not essential to daily animal activities, the effects are not likely to be important or perhaps not even observable because those animals who's individual annoyance sensitivity is exceeded will avoid this location or develop adaptive behaviors.

If the offending point of current exposure is present at some location that is necessary for the animals to make contact the responses depend on the timing of the current availability. For example, if the offending is only present for brief periods of the day (several voltage 'spikes') the result is likely to be minimal or non-existent. Animals that come into contact with annoying stimuli may be deterred from a positive motivator (food or water) for a short period but will resume normal behaviors quickly if the annoying stimuli are removed.

The most extreme response to electrical exposure will occur if the current flowing through the animal is of sufficient level to be painful and if the animals cannot avoid the offending current in the course of meeting their daily water or feed requirements. There are a number of studies which have documented delays in drinking behaviors which have been shown to occur at levels somewhat above behavioral response threshold levels and only in situations in which animals had no source of water other than the electrified location. Reduction in daily water or feed intake have also been documented but are evident only in similar forced exposure situations and at current levels above those required to produce delays in drinking or eating behaviors. This forced exposure may occur on a farm if the only source of water or feed has sufficient voltage difference between an animal contact point and the floor. The effects of this situation would be minimal or nonexistent if animal could meet their water or feed requirements in another location on the farm with lower electrical exposure levels. The application of a equipotential plane around animal waterers and feeding locations, as is required by electrical codes, is a simple electrical solution to minimize contact potentials (even when neutral voltage sources are considerable) at these critical locations on farms.

3.19.2. Compilation of Dairy Cow Reponses to Constant voltage Exposures

Figure 6 illustrates the combined results of 28 tests on 11 cows in which an ascending series of 60 Hz voltage was applied through various body pathways until a behavioral response threshold was observed (Whttlestone, 1975; Lefcourt, 1982). There are many fewer data for this type of experiment as most researchers quickly shifted from controlled voltage to controlled current exposures to characterize individual animal response thresholds in an attempt to improve reputability of responses.

Most of the studies that used constant voltage exposure have report on group average rather than single animal responses but many of these studies give some indication behavioral responses. Table 3 presents a summary of experiments in which groups of cows were exposed to constant voltages while drinking, eating or during milking. Constant voltage exposure to groups of cows is more representative of exposure conditions encountered on a farm, in which voltage exposures are relatively constant but current dose will vary because of differences in cow body resistances and variations over time in contact resistances. Given the distribution of current sensitivities presented above, it would be expected that at moderate voltage levels some cows may show behavioral responses while others would not. Acclimation has also been noted by many researchers. This would manifest in a reduction in behavioral responses and aversion over time.

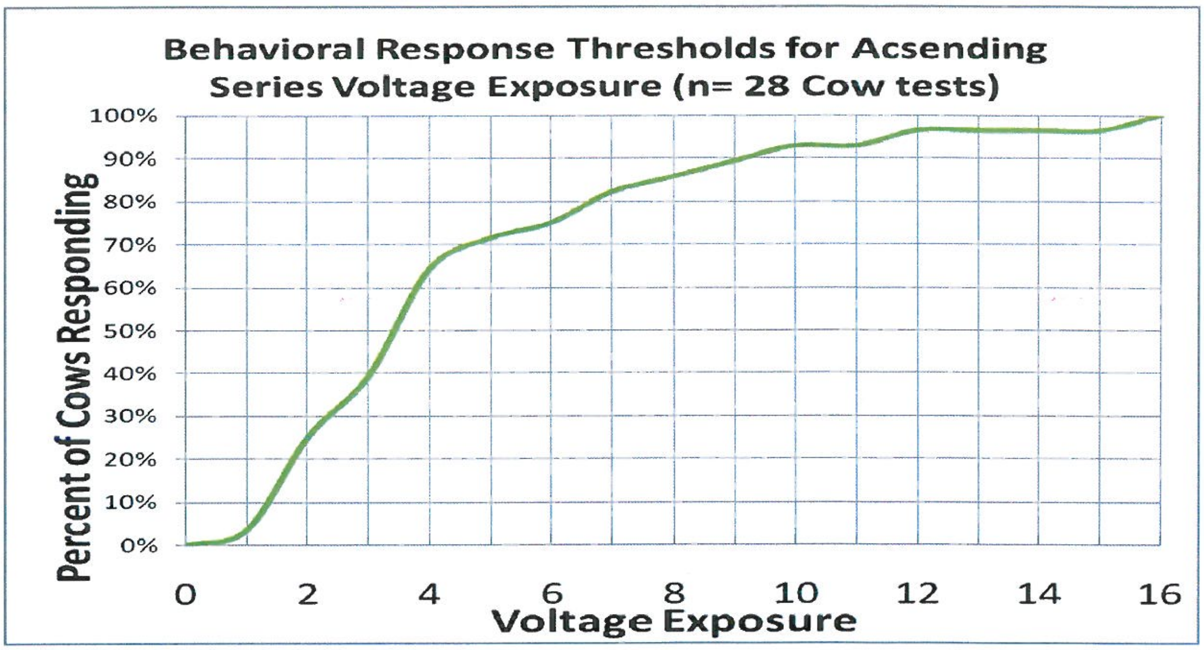

Figure 6. Summary of Dairy Cow Response Thresholds to Ascending voltage Series Exposure.

The data presented in Figure 6 is of limited value in establishing definitive response thresholds because these data represent a variety of exposure pathways, most not representative of farm conditions and relatively few cows. It is instructive to examine the responses that occurred below 2 V. Five of these were from an experiment by Lefcourt (1982) in which voltage was applied to EKG patches from front to rear hocks on shaved areas of skin. Another 2 cows were from the experiment by Whittlestone (1975) when voltage was applied between metal plates applied to cows' rumps with conductive gel. Neither of these conditions are representative of farm conditions.

A much large sample size is represented in the many studies in which groups of cows were exposed to constant voltages when attempting to drink or eat or during milking summarized in Table 3. These exposure conditions are more representative of farm conditions and represent over 800 cow tests (some cows were used in multiple experiments).

Table 3. Summary of experiments in which groups of cows were exposed to constant voltage when attempting to eat or drink, or during milking.

V	Author	Year	# Cows	Exposure Pathway and Duration	Responses
0.5	Gorewit	1989	6	Metallic Water Bowl to metal floor plate, 21 Days (0.6 to 1.3 mA)	No delay to drink, NC in daily water Intake, milk production or composition
1.0	Gorewit	1989	6	Metallic Water Bowl to metal floor plate, 21 Days (1.2 mA to 4.0 mA)	Delay to drink in some cows (average about 2 hrs), NC in daily water Intake, milk production or composition
1.0	Gorewit	1992	10	Metallic Water Bowl to FH on metal grid, full lactation	Delay to drink in some cows, NC in feed or water intake, SCC, MY or composition, health or reproductive performance
1.0	Gorewit	1997	4	Metallic Water Bow to FH on metal floor mats, 7 days	Unspecified delay to drink; NC in water or feed, MY or composition, SCC or *staph. aureus* infected quarters, blood chemistry, milk microbiology or cortisol;
1.0	Gorewit	1999	4	Metallic Water Bow to FH on metal floor mats, 7 days with *strep. uberis* mastitis challenge	NC in milk production, feed or water intake, SCC, milk fat or protein
1.0	Gumprich	1992	30	1 V morning and evening for 3 hrs each, 0.3 V other times of day from water bowl and stalls to metal grid at rear of stall, for 2 periods of one week each over 16 weeks	NC in behavior, daily milk production, milking time, water consumption, feed consumption, breeding; Increased milk fat
1.8	Southwick	1992	120	Switchback Farm Study , Maximum cow contact voltage measured waterline - floor	NC in water (although higher during exposure), milk production, SCC (although lower during exposure)
1.85	Craine	1975	30	Ascending 1.85 to 8 V water bowl – AH, 5 days (2-day recovery)	NC in water intake
2.0	Aneshansley	1992	7	Copper Electrodes in teatcups to RH on metal plate, During milking (L1)	NC in behavior, MY or composition, SCC or milking duration
2.0	Gorewit	1989	6	Metallic Water Bowl to metal floor plate, 21 Days (4.7 to 7.9 mA)	Delay to drink (average 3 hrs), NC in daily water Intake, MY or composition
2.0	Gorewit	1992	10	Metallic Water Bowl to FH on metal grid, full lactation	Delay to drink in some cows, NC in feed or water intake, SCC, MY or composition, health or reproductive performance
2.0	Gorewit	1997	4	Metallic Water Bow to FH on metal floor mats, 7 days	Unspecified delay to drink; NC in water or feed intake, MY or composition, SCC or *staph. aureus* infected quarters, blood chemistry, milk microbiology or cortisol;
2.0	Gorewit	1999	4	Metallic Water Bow to FH hooves on metal floor mats, 7 days with *strep. uberis* mastitis challenge	NC in milk production, feed or water intake, SCC, milk fat or protein
2.0	Rousell	2007	20	Metallic Feed Bowls to AH on metal floor plate (L1)	heifers performed muzzle-grooming (P<0.01) and head shaking
2.3	Rousell	2007	20	Metallic Feed Bowls to AH on metal floor plate (L1)	percentage feed eaten and time spent eating in the electrified feeder decreased

2.5	Gumprich	1992	30	water bowl and stalls to metal grid at rear of stall, 2.5 V morning and evening for 3 hrs each, 0.75 V other times of day from, for 2 periods of one week each over 16 weeks	NC in behavior, MY or composition, water or feed consumption, or breeding; 12 second longer milking time
3.0	Craine	1975	70	Free choice of Watering Devices with 0 V, 3 V, 6 V, or 8 V	Waterer nearest the cows always had highest water consumption regardless of voltage, average at 3-V waterer was 20% lower than control
3.0	Gorewit	1989	20	Metallic Water Bowl to metal floor plate, 2 Days (5.1 to 8.7 mA)	Average delay to drink 4 hrs; NC in daily total water intake
3.0	Rousell	2007	20	Metallic Feed Bowls to AH on metal floor plate (L1)	heifers changed more quickly to the non-electrified feeder
4.0	Aneshansley	1992	7	Copper Electrodes in teat cups to RH hooves on metal plate, During milking (L1)	Behavior changes, NC in MY or composition, SCC or milking duration
4.0	Aneshansley	1992	8	Copper Electrodes in teat cups to RH on metal plate, During milking (ML cows)	NC in behavior, MY , SCC or milking duration, 0.1% increase in Protein
4.0	Craine	1975	30	Ascending 1.85 to 8 V water bowl – AH, 5 days (2-day recovery)	Water suppression, gallons per drink increased, resumed normal drinking during the 2-day recovery period
4.0	Gorewit	1989	20	Metallic Water Bowl to metal floor plate, 2 Days (6.4 to 11.8 mA)	Average delay to drink 8 hrs; NC in daily total water intake
4.0	Gorewit	1989	6	Metallic Water Bowl to metal floor plate, 21 Days (5.5 to 12.1 mA)	2 Cows did not drink for 36 hrs and removed, Remaining cows average delay to drink about 8 hours, NC in daily total water; 7.5% decreased feed in 1 cow
4.0	Gorewit	1992	12	Metallic Water Bowl to FH on metal grid, full lactation	1 Cow and 1 heifer did not drink for 36 hrs and were replaced, Remaining 10 cows drank after some delay; NC in feed or water intake, MY or composition, SCC, health or reproductive performance
4.0	Gorewit	1997	4	Metallic Water Bow to FH on metal floor mats, 7 days	Unspecified delay to drink; NC in water or feed intake, MY or composition, SCC or *staph. aureus* infected quarters, blood chemistry, milk microbiology or cortisol;
4.0	Gorewit	1999	4	Metallic Water Bow to FH on metal floor mats, 7 days with *strep uberis* mastitis challenge	NC in MY, feed or water intake, SCC, milk fat or protein
5.0	Gorewit	1989	22	Metallic Water Bowl to metal floor plate, 2 Days (8.6 to 15.2 mA)	2 heifers did not drink for 36 hours and were replaced; remaining 20 cows showed Average delay to drink 8 hrs; NC in daily total water intake
5.0	Gumprich	1992	30	5 V morning and evening for 3 hrs each. 0.75 V other times of day from water bowl and stalls to metal grid at rear of stall, for 2 periods of one week each over 16 weeks	Reduced water intake and residual effect on milk production: NC in milking time, milk composition, feed consumption, or breeding
6.0	Craine	1975	30	Ascending 1.85 to 8 V water bowl – AH, 5 days (2-day recovery)	Water suppression, gallons per drink increased, resumed normal drinking during the 2-day recovery period
6.0	Craine	1975	70	Free choice of Watering Devices with 0 V, 3 V, 6 V, or 8 V	Waterer nearest the cows always had highest water consumption regardless of voltage, average water at 6-V waterer 66%

					lower than control
6.0	Gorewit	1989	22	Metallic Water Bowl to metal floor plate, 2 Days (9.2 to 17.4 mA)	2 heifers did not drink for 36 hours and were replaced; remaining 20 cows showed Average delay to drink 10 hrs; NC in daily total water intake
7.0	Craine	1976	30	Ascending 1.85 to 8 V water bowl – AH, 5 days (2-day recovery)	Water suppression, gallons per drink increased, resumed normal drinking during the 2-day recovery period
8.0	Aneshansley	1992	7	Copper Electrodes in teat cups to rear hooves on metal plate, During milking (L1 cows)	Behavior changes, NC in MY or composition, SCC or milking duration
8.0	Aneshansley	1992	8	Copper Electrodes in teat cups to RH on metal plate, During milking (ML cows)	Behavior changes, NC in MY or composition, SCC or milking duration
8.0	Craine	1975	70	Free choice of Watering Devices with 0 V, 3 V, 6 V, or 8 V	Waterer nearest the cows always had highest water consumption regardless of voltage, average water at 8 V waterers was lower than the control.
8.0	Craine	1977	30	Ascending 1.85 to 8 V water bowl – AH, 5 days (2-day recovery)	Discontinued after 1 day, many cows refused to drink.
16.0	Aneshansley	1992	8	Copper Electrodes in teat cups to RH on metal plate, During milking (ML cows)	Behavior changes, NC in MY or composition, SCC or milking duration

Notes: Response shading code: **None** = no change in behavior in any cows, **Green** = mild behaviors in some cows, **Yellow** = more pronounced behavior with delays to drink in some cows, **Red** = Strong aversion in some cows. **NC** = No Change, **FH**= Front Hooves, **RH** =Rear Hooves , **AH** = All Hooves, **L1** = 1st Lactation, **ML** = multiple Lactation, **SCC** = Somatic Cell Count, **WMT** = Wisconsin Mastitis Test. **Prolactin** is a hormone associated with lactation. **Oxytocin**, a similar hormone that triggers milk let-down. **Glucocorticoids** are hormones produced in the adrenal glands. **Cortisol** is the most important glucocorticoid that regulates a variety of important cardiovascular, metabolic, immunologic, and homeostatic functions. **Catecholamines** are hormones released by the adrenal glands in situations of stress, the most abundant of these are **Epinephrine (Adrenaline), Norepinephrine** and dopamine.

The highest voltage exposures required to produce a behavioral response is in excess of 15 V. The vast majority of behavioral responses have been noted between 1 V and 8 V. It is instructive to further examine those studies that found behavioral modification at 1 V exposure levels. These were a series of studies performed at Cornell University in which the voltage was applied between a metallic water bowl and a metal plate on the floor in contact with cow's front hooves when drinking. The researchers noted mild behavioral modification of some delay to drink on the first day of voltage exposure but these mild behavioral responses were not shared by all cows and were not sufficient to alter the total daily water consumed by cows.

These studies were repeated several times with exposures of 1 V, 2 V and 4 V applied from water bowl to front hooves on a metal plate for varying amount of time ranging from several days up to a full lactation (305 days). It is clear from these repeated studies that mild behavioral responses were evident on the first day of exposure at the 1 V groups for some cows. As the voltage levels increased to 2 V more cows began to show behavior modification, and at 4 V the behavioral modification became again more apparent. There were several cows at the 4 V exposure level and several cows exposed to 6 V that refused to drink for 36 hours and were removed from the study. These cows represent only a small percentage of all cows tested and it was only at levels of 4 or 6 V that these dramatic aversions occurred. Most cows adapted to these exposure levels in a way that did not change their total daily water consumption even on the first day of exposure.

3.19.3. The Solution to Contact Resistance

The combined data from constant voltage exposures representing over 850 cow tests and constant current exposures representing over 750 cow tests provides useful input to the problem of contact resistance. The vast majority of behavioral responses occur between current doses of 2 and 10 mA and between voltage exposures of 1 and 8 V. This implies a range real-world cow + contact resistance between 500 Ohms and 1000 Ohms as estimated by the authors of USDA handbook 696 (1991). There are a limited number of behavioral responses reported in the Cornell studies at 1 V exposure when the contact points were a metallic water bowl and metal plate in contact with cow's front hooves (that may have been wet because of its proximity to the water bowl). Spot checks of current delivered in these studies indicated that cow+contact resistance ranged between 250 Ohms (likely at those times in which the foot contact resistance was reduced to a negligible value on a clean, wet controlled metal plate) and 830 Ohms (likely at those times when the foot contact resistance was increased to a value in the range of 250 ohms for a dry metal plate and/or some debris present on the plate). The average cow + contact resistance in these spot checks was about 500 Ohms.

It is instructive to compare responses to the multiple Cornell studies that used 1 V, 2 V, and 4 V exposures to the New Liskeard Study that used exposures of 1 V, 2.5 V and 5 V continuously with periods of elevated voltages. The New Liskeard study used a more typical concrete contact surface for cow's rear hooves. They did not observe changes in the cows' behavior, feed consumption or production at the 1 V and 2.5 V exposure levels. They did observes some changes in the water and feeding behaviors at the 5 V exposure level but did not report the extreme aversion of a few cows refusing to drink for 36 hours as noted in the Cornell studies at the 4 V exposure level. This is consistent with higher cow+contact resistance and lower current dose produced by the more realistic concrete floor surface used in the New Liskeard studies compared to the metal plate used in the Cornell studies.

The results of the combined current dose response experiments, voltage exposure response experiments, and measurements of body and contact resistances is also consistent with the lowest (worst case) cow + contact resistance as low as 500 Ohms as estimated by the authors of USDA handbook 696 (Lefcourt, 1991) that may occur in some unusual situations on farms (firm application of the muzzle to a wet metallic watering device and hoof contact on a clean, wet, contoured metallic plate on the floor).

These studies on responses of dairy cows to electrical exposure agree well with each other and with predictions from neuro-electric theory and practice. There is a high degree of repeatability across studies in which exposures and responses have been appropriately quantified.

3.19.4. Animal Health and Production

Several studies have documented changes in animal productivity (dairy cow milk production, swine weight gain) but only as a result of current exposures well above those required to produce behavioral modification and only in forced exposure conditions. Likewise there have been some studies that have documented increases in stress hormone levels in animals but these have occurred in only some animals and only at extreme exposure levels that also produce extreme behavioral responses.

The several studies that have been done to examine direct physiological responses at current exposure levels below the behavioral response threshold (Reinemann, 1999a; Sheffield, 2003). These studies were designed to examine a fundamentally different type of exposure than the relatively short duration exposures that might occur when animals are eating, drinking, being milked, or being moved between building transitions. The premise in these studies was that cows immune function might be affected by continuous exposure to low level voltage and current as might be produced by currents flowing in the earth; the hypothesis presented by the Minnesota Science advisors. In both of these studies, current was applied from front to rear hooves for 12 to 24 hours per day for periods of 2 or 3 weeks. The current dose in both of these studies was 1 mA, which was chosen to be below the behavioral response threshold for any cow (and indeed no behavioral responses were observed) but 100 to 1000 times higher than would be generated by currents flowing in the earth. In the first of these studies (Reinemann, 1999a) one of 13 response variables was statistically significant but did not appear to be entirely consistent with other observations. And physiological experts concluded that, collectively, these results suggest that exposure to 1 mA of 60 Hz electrical current for two weeks had no significant effect on immune function of dairy cattle.

In the second study (Sheffield, 2003) used a new technique to measure a several thousand gene expression responses to 1 mA of current exposure for 3 weeks. There were possible changes in 3 parameters, however, the researcher noted that most measures were not affected, suggesting that those that were could be Type I errors, due to the large number of hypotheses tested. To put this possible response in context, a recent study on gene expression in cows Moyes (2008) found that mastitis infection resulted in 2,104 differentially expressed genes. Sheffield (2003) concluded that these studies suggest that electrical impacts on immune function are of relatively small impact compared with infection and inflammation. Any effects observed appear to affect only a small subset of immune system regulators, compared with most disease processes, which affect a wider spectrum of regulators. As a result, impacts of electrical exposure on animal health and disease is likely to be difficult to detect reliably, particularly without examining large populations, and would therefore be undetectable on commercial farms.

Controlled research clearly indicates that while it is possible to induce physiological changes in dairy cows as the result of electrical exposures, these responses occur at exposure levels well above those that produce behavioral changes. The extensive field data collected by the PWSC (2007) provides further confirmation of these experimental results.