THESIS

EFFECTS OF LED LIGHTING CHARACTERISTICS ON CATTLE MOVEMENT AND CHUTE CHOICE BEHAVIOR

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ABSTRACT

EFFECTS OF LED LIGHTING CHARACTERISTICS ON
CATTLE MOVEMENT AND CHUTE CHOICE BEHAVIOR

Lighting is an important but often overlooked component of the cattle production environment. As facilities transition to light-emitting diode (LED) systems, differences in flicker, spectral output, and intensity may influence cattle behavior. This study evaluated how two LED lighting treatments affected movement and chute choice in a controlled handling system. In this design, cattle were explicitly given a choice between two chutes, allowing for direct assessment of lighting preference.

A total of 200 Angus (heifers and steers) were individually tested in a dual-choice chute under two lighting conditions that differed in flicker, color rendering index (CRI), and brightness. One lighting treatment was characterized by greater temporal instability (perceived flicker), lower CRI, and reduced brightness, while the other provided more stable illumination, higher CRI, and increased brightness. Behavioral responses including chute choice, latency, and decision time were recorded, with latency and decision time measured in seconds.

Cattle were moved individually into the testing area to prevent social influences on decision-making. To reduce following behavior, animals were released from the start box one at a time with no visual contact with other cattle. Each animal began from the same starting point and was allowed to voluntarily choose between the two chutes, ensuring that movement reflected individual perception rather than herd dynamics or handler pressure. The next cattle was not released until the one prior had exited the chute house.

Cattle selected one lighting condition in 60% of trials, with responses influenced by chute placement and sex. Steers showed a stronger, more consistent preference, while heifers were more variable. These differences may reflect variation in temporal light stability and intensity. While the study was initially designed under the assumption that flicker would be the primary factor influencing behavior, the observed responses suggest that other characteristics, such as CRI and brightness, may also play a significant role, either independently or in combination with flicker.

Overall, the findings highlight the importance of species-specific visual perception when implementing LED lighting, with implications for animal welfare and handling efficiency.

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CHAPTER 1 – LITERATURE REVIEW

1. Introduction

Lighting is an important but often overlooked component of the cattle production environment. As livestock facilities increasingly transition from incandescent and fluorescent lighting to light-emitting diode (LED) lighting, questions arise about how differences in light quality may influence cattle behavior, welfare, and handling efficiency (Phillips, 2016). Unlike traditional lighting technologies, LED systems vary widely in spectral output, color rendering index (CRI), and temporal light modulation (flicker) (Elvidge et al., 2010; Miller et al., 2012; Kitsinelis, 2019). Most lighting standards are based on human perception; however, cattle possess a visual system that differs substantially from that of humans (Phillips, 2016). As a result, lighting that appear neutral or comfortable to people may still influence how cattle perceive and respond to their environment (Phillips, 2016).

This chapter reviews the literature relevant to cattle vision, behavior, and welfare in relation to lighting, with a particular emphasis on LED flicker and color rendering. Since direct research on LED lighting effects in cattle is limited, this review draws from multiple bodies of work, including studies of cattle handling and facility design, research on visual perception across species, and lighting engineering literature. Together, these sources provide a foundation for understanding how LED lighting characteristics may shape cattle responses in managed environments.

2. Visual Sensitivity and Behavioral Responses of Cattle

Cattle are highly visually oriented animals that rely on vision to navigate their surroundings, evaluate footing, and detect potential threats (Grandin, 1980). As prey species, they are especially sensitive to sudden changes or inconsistencies in their visual environment (Grandin, 1997). A substantial body of observational and experimental work by Temple Grandin has shown that cattle respond strongly to visual stimuli such as shadows, high-contrast patterns, reflections, and abrupt changes in lighting (Grandin, 1980; Grandin, 1997; Grandin, 2007). These visual disruptions can lead to balking, hesitation, increased stress, and reduced ease of movement through handling facilities (Grandin, 1980, 1997).

Field studies conducted in commercial handling environments support these observations. Wilson (2005) reported that changes in shadow contrast and unexpected visual stimuli significantly altered cattle movement patterns, increasing stopping and resistance behaviors. Similarly, Hubert (2002) emphasized that poor visual design in working facilities compromises both animal welfare and handler safety. Together, this literature highlights that even subtle visual features can have meaningful effects on cattle behavior, suggesting that lighting characteristics may play an important role in shaping cattle responses during handling.

3. Visual Capabilities of Cattle

3.1 Spectral Sensitivity and Color Vision

Cattle possess dichromatic color vision, meaning they have two types of color-sensitive cone photoreceptors in their eyes (Gilbert & Arave, 1986). Physiological evidence supports this classification; photopigment analyses in domestic ungulates, including cattle, goats, and sheep, demonstrate the presence of two cone types with peak sensitivities in the short and medium-to-long wavelength ranges (Jacobs et al., 1998). Their cones are most sensitive to short wavelengths (perceived as blue) and medium-to-long wavelengths (perceived as green-yellow) (Gilbert & Arave, 1986). While cattle's ability to discriminate colors is more limited than that of humans, they can still distinguish between different wavelengths and react behaviorally to changes in light composition. This is important for LED lighting, which often emits non-continuous spectra—light made up of narrow, distinct wavelength peaks—unlike the broad spectrum produced by incandescent lighting (Elvidge et al., 2010).

Color rendering index (CRI) describes how accurately a light source reveals object colors compared to natural light, with higher CRI values indicating that colors appear truer to life (Elvidge et al., 2010; Kitsinelis, 2019). Although CRI is typically evaluated from a human perspective, changes in spectral balance (the mix of wavelengths in light) associated with low-CRI lighting may alter how cattle perceive contrasts, edges, and surface textures. Reduced or distorted color rendering could exaggerate contrasts or shadows in the environment, potentially increasing fear or hesitation during handling (Grandin, 1997; Phillips, 2016). While direct studies on CRI perception in cattle are lacking, the known importance of visual uniformity in facility design suggests that color rendering differences may influence cattle behavior.

3.2 Temporal Resolution and Flicker Sensitivity

Another critical aspect of visual perception is temporal resolution, commonly measured using critical flicker fusion frequency (CFF), which represents the frequency at which a flickering light is perceived as steady (Simonson, 1952; Landis, 1954). Although CFF has not been directly measured in cattle, foundational work by Landis and Simonson demonstrated that

CFF varies systematically with luminance, stimulus size, and retinal location across species (Landis, 1954; Simonson, 1952).

Behavioral studies in other mammals indicate that many species have higher flicker sensitivity than humans. Dogs exhibit elevated CFF thresholds under photopic conditions (Coile et. al. 1989), and cats demonstrate similar capabilities (Loop & Berkeley, 1975). These findings suggest that mammals with visual systems adapted for motion detection may perceive flicker at frequencies produced by artificial lighting systems (Miller et al., 2012). Given that cattle are prey animals that rely heavily on visual cues to detect movement and change, it is plausible that their temporal resolution is sufficiently high to detect certain forms of LED flicker.

4. Evidence from Other Species: Implication for Cattle

Avian vision research provides compelling evidence that animals may perceive flicker well beyond human thresholds. Chickens and other bird species exhibit exceptionally high CFFs, sometimes exceeding 100-150 Hz under high light intensities (Lisney et al., 2011; Bostrom et al., 2016). Rubene et al. (2010) further showed that flicker fusion thresholds in birds vary with both wavelength and light intensity, indicating that temporal and spectral properties of light interact to shape perception.

Although birds differ anatomically from mammals, these findings establish an important principle: flicker that is not perceptible to humans may still be perceptible to animals. When combined with mammalian data from dogs and cats, this evidence supports concern that cattle may be capable of detecting flicker frequencies produced by some LED systems, particularly under bright lighting conditions common in agricultural facilities.

5. LED Lighting Characteristics: Flicker and Color Rendering

LED lighting introduces both opportunities and challenges compared to traditional light sources. Flicker in LED systems arises from temporal light modulation caused by drivers, pulse-width modulation, or dimming controls (Miller et al., 2012; Kitsinelis, 2019). Depending on system design, flicker frequencies can range from very low values that are visible to humans to much higher frequencies that are generally considered imperceptible to people but may still be detectable by animals.

In addition to flicker, LED systems vary widely in CRI and spectral composition (Elvidge et al., 2010; Kitsinelis, 2019). Low-CRI LEDs may distort color appearance and reduce spectral richness, potentially altering animals' perception of depth, texture, and contrast (Elvidge et al., 2010). While CRI standards are designed for human visual tasks, changes in spectral distribution may still affect cattle by modifying how environmental features are visually processed (Phillips, 2016). This is relevant in handling facilities where cattle rely on visual cues to assess footing, spatial boundaries, and escape routes.

6. Behavioral and Welfare Implications of Lighting Quality in Cattle Facilities

Cattle responses to visual stressors include increased vigilance, balking, vocalization, and resistance to movement (Grandin, 1980; Willson, 2005). These responses are commonly interpreted as indicators of fear or uncertainty and are associated with compromised welfare and increased risk of injury to both animals and handlers. Phillips (2016) emphasizes that environmental predictability and sensory comfort are central components of good cattle welfare.

Lighting that produces perceptible flicker or poor color rendering may function as a chronic visual stressor. Unlike brief disturbances, continuous exposure to inadequate lighting could elevate baseline stress levels or increase reactivity during handling. Hemsworth et al. (2015) highlight that environmental stressors, even when subtle, can accumulate to affect livestock welfare and productivity. Therefore, both flicker characteristics and CRI warrant consideration as potential contributors to cattle stress and handling difficulty.

7. Knowledge Gaps and Rationale for the Present Study

Despite extensive research on cattle handling, facility design, and general lighting conditions, there is a notable lack of empirical studies directly examining the effects of LED flicker and color rendering on cattle behavior and welfare. Existing literature collectively demonstrates that cattle are sensitive to visual inconsistencies (Grandin, 1997), that many animals perceive flicker beyond human thresholds (Lisney et al., 2011; Coile et al., 1989), and that LED lighting varies widely in both temporal modulation and spectral quality (Miller et al., 2012).

The absence of cattle-specific data represents a critical gap, particularly given the rapid adoption of LED lighting in agricultural environments. Investigating how flicker frequency and CRI influence cattle behavior, movement, and stress responses will contribute to evidence-based lighting recommendations and support improvements in animal welfare and handling safety.

8. Summary

The literature indicates that cattle possess visual sensitivities that make them vulnerable to subtle lighting-related stressors. Research on cattle behavior highlights the importance of visual uniformity in handling environments (Grandin, 1980), while vision science across species suggests that flicker and spectral properties may be perceptible to cattle even when unnoticed by humans (Bostrom et al., 2016). LED lighting introduces variability in both flicker and color rendering that may meaningfully alter cattle's perception of their environment. Together, these findings provide a strong foundation for the present study, which aims to evaluate how LED flicker and CRI influence cattle behavior.

CHAPTER 2 – EFFECTS OF LED LIGHTING CHARACTERISTICS ON CATTLE MOVEMENT AND CHUTE CHOICE BEHAVIOR

1. Introduction

Efficient cattle movement through handling facilities is important for both animal welfare and handler safety. Cattle are highly sensitive to their surroundings, particularly to visual stimuli such as shadows, contrast, and lighting conditions, which can influence their movement through chutes and alleys (Grandin, 1980; Willson, 2005). Even small environmental changes, such as shifts in lights or shadows, can lead to hesitation or disruptions in flow (Wilson, 2005; Phillips, 2016). Previous observations, including those described by Temple Grandin, suggest that incandescent lighting supports smoother cattle movement, likely because it does not produce noticeable flicker (Grandin, 1980; Grandin, 2007).

Vision plays a central role in how cattle interpret their environment (Phillips, 2016). As dichromatic animals, cattle perceive a limited range of wavelengths compared to humans, which can affect how they detect contrast and depth (Jacobs et al., 1998; Gilbert & Arave, 1986). In addition to spectral sensitivity, temporal aspects of vision are also relevant. Critical flicker fusion frequency (CFF) represents the threshold at which a flickering light is perceived as continuous and varies widely across species (Landis, 1954; Simonson, 1952). Studies in other animals including birds and mammals, show that some species can detect flicker at much higher frequencies than humans, suggesting that artificial lighting may be perceived differently across species (Boström et al., 2016; Lisney et al., 2011; Coile et al., 1989).

Modern livestock facilities are increasingly transitioning away from incandescent to LED lighting due to energy efficiency, longevity, and lower heat production. Another reason this transition is happening is due LED lights being more available then incandescent or fluorescent lights. However, LED systems differ from traditional lighting in several ways, including spectral output and temporal light modulation, commonly referred to as flicker (Elvidge et al., 2010; Miller et al., 2012; Kitsinelis, 2019). While flicker is often imperceptible to humans, it may still be detected by animals depending on their visual processing capabilities. This raises concerns about whether certain LED characteristics could influence behavior, stress, or movement in cattle.

Despite the known importance of vision in cattle behavior (Phillips, 2016), relatively little research has directly evaluated how specific lighting properties, such as flicker, brightness, and spectral composition, affect movement through handling systems. Given the established link between environmental design and animal welfare (Hemsworth et al., 2015) understanding how cattle respond to different lighting conditions is increasingly relevant.

The objective of this study was to evaluate chute choice when exposed to two LED lighting treatments that differed in flicker presence, color rendering index (CRI), and brightness. Initial emphasis was placed on flicker as a potential driver of behavioral responses: however, additional differences in brightness and spectral properties were also considered.

2. Materials and Methods

2.1 Experimental Arena

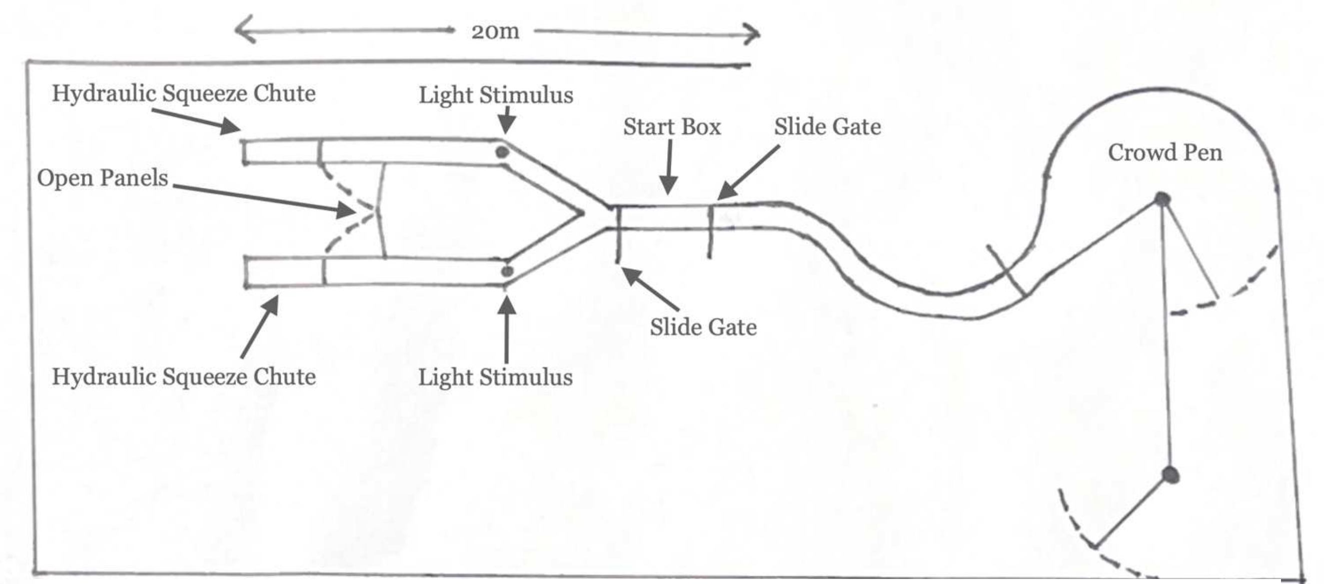

Figure 1. Layout of the dual-alley choice chute used to assess cattle responses to light stimuli. Cattle move from the crowd pen through a start box into a two-choice chute, with light stimuli positioned above each alley and gates controlling movement.

The study was conducted at the Eastern Colorado Research Center (ECRC) using a dual-alley choice chute system designed to allow the cattle to freely select one of two chutes (Figure 1). For the experiment, the panels immediately before the hydraulic squeeze chutes were opened so that animals could walk through without being caught or restrained. Two

Figure 2. Photo of Decision Point in Dual-Alley Chute

LED lights (Light A and Light B) were installed, one above each chute turn using secured wiring (Figure 2), allowing the lights to hang directly over the end of the decision area and illuminate each alley consistently.

2.2 Animals

A total of 200 Angus and Angus-Hereford cross heifers and steers were used (100 heifers and 100 steers). All cattle were preconditioned prior to weaning, weaned 34 days before the study, and averaged 240.40 kg (530 lbs.) at the time of testing. Steers were not implanted, and heifers were pre-pubertal at the time of the study.

All cattle had prior experience with the chute system used in this study. Specifically, cattle had been processed through this chute twice on the right side prior to testing. During the first processing event, calves received a weaning booster vaccination, and during the second, they received an ear tag and a topical back pour treatment. The chute house was also routinely illuminated with LED lighting, meaning cattle were previously exposed to similar lighting conditions. This chute system was the only handling system these animals had previously experienced.

Cattle housing and routine management prior to testing were performed by ECRC personnel following standard facility procedures. All procedures involving animals were reviewed and approved by the Institutional Animal Care and Use Committee (IACUC) at Colorado State University (Protocol #6880).

2.3 Light stimuli

Two LED lighting treatments were used: Light A (GE Refresh LED bulb) and Light B (Waveform Lighting LED bulb) (Table 1). When using an iPhone 12 Pro camera in slow motion (1080p at 240 fps), Light A exhibited measurable flicker. Additionally, Light A had a lower color rendering index (CRI) compared to Light B according to manufactures specifications.

Light Specifications

	Light A	**Light B**
Flicker	Yes	No
Light Type	LED	LED
Wattage	13.5	15
Bulb Shape Size	A21	A21
Bulb Base	E26	E26
Color Temperature	5000 Kelvin	5000 Kelvin
Brightness	1600 lumens	1600 lumens
Color Rendering Index	82	95
Acceptable Wattage & Freq.	100-200 Voltz, 60 Hertz	90-240 Voltz, 50-Hertz

Table 1. Manufacturer-reported technical specifications of Light A and Light B used in the experiment.

2.4 Photometric and Spectral Characterization

Both lights were characterized using photometric and spectral analysis. Spectral properties were measured using a photoluminescence system equipped with a silicon detector (Ocean Optics) with data collected through Spectral Suite Software. A 1.6 absorptive neutral density filter (Thor Labs) was placed between the light source and detector to prevent signal saturation. The detector, filter, and light source were held in direct contact during measurements.

Spectral irradiance data were recorded for 30 seconds for each light. Light B was measured first, with the detector positioned directly above the bulb. Light A was measured second; due to labeling on the bulb surface, measurements were taken from the side of the light source.

To evaluate flicker characteristics, light intensity was recorded over time and analyzed at primary emission peaks. Additional analyses included intensity at maximum emission wavelength and total integrated intensity across wavelengths using custom MATLAB code.

Illuminance (Ev) was measured in a dark room with no windows, using a Flashmate L-308BII light meter from 1 meter away and converted to lux (LX). Light A measured 14.7 EV, corresponding to 66,540 LX. Light B measured 15.1 EV, corresponding to 87,800 LX (27.55% difference).Illuminance was measured at a standardized distance of 1 meter to ensure consistent comparison between light sources, as light intensity measurements are influenced by the conditions under which they are recorded, including distance from the source (Miller et al., 2012). Preliminary estimates were obtained using a smartphone-based application; however, final values were determined using the calibrated light meter.

2.5 Experimental Design

The study used an individual-choice design in which one animal was tested at a time to prevent following behavior. Cattle were assigned to lighting treatments based on the location of the light within the choice chute. Two LED lighting treatments (Light A and Light B) were installed at the chute angle of both the right and left chutes. Left and right designations are reported from the perspective of the animal as it moved through the chute system. To control side bias, light placement was counterbalanced across trials.

For steers, the first 50 trials were conducted with Light A on the left side and Light B on the right side. For the second 50 trials, Light A was placed on the right and Light B on the left. The same two-phase counterbalancing was replicated for heifers. The primary outcome variable was chute choice, recorded as right or left during data collection and later recoded according to which light the animal chose. Secondary variables included latency to leave the release area and decision time and were recorded using an iPhone stopwatch.

All testing was conducted at night to ensure that the only illumination came from the experimental light treatments.

2.6 Procedure

Animals were brought as a group from their holding area to the crowd pen, where then individually they were brought to the choice chute release system by trained ECRC personnel using low-stress cattle handling methods. Workers used handheld flashlights to guide movement, but no overhead barn lighting was used. The only fixed lights illuminated during testing were the two experimental LEDs.

Each animal entered the start box, the space between two sequential gates, ensuring that only a single cow could be released at a time. Once the animal had settled, the front gate was opened, and the trial began. Latency to leave the release area was measured as the time from gate opening until the animal's shoulder crossed the threshold of the release gate. Decision time was measured from when the shoulder crossed the threshold until the animal's head passed underneath the chosen light at the end of the chute.

Two observers stood on opposite sides of the chute system. Neither observer was informed which chute contained Light A or Light B, maintaining partial blinding during data collection. Observers also had separate responsibilities to improve data accuracy. Observer 1 recorded latency time and chute choice, whereas observer 2 recorded decision time and coat color.

The next animal was not released until the previous animal had fully exited the chute house. Two animals (one heifer and one steer) required prompting using a flag by ECRC staff and were excluded from the dataset to avoid influencing behavioral outcomes.

2.7 Statistical Analysis

Statistical analyses were conducted in RStudio (R Version 2025.5.1.513). Latency time and decision time were analyzed as continuous response variables, while chute decision was treated as a categorical outcome. Differences in latency and decision time across treatment groups were assessed using linear models. Chute choice was analyzed using a chi-square test to evaluate differences in distribution across light conditions as well as using logistic regression with light choice (binary: flicker vs. no flicker) as the response variable. The full model included sex, coat color, and flicker direction (right vs. left) as fixed effects. Likelihood ratio tests were used to assess model terms. Coat color did not show statistical evidence of an association with light choice and was therefore removed from the final model. Odds ratios (OR) and corresponding p-values were reported. Statistical significance was set at $\alpha = 0.05$

3. Results

3.1 Spectral and Flicker Characteristics of Light Treatments

Light A and Light B differed in both spectral output and temporal intensity variation. Light A exhibited measurable fluctuations in intensity over time, whereas Light B remained relatively stable. Illuminance also differed between treatments, with Light B producing higher lux values.

3.2 Chute Choice by Light Treatment and Sex

The chute choice differed for the cattle by both light placement and sex (Table 2; Figure 2). When Light A was positioned in the right chute, most of both heifers and steers selected the right chute. Specifically, 72% of heifers and 78% of steers chose Light A when it was in the right chute.

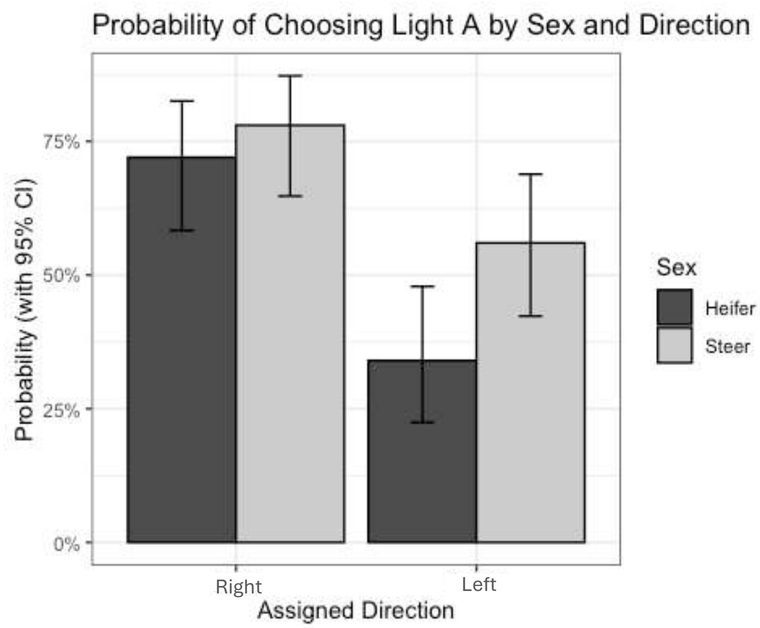

Figure 3. Probability of choosing Light A by sex and assigned direction, with 95% confidence intervals. Selection was higher in the right direction, and steers showed a greater probability than heifers.

In contrast, when Light A was positioned in the left chute, selection of Light A decreased, mainly among heifers. Only 34% of heifers selected Light A when it was in the left chute, whereas 56% of steers selected Light A. Across both light positions, steers selected Light A more frequently than heifers. The reported results are based on the final logistic regression model accounting for sex and flicker direction. Steers had higher odds of selecting the flickering light compared to heifers (OR = 1.92, $p = 0.035$). Flicker direction also significantly influenced choice, with lower odds of selecting the flickering light when it was positioned on the left compared to the right (OR = 0.26, $p < 0.001$).

Table 2. Proportion of cattle choosing Light A by sex and chute direction, including sample size (N), standard error (SE), and 95% confidence intervals.

Sex	Light_A	N	Proportion chose Light A	Percent chose Light A	SE	CI_lower	CI_upper
Heifer	Right	50	0.72	72	0.06	0.60	0.84
Heifer	Left	50	0.34	34	0.07	0.21	0.47
Steer	Right	50	0.78	78	0.06	0.67	0.89
Steer	Left	50	0.56	56	0.07	0.42	0.70

3.3 Overall Preference for Light A

Overall, 60% of cattle (120/200) selected Light A (Table 3). When examined by sex, steers showed a higher overall preference for Light A of 67%, compared to heifers of 53%.

Table 3. Light A Preference by Sex with Corresponding 95% Confidence Intervals

Group	n	Proportion chose Light A (%)	Lower CI (%)	Upper CI (%)
Overall	200	60	53.1	66.5
Heifer	100	53	43.3	62.5
Steer	100	67	57.3	75.4

3.4 Latency to Leave the Release Area

Mean Latency to leave the release area differed between sexes (Table 4). Heifers exited the release area faster than steers, with a mean latency of 3.56 ± 0.30 s, compared to 4.19 ± 0.55 s for steers. Confidence intervals overlapped between groups.

Table 4. Latency to Enter the Cute (s) by Sex (mean ± SE and 95% CI)

Sex	N	Mean Latency (s)	SD	SE	Lower	Upper
Heifer	100	3.56	3.02	0.30	2.97	4.16
Steer	100	4.19	5.54	0.55	3.10	5.27

3.5 Decision Time

Decision time also varied by sex (Table 5). Heifers took longer on average, to make a chute decision (3.78 ± 0.70 s) compared to steers (2.99 ± 0.31 s). Variability in decision time was greater for heifers, as indicated by a larger standard deviation.

Table 5. Decision time (s) by Sex (mean ± SE and 95% CI)

Sex	N	Mean Decision Time (s)	SD	SE	Lower	Upper
Heifer	100	3.78	6.986454	0.70	2.41	5.15
Steer	100	2.99	3.067260	0.31	2.39	3.59

3.6 Light Characterization

To further characterize these differences, spectral output and temporal stability were evaluated (Figures 3 and 4). Both lights showed similar overall emission patterns, with peaks within the same range (Figure 3), although Light B exhibited slightly higher relative intensity across most wavelengths.

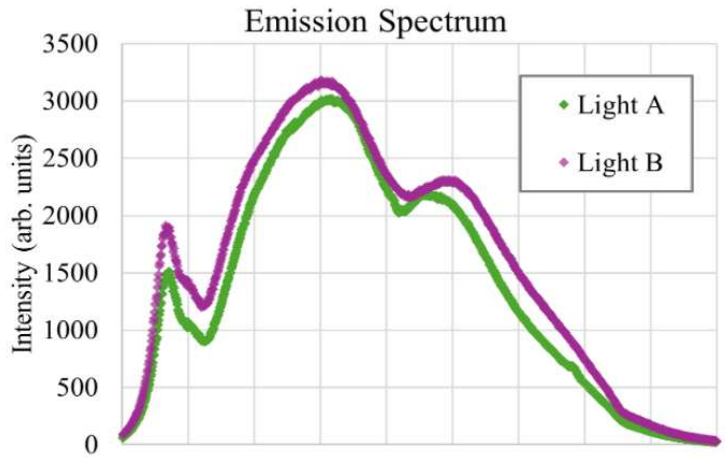

Figure 4. Emission spectra of Light A and Light B based on spectral irradiance measurements, showing similar distributions with peaks in the green-yellow range and higher overall intensity in Light B.

In contrast, Temporal measurements revealed clear differences in stability. Light A showed noticeable fluctuations in intensity over time, consistent with flicker whereas Light B remained relatively constant over time (Figure 4).

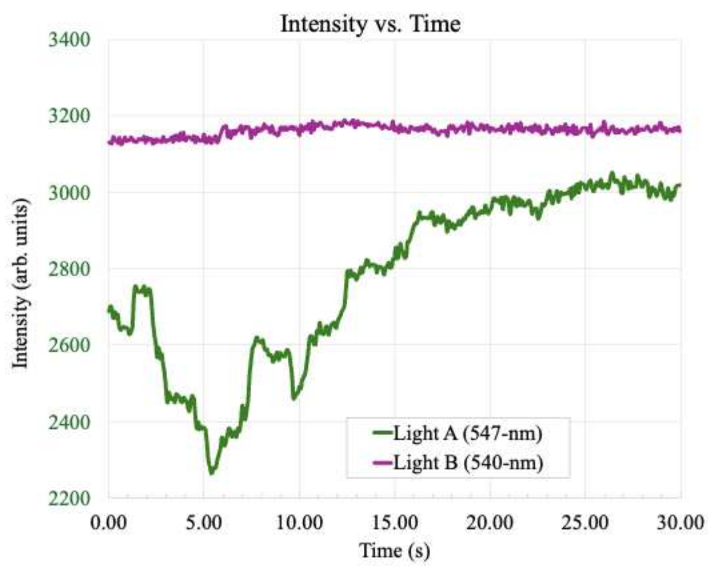

Figure 5. Intensity over time for Light A and Light B based on temporal measurements, showing greater fluctuation (flicker) in Light A and relatively stable output in Light B. Intensity is only for Light A, Light B is placed on this graph only for comparison.

4. Discussion

4.1 Summary of Key Findings

Overall, cattle selected Light A in 60% of trials, indicating a preference for this lighting condition. Chute placement strongly influenced choice behavior, with cattle more frequently selecting Light A when it was positioned in the right chute, which they had previously been exposed to twice. Sex differences were also observed, as steers selected Light A more frequently than heifers, while heifers showed a stronger tendency to choose the previously experienced chute. Secondary behavioral measures differed by sex, with heifers exhibiting shorter latency times but longer decision times than steers.

4.2 Effect of Light Placement and Side Bias

Chute placement had a pronounced effect on cattle choice behavior, suggesting a side bias associated with prior experience in the facility. The selection of Light A was highest when it was in the right chute, particularly among heifers. This pattern indicates that spatial familiarity influenced decision-making and may have overridden lighting effects in some cases. Prior experiences associated with the right chute involved routine handling procedures (e.g., vaccination, ear tagging, and back pour application) that were not strongly noxious, and these procedures were applied consistently across sexes. As a result, the right side was unlikely to be perceived as aversive and may have been associated with neutral or even positive handling experiences. These findings highlight the importance of accounting for facility layout and animal experience when evaluating behavioral responses to environmental stimuli (Grandin, 1980; Wilson, 2005).

4.3 Sex Differences in Light Choice

Steers selected Light A more frequently overall than heifers, whereas heifers demonstrated greater reliance on chute position. These sex differences were consistent across light placements. Observational behaviors such as backing up or head bobbing during the decision period were more commonly observed in heifers than steers suggesting increased hesitation or assessment behavior. Although these observations were not quantified, they provide additional behavioral context supporting sex-based differences in decision-making strategies.

4.4 Interpretation of Light Characteristics

Light A exhibited flicker and a lower color rendering index compared to Light B. Although flicker was initially expected to influence cattle behavior, the observed preference for Light A suggests that flicker alone did not determine chute choice under these conditions. While the study was originally designed to evaluate flicker as a primary factor, the results indicate that other lighting characteristics, brightness and spectral output, also potentially contributed to cattle preference. With regards to these characteristics, cattle selected Light A more frequently overall. This finding challenges the assumption that flicker is inherently aversive to cattle, as previous research has shown that flicker perception varies depending on species and light properties (Miller et al., 2012; Kitsinelis, 2019). This suggests that other lighting properties, such as spectral composition or contrast, may affect perception (Elvidge et al., 2010). These results indicate that cattle responses to LED lighting are multifactorial and cannot be attributed to flicker alone.

In addition to flicker and CRI differences, Light B produced substantially higher illuminance compared to Light A. Differences in brightness may have influenced cattle perception and choice behavior. Therefore, responses observed in this study likely reflect combined effects of flicker, spectral output, and intensity.

4.5 Latency and Decision Time as Behavioral Indicators

Sex differences were also evident in secondary behavioral measures. Heifers exited the release area more quickly but took longer to make a chute decision, whereas steers exited more slowly but committed to a choice more rapidly. These patterns may reflect differences in caution or decision-making strategies when animals are tested individually, potentially related to stress or vigilance response. Together, latency and decision time provide notable behavioral context for interpreting chute choice outcomes (Hemsworth et al., 2015).

4.6 Methodological Strengths

The study design included several strengths. Individual testing minimized following behavior, allowing for independent decision-making. The counterbalanced design helped control side bias, and partial observer blinding reduced potential recording bias. Conducting the study at night minimized external lighting variation, and excluding prompted animals improved the reliability of behavioral responses.

4.7 Limitations

This study had several limitations. Data was collected at a single facility using one chute configuration, which may limit generalizability. Residual side bias related to prior chute experience may have influenced choice behavior despite counterbalancing. Preliminary light intensity estimates were obtained using a smartphone-based application, which is less precise than calibrated photometric instruments; however, final illuminance values were confirmed using a professional light meter. Additionally, cattle were exposed to lighting treatments only once, and repeated exposure may yield different behavioral responses. Another limitation of this study is that spectral measurements were collected without a fixed mounting apparatus. The detector, filter, and light source were held manually, which may have introduced minor variability in positioning and angle during data collection. Although care was taken to maintain consistency, small differences in alignment could have affected measured irradiance values. Future studies should use a standardized mounting system to improve measurement consistency and reproducibility.

4.8 Practical Implications

These results suggest that LED characteristics can influence cattle movement through handling systems. In addition to light type, spatial familiarity of the cattle's surroundings appears to play a significant role. Together, these findings highlight the importance of considering both lighting properties and facility design when aiming to improve cattle flow.

5. Conclusion

Cattle responses to lighting were affected by multiple interacting factors, including light characteristics, spatial context, and sex. The strong effect of chute placement underscores the importance of prior experience in shaping cattle behavior. These findings contribute to a better understanding of how lighting influences cattle movement and may support improvements in livestock handling facility design.

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