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Solid-State Lighting Program:

Domesticated Animal Responses to Light R&D Discussion

November 2022

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Solid-State Lighting Program
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Comments

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1 Introduction

On November 30, 2021, thirteen experts in the fields of lighting technology and domesticated animal physiological responses to light gathered at the invitation of the Department of Energy (DOE) SSL Program. The meeting was held virtually. One objective of the meeting was to determine the state of understanding of domesticated animal physiological responses to light as they relate to agricultural and research animals. Additionally, the meeting set out to begin connecting this understanding with comprehension of human physiological responses to light. The meeting commenced with brief presentations given by attendees describing their relevant research interests. The presentations were followed by a discussion of the general understanding of domesticated animal responses to light.

This topic is of interest to the US DOE SSL Program because LED lighting technology provides the opportunity to not only reduce lighting energy consumption related to animal settings but to also increase health and productivity. Improved lighting enabled by LED technology can increase animal production efficiency and improve domesticated animal health. However, the understanding and practice needed to engage these benefits is still at a nascent state. Advancements in understanding animal physiological responses to light can also inform understanding of human physiological responses to light. Animal populations may also provide opportunities for research unavailable with human subjects.

Two groupings of researchers were present at the meeting. There were researchers who work with animals of direct economic interest (pigs, cows, horses), and there were researchers who work with animals used for research of human medical interests. All of the presented research was on mammals. It is likely that findings of physiological responses to light can cross translate to humans and different animals, but the specific extent of cross-over is not fully understood.

This report summarizes the R&D themes and the discussions of various aspects of domesticated animal responses to light. Overviews of the participants' presentations and related remarks are included in Appendix A of the report.

1.1 Key Conclusions

The meeting format encouraged each of the attendees to participate and present findings from their own research. The discussions following the presentations offered the opportunity for discussion of additional details from the presented R&D, crossover understanding between different animals and humans, and discussion of lighting considerations in various domesticated animal settings. There were some recurring themes that arose during these discussions regarding research areas that could advance understanding. These discussion themes are listed here:

- Production benefits with improved lighting
- Various physiological responses to light
- Characterization of the lighting stimulus
- Practical considerations in the animal environment
- Common elements and differences in animal physiology and behavior related to light

1.1.1 Production benefits with improved lighting

Analysis by the DOE SSL Program shows that lighting energy can be reduced by around 25% using LED lighting compared to conventional lighting technologies. [1] Lighting can also affect animal well-being, behavior and management, and productivity by influencing the feed conversion ratio. Thus, understanding animal physiological impacts to light has a direct energy impact as well as well-being and production economic impacts. Similar to humans, animals have circadian rhythms which are strongly affected by lighting conditions, so lighting needs to be present in the animal environment for visual function as well as non-visual physiological impacts. Researchers have found that reproduction, off-spring health and well-being, milk production, aggression and dominance behaviors, and general well-being can all be influenced by lighting.

1.1.2 Various physiological responses to light

Meeting participants presented a range of measurable physiological responses that occur as a response to changes to lighting stimulus. Changes include different intensity, different spectral power distribution (SPD) of the light, and different daylengths of the lighting. As with human lighting, optical distribution, glare, and flicker also have impacts.

With swine, it was noted that piglets are subjected to a 24 hour lights on cycle. They are then shifted to a diurnal cycle later in life. One reason for this is to attract piglets away from the sow and reduce the likelihood of piglets getting crushed. While this clearly has a direct impact on well-being, it raises the question of the longer term health and well-being impacts of the 24 hour light cycle. Meeting participants also described how lighting can affect seasonal fertility in both male and female pigs. In addition, lighting can affect eating times and may be able to induce eating.

Lighting can also be engineered to stimulate horse biological clocks and improve equine health, performance, and behavior. In particular, lighting can be managed throughout the year to affect mare gestation time, foal weight, and foal development. Engineered lighting can increase bovine milk production as well. It could also support improved navigation within the dairy parlor. This is important for situations with automated milking systems. Bovines were used to research melatonin production and pupil responses to different colors of light.

In discussion of lab animal research, attendees highlighted that rodent models can be used to advance understanding of human physiological responses to light. Results from lab studies have helped to elucidate internal physiological mechanisms of how light regulates the function of the suprachiasmatic nucleus (SCN). Lighting studies have also shown how multiple health indicators are improved for lab rodents when lab lighting is switched to higher blue content light. This type of research highlights that the SPD, timing, and intensity of light can be potent factors affecting the health and biomarkers of lab animals. This can influence study results.

1.1.3 Characterization of lighting stimulus

Since light can be a potent factor in a lab animal research study, lighting conditions should be clearly reported, including intensity, SPD, and timing. This will enable full replication of lab conditions and consideration of lighting impacts. Since lighting conditions can be impactful and potent stimulus within the animal husbandry environment, they should be well characterized in these settings as well. Meeting participants noted that there can be inconsistent lighting within animal environments, with different portions of the animal environment experiencing different light levels. Lighting conditions can also be seasonally and diurnally affected if animals are spending some of their time outdoors. This is not to say that lighting conditions must be consistent, but rather that lighting stimulus should be clearly characterized in order to understand the associated physiological response.

1.1.4 Practical considerations in the lighted environment

It will be important to control lighting to understand and promote physiological responses in animals. However, lighting functions beyond the animal physiological response may need to be considered. In most animal husbandry situations, human caretaker visual function must be accommodated. Researchers showed how visual function for animals could be affected by different lighting treatments. More extreme treatments, such as UV-B treatments for piglets to induce vitamin D, may require safety precautions so that excessive human exposure is avoided. Typical lighting considerations remain important for commercial use and economic feasibility, including lifetime of lighting products within the animal environment, optimal product form factors, replaceability, and cost. Accounting for these factors allows for a compelling return on investment when the animal physiological responses are convincingly demonstrated.

1.1.5 Common elements and differences in animal physiology and behavior related to light

Comparing physiological responses to light can be a powerful technique to advance basic understanding of visual and non-visual and behavioral response to light. Lab animal research is already an important means of understanding many aspects of human health and physiology. Research with other domesticated animals can further advance physiological impacts, since the findings could have implications on human health while also improving animal production efficiency. Additionally, findings from one type of animal may (or may not) cross over to other animals which is an important finding itself. As understanding improves for more and more domesticated animals in controlled settings, common elements and differences in responses can be evaluated. These can be used to understand the underlying fundamental physiological mechanisms for these responses for all animals and humans as well. This comprehension can facilitate even broader health and well-being benefits for both humans and animals.

Appendix A: Participant Presentations

Provided descriptions are paraphrased summaries of the presented materials.

Kyung Lee, Guidehouse

This presentation covered analysis of lighting energy consumption for animal production and the potential for energy savings if lighting was shifted to LED from conventional technologies. For this analysis, the total production area, lighting power density, lighting hours of use, and lighting technology mix were estimated for poultry, dairy, and hog production in the U.S. The status quo was compared against the case of all LED usage. In 2019, animal lighting consumed an estimated 3.7 TWh of site electricity (35 tBtu of source energy consumption). If lighting was switched to LED technology, there could a 25% energy savings equating to $96 million in electricity cost savings. Upgrades to lighting could also enable improved animal health and well-being, improved behavior and management, increased yield and feed conversion rates, and improved operational cost efficiency. [1]

Jeremy Marchant, USDA-ARS

Pigs have many biological rhythms. These include rhythms for feeding, activity, cortisol and other hormones, blood parameters, body temperature, and heart rate variability. These rhythms can be affected by internal processes and external stimuli. Diurnal rhythms are circadian rhythms that are synchronized with the day/night or light/dark cycle. There are numerous hormones and other biomarkers that show a diurnal cycle in pigs. The natural light cycle, intensity, and timing for pigs can be compared against light in the production setting to understand possible differences in physiological responses. Measurements in production settings show that there can be dramatic differences in light intensity. With a breeding herd, research has shown that light photoperiod can affect seasonal fertility in sows and sperm production in boars. Light intensity can affect melatonin and prolactin levels. Responses to the spectrum of light have not been studied extensively. With a slaughter herd there is evidence that longer light periods can improve production, while light intensity can affect activity levels and aggression. Blue light spectra can have a calming effect. Future studies could look at photoperiod in the farrowing house and nursery, applying different photoperiods to evaluate effects on young pigs.

Steve Hoff and Ben Smith, FarrPro

FarrPro is exploring the use of UV-B treatments on piglets to induce naturally synthesized vitamin D in production environments with little or no naturally occurring UV light. Initial research has been conducted at Iowa State University, exposing piglets from the age of 7 days until weaning. Blood was sampled and assayed for vitamin D levels. Results showed an increase in vitamin D levels after 14 days. There were practical issues with the use of UV-B LEDs in the production environment with fixtures getting damaged over time. Future research will explore dosage and effectiveness of UV-B treatments as well as practical considerations for delivery of UV treatments in the production environment.

Barbara Murphy, University College Dublin

Horses need light for vision and maintenance of biological rhythms. Blue light provides a greater stimulus, as demonstrated by human research. Managing light stimulus in horses can strengthen circadian rhythms with implications for health, performance, and behavior. Light can also influence circannual rhythms, which can affect reproduction, coat condition, growth, and performance. Blue light delivered to a single eye using a mask allows for both horse movement and management of the light stimulus. Research results showed that use of the mask was an effective alternative to light management within the stables. When using the mask, overhead lighting could be reduced, mares benefited from increased exercise and reduced stress, and masks generally enabled natural behaviors while managing the light stimulus. Follow on research found that mares fitted with light masks had reduced gestation length, increased foal birth weights, and reduced foal hair weight and coat length. Another round of research showed that post-foaling ovulation was advanced, larger follicles developed during the first post-foaling cycle, and mares were born more mature and stood more quickly. Light management techniques can also be applied within horse stables to enrich the blue content of the light during the day, reduce blue content at night, and have smoother dusk/dawn transitions in support of strengthened circadian rhythms. Stable light management can facilitate circannual light changes that influence metabolism and reproduction and optimize performance. Commercial user feedback of these equine light management tools has provided additional directions for research on physiological responses to light. These responses include positive impacts on wound healing time, ringworm removal, focus, feeding habits, sleep quality, alertness, mucus production, and conception rates. [2] [3] [4] [5]

The benefits of light masks were not limited to horses. In cows, the use of the mask led to a 9% increase in milk production. [6]

Sofia Lindkvist, Swedish University of Agricultural Sciences

Light can be an important management tool for dairy production. Controlling light for a long (16h) daylength can increase milk production. The indoor light environment also affects bovine pupil response, diurnal rhythms, activity, and cow navigation within a dimmed light environment. Cow pupil responses to different light SPDs were studied. At low light intensity, cow pupils were equally, fully dilated for red, white, and blue light. At higher intensity, pupils were dilated for red light but were contracted with blue and white light. In addition, plasma melatonin was measured for cows under different diurnal light treatments. Red and blue light during the day induced greater and more rapid production of melatonin in the following dark period compared to white light. Research was also performed on cow navigation within the dairy parlor under different lighting conditions and with different obstacles. Number of steps, step length, and interactions with the obstacles were recorded. [7]

Steven Moeller, USDA-ARS

Pigs have a two lobed eye response spectrum. One lobe overlaps with the human eye response, while the other is blue shifted.

Swine lighting can influence production, caregiver performance, and animal welfare. For example, light can affect male sperm quality and female cycling and ovulation rate. Daylight control and feeding and resting time can influence growth and efficiency. In addition, light intensity, distribution, and flicker can impact pigs. Animal welfare, including behavior, can also be affected. This can be used to make animal handling for tasks like internal movement and loading easier. Finally, when considering how to use light to achieve outcomes in pigs, it is important to account for caregiver well-being, since caregivers are likely to spend a lot of time in the pigs' environment.

Robert Lucas, The University of Manchester

In mice animal models, the magnitude of circadian response is better defined by the melanopic response spectrum than with the cone-opic response. Engineered light stimulus with contrasting levels of cone and melanopic content were shown to mice. Impacts on the suprachiasmatic nucleus (SCN) were measured. Measured response of the SCN showed closer association with melanopic response levels than cone responses. Researchers found – "An increase in melanopic irradiance always excites SCN. An increase in 'cone-opic' irradiance sometimes does." This research shows that mouse circadian light response can be predicted by measuring melanopic irradiance. [8]

Stuart Peirson, The University of Oxford

The eye serves two functions – image forming for vision and non-imaging forming effects on circadian rhythm and endocrine production. It is important to understand the effects of artificial light environments on physiology and behaviour. Methods of studying animal physiology and behaviour (lab animal welfare) need to be refined. Photoreceptors in the eye are comprised of rods, cones, and melanopsin ipRGCs. Electric light can cause circadian misalignment due to relatively low light levels during the day and evening light exposure. This affects humans and likely affects lab animals. Dim light in the evening (DLE) can delay activity onset and offset, reduce sleep duration, delay body temperature rhythms, delay rhythms in peripheral organ clocks, and affect memory. DLE can also affect metabolic rhythms. DLE interventions show mixed results. Future directions for research include understanding animal responses in relation to both the species-specific visual and non-visual physiology, understanding the aspects of light-related physiological responses that are of highest interest, and understanding impacts of different environmental conditions – natural light, artificial light, light pollution. [9]

Robert Dauchy, Tulane University

Fluorescent lighting and LED lighting typically used in lab have greatly different SPDs, which can evoke different physiological responses. The teams at Tulane and Thomas Jefferson University have been researching these effects on lab animals. Melatonin-depleted blood from premenopausal women exposed to light at night stimulates growth of human breast cancer xenografts in nude rats. Daytime blue light enhances the nighttime circadian melatonin inhibition of human prostate cancer growth. Daytime blue rich light affects the amplitude and circadian regulation of rodents. Studies only changing blue light during the day while keeping irradiance, photon flux, and illuminance similar for lab rodents show lower dietary and water intake, lower animal growth rates, lower neuroendocrine and neurobehavioral parameters, and slower rates of animal metabolism and physiology. All of these are factors associated with the promotion of animal health and wellbeing. [10] [11] [12] [13]

John Hanifin, Thomas Jefferson University

Light is a key extrinsic factor to be considered in operations and design of animal room facilities. Intensity, spectrum, and timing of lighting influences visual and non-visual effects in lab animals. There are multiple factors in the transduction of light from the eye to the physiological response. These include:

- Conscious and Reflex Behavior
- Ocular Media Transmission
- Iris/Pupil Dilation
- Photoreceptor Sensitivity
- Photoreceptor Distribution
- Neural Integration of Time/Space
- State of Retinal Adaptation

Research has shown that the spectrum of light can affect circadian behavior, organ weights, pineal melatonin, and other endocrine levels. Understanding of the relationship between light, ipRGCs, and melanopsin has greatly advanced over the last two decades. There is now a toolbox based on this research to calculate alpha-opic illuminance levels and foster clear reporting of lighting stimulus. Looking forward, LEDs provide tremendous energy savings/efficiency. Spectral tunability of LEDs presents new opportunities for the care and maintenance of different animal species. There needs to be careful interpretation of research results during the transition to new technology. [14]

George Voros, The Cleveland Clinic

Light is a powerful extrinsic force. It regulates circadian rhythms and is perceived by rods, cones, and ipRGCs. Over approximately one month the effects of different lighting conditions on mice were observed. Weight, food intake, water intake, and nesting behavior was recorded and then blood was collected. The fluorescent and LED lighting treatments had similar irradiance and melanopic lux levels but with vastly different spectral power distributions. The research showed limited impacts on mice based on the different lighting conditions when melanopic lux and irradiance are controlled.

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