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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

USDA-ARS and DOE Solid-State Lighting Program:

Domesticated Animal Responses to Light R&D Meeting

December 2022

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Comments

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1 Introduction

On December 13, 2022, experts in the field of domesticated animal responses to light gathered at the invitation of the U.S. Department of Energy (DOE) Solid State Lighting (SSL) Program and U.S. Department of Agriculture (USDA), Agricultural Research Service (ARS). The meeting was held virtually. The objectives of the meetings were to:

1. Highlight research and development (R&D) opportunities for understanding animal responses to light
2. Bridge R&D efforts among animal scientists and LED technologists
3. Facilitate collaboration
4. Provide guidance to R&D agencies

The US DOE SSL Program and USDA-ARS have an aligned interest in this topic because LED lighting technology provides the opportunity to not only reduce lighting energy consumption but also to advance the understanding of the role of light on animal health and productivity. LED lighting technology provides new levels of efficiency and control in the delivery of lights to animals in controlled environments. LED lighting can be engineered to provide tailored spectral power distribution, tailored optical distribution, and precise intensity control while also saving energy compared to previous lighting technologies. These new levels of control require new understanding of animal physiological responses to light and their relationship to animal health. The LED technology platform also requires new practical understanding for the cost-effective deployment of the technology, particularly with respect to the new features offered by the technology.

This report summarizes the R&D themes and the discussions. Overviews of the participants' presentations are included in Appendix A of the report.

2 Key Themes

The meeting format asked each participant to present findings and research directions from their own activities. Recurring themes that arose in the presentations and subsequent discussions regarding research areas that could advance understanding included:

- Animal physiological responses to light
- Characterizing of lighting conditions

2.1 Animal Physiological Responses to Light

Researchers at this meeting described the significance of lighting on health and reproduction . Supporting domesticated animal health and managing and optimizing reproduction cycles and off-spring health can be highly impactful for animal husbandry and production.

There is new understanding of how different lighting conditions are received and processed by animals (including humans) and how lighting can affect health. There are four primary physical parameters of lighting inputs: irradiance, wavelength, time, and duration of light stimulants. Each parameter is a factor in the physiological responses to light by animals, including effects of the circadian and neuroendocrine systems. There are several elements involved in transduction of light signals to the brain: conscious and reflex behavior, ocular media transmission, iris/pupil dilation, photoreceptor sensitivity and distribution, neural integration of time/space and state of retinal adaption.

Light supports visual and non-visual functions in animals. Non-visually, lighting conditions can affect natural melatonin levels which can interrupt metabolism and other neuroendocrine features and can contribute to tumor growth. A recent study was conducted at Tulane University to investigate how nighttime melatonin levels in mice were affected by exposure to white fluorescent light and blue-enriched LED lights during the day. The study concluded that animals exposed to blue-enriched LED lights during the day experienced an amplitude enrichment of 6-9x higher levels of melatonin at night compared to mice exposed to fluorescent white light. These higher melatonin levels led the mice to experience lower dietary and water intake, growth rates, lower neuroendocrine and neurobehavioral parameters, and slower rates of animal metabolism and physiology, which are all factors associated with the promotion of animal health and wellbeing.

Non-visual effects of lighting on neuroendocrine function can also affect reproductive cycles and the phenotype of the offspring. With humans and rodents, studies have shown that the timing of puberty can be affected by light exposures. Earlier puberty with gilts (young female swine) could have a meaningful effect on their reproductivity resulting in increased production of off-spring.

2.2 Characterizing Lighting Conditions

The lighting conditions in controlled environment production settings are seldom well characterized. Animals visual systems also differ from that in humans. For example, mice only have two cone pigments (G + UV) while humans have three (R+G+B). Animal visual acuity can also be different than humans: mice would be considered legally blind by human terms. However, the differences in vision between animals and humans can be difficult to measure and characterize because light intensity is almost universally measured in terms of human visual perception with photometric (human-based perception) units – e.g. lumens and illuminance.

As such, there is a need to use a system to measure animal-specific visual and non-visual light conditions. More general measurements of light can be in radiometric units (radiant power and irradiance), and the spectral power distribution (colors) of light can measured. With this information, animal-specific visual and non-visual responses to light can be characterized. There is a model adopted by the International Commission on Illumination (CIE) that uses α-opic lux units instead of photopic lux. The α-opic lighting system can account for activity of all photoreceptors, not just those involved in visual light processing, for specific species. Characterizing activity at the photoreceptor level provides a more effective model to assess the impact of light on both the visual and biological effects. Additionally, a lighting system that can be analyzed at the photoreceptor level allows researchers to study the non-visual impacts of light on animal species with different photoreceptors than that in humans. For example, the Rodent Irradiance Toolbox provides a method to calculate equivalent daylight illuminance (EDI) lux values using weighting factors based on murine photoreceptors. This system measures the light available to each photoreceptor in the eye of a mouse, which can help better measure both visual and non-visual responses for rodents. Similar tools could be applied for any animal species. Understanding lighting conditions from the animal perspective can also enable improved visual function as animals move themselves to different areas within the production environment.

2.3 Summary

LED lighting technology is more efficient than previous lighting technologies and offers new capabilities to improve the health, wellbeing, and productivity of domesticated animals. Recently, there have been profound advancements in the understanding of human non-visual responses to light. Research is required to better understand these responses for a wider variety of species. To optimize the lighting impacts, the lighting conditions need to be well characterized and understood in terms of animal visual perception and non-visual responses.

Appendix A: Participant Presentations

John Hanifin, Thomas Jefferson University: Relevance of Light on Circadian, Neuroendocrine, and Neurobehavioral Regulation in Laboratory Animal Facilities

John Hanifin introduced the factors that can impact non-visual light processing. The presentation provided an overview of the basic neural pathways through the lateral geniculate nucleus (LGN) and the suprachiasmatic nucleus (SCN) by which light information travels to the brain from the retina. The presentation focused primarily on the pathway through the SCN to the hypothalamus where light serves as an internal oscillator to regulate biological cycles. Different light parameters can impact how light is received and processed by the SCN. There are four primary physical parameters of photic input: irradiance, wavelength, time, and duration of light stimulants. Each parameter is a contributor to the efficacy of the circadian and neuroendocrine systems.

There are several elements involved in transduction of light signals to the brain: conscious and reflex behavior, ocular media transmission, iris/pupil dilation, photoreceptor sensitivity and distribution, neural integration of time/space and state of retinal adaption. The presentation focused on ocular media transmission, specifically on how the ocular lens changes with time. As humans age, the lens becomes pigmented which results in the reduced transmission of short-wavelength light. Light transduction via the lens of both humans and animals needs to be considered especially for LEDs with different wavelengths or spectral tunability.

Bob Dauchy, Tulane University School of Medicine: The Influence of Daytime LED Light Exposure on Circadian Regulatory Dynamics of Animal Metabolism and Physiology

Melatonin has been shown to inhibit tumor growth in humans and rodents through the suppression of linoleic acid, which is an omega-6 fatty acid. Linoleic acid is common in the western diet, accounting for about 60% of fat intake in the western diet and has been shown to stimulate tumor growth. Light exposure at night suppresses melatonin levels which can interrupt metabolism and other neuroendocrine features and can contribute to tumor growth. However, there is less information on how daytime light exposure, specifically exposure to blue-enriched LED lighting, which has a similar wavelength to sunlight, can impact neuroendocrine, physiological, and metabolic parameters associated with animal health and wellbeing.

A study was conducted to investigate how nighttime melatonin levels in mice were affected by exposure to white fluorescent light and blue-enriched LED lights during the day. The study concluded that animals exposed to blue-enriched LED lights during the day experienced an amplitude enrichment of 6-9x higher levels of melatonin at night compared to mice exposed to white light. These higher melatonin levels led the mice to experience lower dietary and water intake, growth rates, lower neuroendocrine and neurobehavioral parameters, and slower rates of animal metabolism and physiology, which are all factors associated with the promotion of animal health and wellbeing. Additionally, it appeared that mice that experienced an enhanced melatonin surge at night showed younger phenotype which could potentially have implications on aging.

Stuart Peirson, University of Oxford Sir Jules Thorn Sleep and Circadian Neuroscience Institute (SCNi): Measuring Light for Visual and Non-visual Responses in Mice

As an overview, light has two primary functions – visual, and non-visual. Non-visual processing is used to regulate biological functions, such as sleep and the circadian rhythm. Mice are often selected as subjects of studies concerning the eye because the mouse retina shares similar characteristics to the human retina. However, there are some differences as well. Mice only have two cone pigments (G + UV) while humans have three (R+G+B). Mice visual acuity is also very poor and they would be considered legally blind by human terms. Mice also have a different sensitivity to color compared to humans. They are more long-wavelength depleted. Even though mice have UV and green cones, they are still able to detect red light, they are just less sensitive – specifically 12x less sensitive compared to humans. These are also non-visual differences in processing light as different parts of the eye are responsible for those functions. These differences are harder to measure because light intensity is typically measured in terms of photopic lux, which is not something that can characterize non-visual light. Lux is also based on human visual sensitivity and is not relevant for non-human species.

As such, there is a need to use a system to measure non-visual light. There is a model adopted by the CIE that uses α-opic lux units instead of photopic lux, expressed as an Equivalent Daylight Irradiance (EDI) metric. This lighting system is based on identities under daylight conditions and is essentially identical to the photopic lux metric in daylight. (e.g. 1000 photopic lux is equivalent to 1000 α-opic EDI lux for rods, cones and melanopsin). The α-opic lighting system can account for activity of all photoreceptors, not just those involved in visual light processing. Being able to break it down on the photoreceptor level gives provides a more effective model that can better assess the impact of light on not just the visual but biological effects. Additionally, a lighting system that can be analyzed at the photoreceptor level allows researchers to study the non-visual impacts of light on animal species with different photoreceptors than humans. The Rodent Irradiance Toolbox provides a method to calculate EDI lux values using weighting factors based on the photoreceptors of a mouse. This system measures the light available to each photoreceptor in the eye of a mouse, which can help better measure both visual and non-visual responses for rodents.

Cristina Saenz de Miera Patin, PhD, University of Michigan: Prenatal Photoperiodic History Affects Brain Development and Reproduction in Mammals

Animals have rhythms in hormones and reproductive cycles that are linked to seasons and corresponding photoperiods. For example, some species experience reproductive physiology changes between summer and winter. The summer can increase thyroid hormone stimulation, which controls metabolism, reproduction, and other functions while in the winter, hormone production can slow. These hormonal patterns are linked to the amount of light in the day, or photoperiod. Studies show that the prenatal photoperiod can affect hormone regulation in the hypothalamus for mice after birth. Animals born in the spring and summer develop “summer phenotypes” in which the increased hormone activity will cause them to go through puberty earlier and develop more rapid growth. Animals born at the end of the season in a decreasing photoperiod instead develop “winter phenotypes” in which their reproductive system development is slowed. Animals born in the same photoperiod (spring and fall) can even experience different reproductive development if they are entering a longer/shorter photoperiod. Animals born in spring experience more rapid testicular growth compared to animals born in fall in the same photoperiod.

With this information, there is an interest to conduct future research to study the effect of photoperiod during pregnancy on not just reproductive systems, but on brain development, as these same hormones can impact brain growth. Particularly since in humans, there have been some trends observed that the photoperiod/season of birth can have an impact on tendencies to develop metabolic diseases and birth parameters. Particular areas of interest involve studying the effects of light pollution exposure on birth outcomes and offspring development as well as how sleep issues and irregular light exposure during pregnancy can impact birth outcomes. Additionally, information is scarce on how light responses at night impact domesticated animals. There is some initial understanding that light exposure can impact melatonin inhibition and desynchronization of circadian and biological rhythms, but would be interested to know about how light exposure can impact offspring born in environments such as breeder facilities, farms, zoos, etc. Future research should investigate if certain lighting environments can hamper growth, endocrinology, fitness, and productivity.

Sofia Lindkvist, Swedish University of Agricultural Sciences: Light Precision for Dairy Cows

The presentation focused on the pupil dilation response to different lighting conditions in dairy cows. In red light for example, cows’ pupils do not dilate when the intensity is increased compared to white light. To further investigate how cows respond to different light wavelengths and intensities, a study was conducted to observe how assess the effect of different lighting conditions on cows’ ability to navigate an obstacle course.

The cows’ speed and stride in navigating the course were measured under different lighting conditions. The test was done in a barn with no outside light and under several different lighting conditions: white light at low (10 lux), medium (60 lux) and high intensity (260 lux), red light at low, medium, and high intensities, and then the same tests of white and red light at varying intensities were repeated but with only a few lights on. A test was also conducted in complete darkness.

The results show that the dark lighting condition didn't impact cow's stride and speed in walking through the obstacle course. The cows walked slowest and with the greatest number of strides during the uneven red light test at medium intensity. There is not a clear answer as to why this occurred, but it may be because the bovine rod photoreceptors are close to saturation while the cones are weakly stimulated in this condition. In the full red-light condition with low intensity, the cows walked the fastest with the least number of strides. Further investigation is needed to figure out why this is occurring.

Clay Lents, U.S. Dept. of Agriculture: Thoughts on Light and Gilt Development

This presentation focused on constraints in swine lifetime productivity. Reproductive failure is the number one reason pigs are culled, and many end up being culled before the net sow value is positive. Average parity at cull is 3.5 and it takes a parity of 3 for a sow to be financially positive. If parity could be improved by even 1/10 to 1/2, there could be an estimated $15-270 million gain in economic benefits in the swine industry.

It is known that gilts that reach puberty at an earlier age have a higher probability of generating a first parity and subsequent parities, shorter wean-to-estrus intervals (WEI), have more regular farrowing intervals, and are therefore less likely to be culled for reproductive reasons. Ultimately, the goal is to slow down growth to support adequate puberty development so sows can produce more pigs and stay in the herd longer. However, slowing down growth too much can also adversely affect puberty.

There is interest, therefore, to study how light may impact swine puberty development as there are studies that show that excessive screen time may be linked to earlier puberty onset in humans and rats. Studies that have examined the impact of how blue light may impact sexual development of gilts are outdated and use too small of a sample size to draw definitive conclusions. This will be an area of research going forward because even if light exposure can have a small effect to swine biological development, it could have a big financial impact on the swine industry. Research should focus specifically on how photoperiod, intensity, and light type can impact factors affecting growth, puberty, and fertility.

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