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学位の種類	博士（人間生物学）
学位記番号	博甲第　10160　号
学位授与年月	令和　3　年　12　月　31　日
学位授与の要件	学位規則　第４条第１項該当（昭和２８年４月１日文部省令第９号）
審査組織	グローバル教育院
学位論文題目	Metabolic implications of polychromatic LED and OLED light exposures at night （夜間の LED と OLED 照射がエネルギー代謝に及ぼす影響）

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論文の内容の要旨
Abstract of thesis

In this doctoral dissertation, the author describes the effects of light-emitting diode (LED) and organic light-emitting diode (OLED) light exposures at night on energy metabolism during subsequent sleep. The summary is as follows:

（目的　Purpose）

Artificial light at night has extended human activity during nighttime; however, health consequences due to excessive light exposure at dark hours have been of global concern. The author aims to solve this global issue. The author described that light pollution in artificial light at night has spread worldwide, impacting animal behavior and plant physiology. In humans, there are some epidemiological studies that showed excessive light at night is related to increased risk of weight gain and obesity. Despite the worldwide concern of adverse effects of light exposure at night, there is still little experimental evidence of the effects of light on metabolism. In addition, OLED has gained popularity in recent years. The author examined the effects of LED and OLED light exposures before sleep on sleep, energy metabolism, body temperatures, and urine melatonin.

（対象と方法　Materials and Methods）

Ten male subjects participated in the author's experiment. The author recruited subjects who were medication-free non-smokers, did not work night shifts, had not engaged in trans-meridian travel at least one month before the

experiment day, reported no sleep disorders, and were classified as intermediate chronotypes assessed based on Morningness-Eveningness Questionnaire. The author collected data from a 9-day experimental protocol including the 7-day at-home sleep/wake regulation period from each subject. This experiment, using a cross-over design, exposed either 1000 lx LED, 1000 lx OLED with reduced spectral content in the short wavelength of blue light (455 nm), or dim (< 10 lx) light to subjects in a metabolic chamber. The author used 4000K polychromatic white LED and 4000K polychromatic white OLED. The author set light panels in front of the subjects, and adjusted distance to achieve an illuminance level of 1000 lux at eye level with melanopic lux of 730 and 780 for LED and OLED, respectively, with spectral peaks of 545 nm for OLED and 455 nm for LED. The author conducted dim light exposure using a ceiling-mounted LED. In each condition, the author allowed subjects to sleep at 24:00 and woke up at 07:00 in their relative clock time. The author continuously exposed subjects to light for four hours while maintaining a sitting posture until their habitual sleep time. The author prohibited subjects from using any devices that emitted light. The author provided breakfast to subjects one hour after awakening, and continuously measured energy metabolism for four hours after waking under regular room light (300 lx). The author assessed energy metabolism using the whole room metabolic chamber, sleep recorded by polysomnography, core body temperature, skin temperature, and urinary 6-sulfatoxymelatonin (aMT6s) during the experiment.

(結果 Results)

The author found that energy expenditure and core body temperature significantly declined during sleep under OLED compared with dim light condition. However, sleep architecture, EEG delta power, or frequency of the stage changes did not significantly change among LED, OLED, or dim light conditions. The author also showed that exposure to LED increased respiratory quotient (RQ) determined as the ratio of $\dot{V}CO_2$ to $\dot{V}O_2$ and reduced fat oxidation compared with OLED during sleep. The author also observed that these effects of energy metabolism persisted to the next morning after waking. The author showed that the average energy expenditure on day 2 was significantly different with lower values under OLED and LED conditions compared with dim light condition. The average RQ remained high after waking with a higher value under LED compared with dim light. Fat oxidation showed a lower value under LED compared with dim light. The author also assessed skin temperature from proximal and distal regions. Proximal temperature revealed a statistically significant interaction between condition and time with a decrease in OLED compared with dim light after waking at 10:00. Distal temperature or the distal-proximal gradient (DPG) did not show any effect from light conditions. The author further investigated correlations between urinary aMT6s and energy expenditure, which showed a positive correlation under OLED, but no correlation was observed under LED or dim light conditions.

(考察 Discussion)

From these results, the author suggested that the influence of light on energy metabolism and thermoregulation observed in the study is possibly affected by regulatory systems unrelated to sleep. The author described that the attenuation in energy expenditure and core body temperature observed in OLED might result from downregulation of metabolism by decreasing body temperature. The author speculated that particular characteristic in wavelength of OLED decreased the temperature during sleep without affecting sleep itself, because light detected by the ipRGCs (Intrinsically photosensitive retinal ganglion cells) sends direct projections to brain areas mediating acute effect on body temperature. The correlation analyses between urinary aMT6s and energy expenditure suggest that the melatonin's role in stimulating lipolysis in intramuscular adipocytes may not be preserved under LED exposure but retained under OLED exposure. Because the spectral composition between LED and OLED did not differ greatly and melanopic lux between LED and OLED in the present study were 730 and 780 lx, respectively, the effect of the spectral composition of LED peaking at 454 nm of blue light might not reflect clearly on the melanopic functions. It leads the author to consider that characteristics of light, apart from wavelength, such as the glare, luminance, and frequency of fluctuation, may play an additional role in human physiology. The author's study provides a further

understanding of the role of light on energy metabolism during sleep and suggests the potential usage of OLED to mitigate the risk of weight gain and obesity related to nighttime light exposure.

審査の結果の要旨
Abstract of assessment result

（批評　General Comments）

The author conducted this research in collaboration with a research group at Yamagata University specializing in OLEDs. This study is one of the first to show that evening light exposure affects metabolism during sleep and the subsequent morning after waking. The final examination committee highly evaluates the dissertation because it opens up the possibility of understanding and mitigating the risk of weight gain and obesity associated with nighttime light exposure.

（最終試験の結果　Assessment）

The final examination committee conducted a meeting as a final examination on September 17th, 2021. The applicant provided an overview of dissertation, addressed questions and comments raised during Q&A session. All of the committee members reached a final decision that the applicant has passed the final examination.

（結論　Conclusion）

The final examination committee approved that the applicant is qualified to be awarded Doctor of Philosophy in Human Biology.