PHYSIOLOGICAL ANTHROPOLOGY: EFFECTS OF ARTIFICIAL LIGHT ENVIRONMENT ON HUMANS

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Contents

Summary

Effects of artificial light environment on humans are described from the viewpoint of physiological anthropology. The effects of light can be analyzed from the aspects of quantity and quality. Relatively few studies about quality of light have been conducted. Two important components of quality of light are color rendering and color temperature. Recently, the effects of color temperature on autonomic nervous activity have been studied by using heart rate variability. These studies demonstrated that sympathetic nervous activities were accelerated at a higher color temperature condition. Some researchers have also evaluated the effects of color temperature by using contingent negative variation (CNV). They have revealed that the amplitude of early CNV at the higher color temperature condition is larger than that at the lower color temperature condition. It has been suggested that higher color temperature may increase physiological strain. Several studies were conducted to evaluate the effects of quality of light on sleep. They showed the light of higher color temperature tended to inhibit nocturnal melatonin secretion and decrease body temperature. In our experiment, the subjects were allowed to adjust the color temperature of the ceiling light to the level at

which their working efficiency could be improved every 10 min from 7:30 to 17:30. The color temperatures selected by the subjects showed the time variation which was similar to the daylight color temperature. Then, the color temperature time varying lighting was compared with constant color temperature lighting. The results demonstrated that the change in color temperature contributed to reduction of fatigue, sleepiness and mental strain and improvement of performance. Recently, our research team studied the effects of lighting on taste sense, and demonstrated that the thresholds of tastes were affected by illuminance and color temperature of lighting.

1. Introduction

Physiological anthropology aims ultimately at biological elucidation of human nature. Until recently, physiological anthropologists studied human nature from various viewpoints including the variability and adaptability of humans. There has been a traditional stream of physiological study in anthropology. Physiological anthropology clarifies this point and emphasizes its importance. We have to admit that we live in an environment that is completely different from that in which our ancestors lived. Development and spread of artificial lighting and air conditioning contributed to improvement of some aspects of our living environment but they created problems such as a lifestyle characterized by reversal of day and night, and cooling disorder. Mechanization of production equipment and transportation facilities caused noise pollution, vibration pollution and atmospheric contamination. Physiological anthropology has attracted much attention because it has been expected to bring about clear solutions to these challenges faced by human beings.

In this section, the effects of artificial light environment on humans, from the aspect of physiological anthropology, are overviewed.

2. Light and human

Living organisms receive a variety of influences from light and the human is no exception. Light is indispensable for our everyday life. There are various lighting equipments in our homes such as ceiling lights, floor lamps and pendant lights in living rooms and dining rooms, table lamps in the bedrooms and desk lamps in libraries and children's rooms where we study. The light produced by such equipment has a broad range of effects on the living body.

2.1. Quantity of light and human

The effects of light can be analyzed from the aspects of quantity and quality. The quantity of light can be expressed by illuminance. Many researchers have long studied the effects of illuminance on working efficiency. These studies have shown that lack of illuminance results in decline in working efficiency and that excessive illuminance increases fatigue. It has been known that illuminance needed for reading increases as we grow older (Figure 1). Many studies have demonstrated that the quantity of light affects our biological clock.

It has been said that the human biological clock works in a 24-25 h cycle. The endogenous rhythm regulated by the biological clock is affected by the 24 h light and dark cycle of the sun, and is precisely adjusted to a 24 h cycle (circadian rhythm). In an experiment, a person was placed in an environment without a day (light) and night (dark) cycle or things suggestive of time. The person was asked to live there for more than two weeks. Under such conditions, the body temperature remained in a cycle of 24-25 h, while the rhythm of sleep and wakefulness was prolonged to 30 h or longer. Accordingly, it was reported that there was a remarkable gap between the two rhythms.

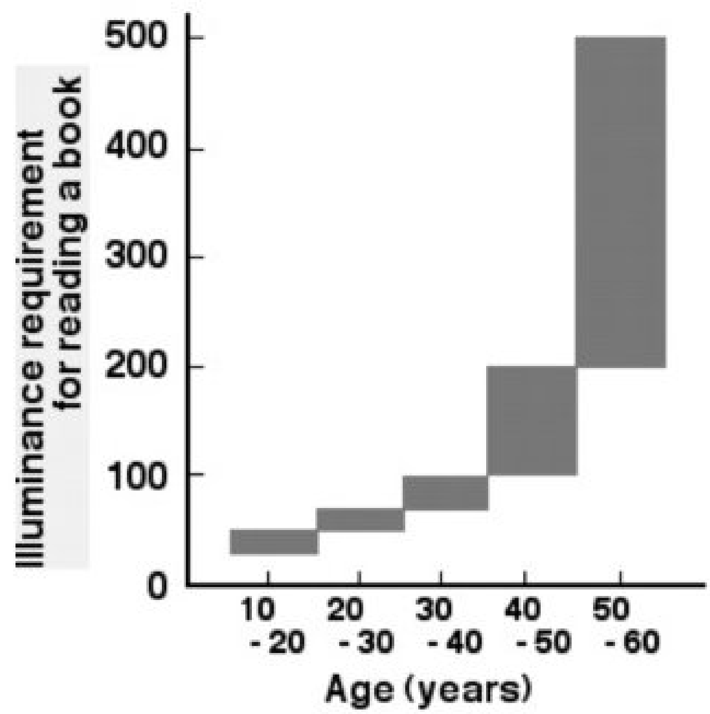

Figure 1. Illuminance requrement for reading a book.
The illuminance requrement of a 40-year-old is taken as 100.
(*From data presented by* Grandjean E. (1969). Light and Colour. *Fitting the Task to the Man*, 89-117. London: Taylor & Francis)

On May 23, 1989, Stefania Follini, a female Italian interior designer, came out of a cave created 9 m below the surface in New Mexico, USA. This 27-year-old female started to live in the cave on January 13, 1989 and stayed there for 130 days. The purpose of this experiment was to clarify the effects on the living body of life in an enclosed space. She had no means of knowing the time as she received no natural light and had no watches. The US-Italy joint research team closely observed the inside of the cave through a camera monitor, but they had no contact with her. Ms Follini overcame solitude by studying English and practicing shape-up and judo. She kept a diary every day and counted the number of days in the cave. She recorded March 14 on the day when she came out of the cave. When she was notified of the real date, she could not believe that it was May 23 and asked to be shown the newspaper as evidence. According to this experiment, the number of days that actually passed was 70 days more than the number of days perceived by the person in the cave. It has been reported that a person who lives in an environment without the light and dark cycle of the sun for a long period of time subjectively experiences an increase in the number of hours per day. The actual number of hours in the perceived day, based on a sleep-wakefulness rhythm, is approximately 48 to 72 h. In Ms. Follini's case, this altered sleep-wakefulness rhythm probably occurred in a repeated manner.

It has been known that exposure to light of higher illuminance exceeding 3000 lx is effective in improving jet lag or seasonal affective disorder.

2.2. Quality of light and human

We have already secure some interesting findings about quantity of light. How much information have we on the effects of quality of light? Color rendering and color temperature are two important components of quality of light. Compared with studies on quantity of light, studies on the effects of color rendering and color temperature on the living body are conducted much less frequently. Recently, in the field of physiological anthropology, an increasing number of researchers have begun to study color temperature. In this section, in addition to the latest findings in the field of physiological anthropology, the effects of quality of light on human physiology will be discussed.

2.2.1. Color temperature of lighting

The color temperature of light is defined as the absolute temperature (K; Kelvin) of the perfect black body that irradiates the light equivalent to the color of the light source. The tincture of blue increases at a higher color temperature, while the tincture of red increases at a lower color temperature. The color temperatures of commercially available fluorescent lamps range widely from approximately 3000 K (light bulb color) to 6500 K (daylight color).

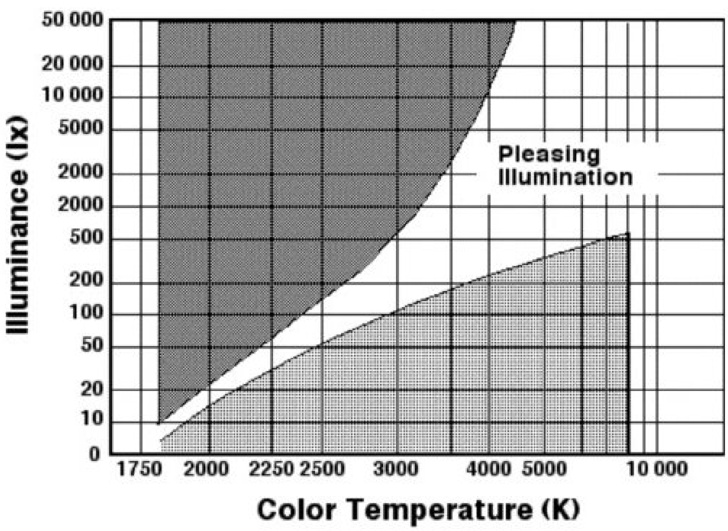

Figure 2. Plesant combination of color temperature and illuminance.
(*From data presented by* Kruithof, A.A. (1941). Tubular luminescence lamps for general illumination. Philips Technical Review 6, 65-96)

Kruithof (1941) first “scientifically” clarified the effects of color temperature of light on humans. At that time, Kruithof was working for Philips as an engineer. More than 60 years ago he revealed the range of comfortable lighting by combining illuminance with color temperature (Figure 2). A combination of a lower color temperature with higher illuminance gives a “stifling and uncomfortable feeling”, while a combination of higher color temperature with lower illuminance gives a “gloomy and uncomfortable feeling.” When these uncomfortable areas are excluded, the remaining central area can be defined as the “comfortable” area which expands with the increase in color temperature. Kruithof’s finding have been frequently cited in recent studies. In view of his finding, authors of textbooks on illuminating engineering, architecture and ergonomics recommend that the color temperature of lighting should be high.

Is Kruithof’s theory strong enough to withstand the latest scientific challenges? Masahiko Sato, one of the leading physiological anthropologists in Japan, has pointed out several problems with Kruithof’s theory. One is the problem related to establishment of the lighting conditions. Unfortunately, no lighting equipments that could accurately reproduce a wide range of color temperatures from 2000 K to 8000 K were available in Kruithof’s days. According to Kruithof, an electric light bulb was used to reproduce a lower color temperature, while a skylight was used to reproduce a higher color temperature. A fluorescent light was used to reproduce the remaining color temperatures. Sato said, “Results obtained from experiments conducted under lighting conditions that were significantly different in quality cannot be comparable.” Although Kruithof stated that he had determined the comfortable range according to the results of physiological measurement, he failed to report what he actually measured in the experiment. Sato said, “At that time, measurement of physiological functions was still in a primitive stage and knowledge about human physiological functions was significantly limited when compared with the current knowledge”.

In view of these comments, we should review Kruithof’s study and prevent further spread of his unauthenticated theory.

2.2.2. Effects of quality of lighting on autonomic nerve response

What results can we obtain if we use the latest measurement method to re-evaluate Kruithof’s study? In the field of physiological anthropology, many studies have been conducted by taking this approach. It has been said that physiological anthropology is anthropology of people who are living in the current technological civilization and also a scientific field which is associated directly with improvement of quality of human life. Because the quality of lighting is a core problem of physiological anthropology, many physiological anthropologists are now working on such studies.

What approach shall we take to clarify the effects of quality of lighting on human? Generally, the living body physiologically reacts to maintain homeostasis when it receives exogenous stimulations such as light, heat and sound. The autonomic nervous system plays an important role in maintaining homeostasis. The autonomic nerves are distributed widely in various viscera (heart, stomach, intestine, etc.), glands (lachrymal gland, sweat gland, etc.) and blood vessels. This nervous system regulates the functions of these organs to control a broad range of activities of the living body. As the word "autonomic" indicates, this nervous system unconsciously and automatically functions without being regulated by the cerebral hemisphere.

As a method for evaluation of autonomic nervous functions, heart rate variability (HRV) has gained the researchers' attention. The heart is regulated by the autonomic nervous system and appears to pulsate in a nearly constant rhythm. Close examination, however, shows that the time intervals between heartbeats are inconsistent and fluctuate in the course of time. This fluctuation of heartbeat is called HRV.

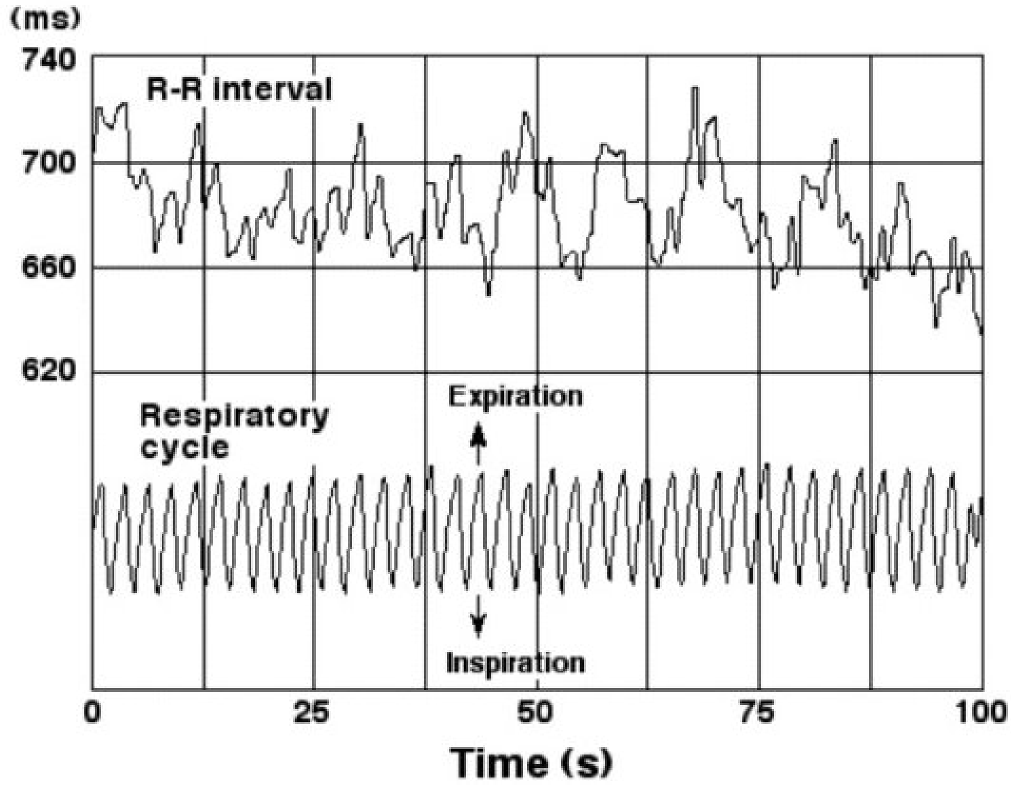

Figure 3. Variation of R-R interval and respiratory cycle.
Time interval of R waves is not consistent even if the heart rate per minute remains constant. Periodic component which corresponds to respiratory cycle is shown in the variation of R-R interval.
(Reproduced *from* Kobayashi H. Ishibashi K., Noguchi H. (1999). Heart rate variability; an index for monitoring and analyzing human autonomic activities. *Journal of Physiological Anthropology and Applied Human Science* **18**(2), 53-59)

In electrocardiography, the time intervals of R waves are measured and the measurement results are plotted along the time axis to visualize the cyclic fluctuation (Figure 3). The time-series HRV data are subjected to frequency analysis by using fast Fourier transform (FFT), auto-regressive model (AR) and maximum entropy method (MEM). The spectrum obtained is usually characterized by two peaks. The data shown in Figure 3 were analyzed and the results were demonstrated in Figure 4. The two peaks corresponded to 0.1 Hz and 0.38 Hz. The components around 0.1 Hz are called Mayer wave related sinus arrhythmia (MWSA), which corresponds to the cyclic variation of arterial blood pressure. The components around 0.38 Hz are related to respiration and are called respiratory sinus arrhythmia (RSA). By analyzing these two types of variation components, the activity of the autonomic nervous system can be evaluated. The power integral value of the low frequency band including MWSA around 0.1 Hz (LF) is related to the cardiac sympathetic and parasympathetic nervous activities, while the power integral value of the high frequency band including RSA (HF) is related to the cardiac parasympathetic nervous activities alone. According to LF and HF values, LF/HF and HF/(LF+HF) are calculated to obtain the index of cardiac sympathetic nervous activities and the index of cardiac parasympathetic nervous activities respectively.

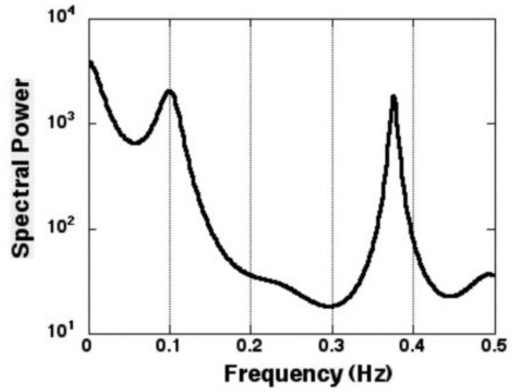

Figure 4. Heart rate variability spectrum derived from MEM.
Two components are revealed approximately in 0.1 and 0.38 Hz.
(*Reproduced from* Kobayashi H. Ishibashi K., Noguchi H. (1999). Heart rate variability; an index for monitoring and analyzing human autonomic activities. *Journal of Physiological Anthropology and Applied Human Science* **18**(2), 53-59)

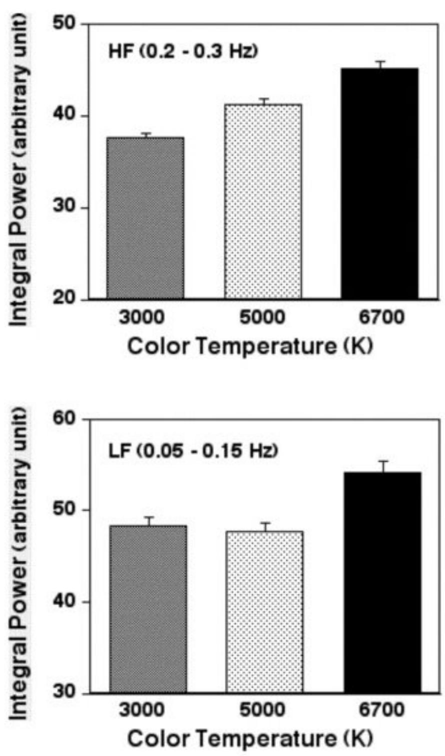

Figure 5. Effects of color temperature on HF and LF components of HRV.

(*Modified from* Mukae, H., Sato, M. (1992). The effect of color temperature of lighting sources on theautonomic nervous functions. *Annals of Physiological Anthrop*ology 11(5), 533-538)

Three levels of color temperature of fluorescent lamps (3000, 5000, 6700 K) and the three levels of illuminance (100, 300, 900 lx) were combined so that HRV could be compared under various lighting conditions. HRV indexes did not differ according to the illuminance conditions but they differed according to the conditions of color temperature. It was suggested that both LF and HF increased under the conditions of higher color temperature (Figure 5) and that excitation of autonomic nerves was accelerated by whitish light. The effects of the two levels of atmospheric temperature (22, 30 ºC) and the two levels of color temperature of lighting (3000, 7500 K: illuminance adjusted constantly to 1500 lx) were evaluated by using HRV. It was found that both LF and HF reached higher values at an atmospheric temperature of 22 ºC and a color temperature of 7500 K.

Recently, our research team combined the noise of three different central frequencies [one octave band noise of 330, 830, 2100 Hz, sound level adjusted constantly to 85 dB (A)] and the three levels of color temperature (2800, 4400, 6500 K: illuminance adjusted constantly to 1500 lx) and evaluated the effects of such environmental conditions on the human. HRV was characterized by the interaction between noise and color temperature. The influence of color temperature differed according to the noise level. The results obtained under condition without noise [background noise ≤ 40 dB (A)] were similar to the above results. In this study, the autonomic nervous activities were analyzed from the aspect of blood pressure. Systolic blood pressure was also characterized by the interaction between noise and color temperature. The effects of color temperature were remarkable and blood pressure increased in a nearly constant manner as color temperature was elevated. This study clarified that the autonomic nervous activities, especially sympathetic nervous activities, were accelerated at a higher color temperature.

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Bibliography

Boyce P.R. (2001). Illumination: Basic Definition. *International Encyclopedia of Ergonomics and Human Factors* (ed. W. Karwowski) 1016-1021. London & New York: Taylor & Francis [This explains the photometric and colorimetric quantities of light and the human visual system].

Deguchi T. and Sato M. (1992). The effect of color temperature of lighting sources on mental activity level. *Annals of Physiological Anthrop*ology **11**(1), 37-43. [This describes the effects of color temperature of lighting sources on contingent negative variation].

Honma K., Honma S. and Wada T. (1987). Entrainment of human circadian rhythm by artificial bright light cycles. *Experientia* **43**(5), 572-574. [This was the first study to show that artificial bright lights

(5000 lx) are able to reset human circardian rhythms during temporal isolation experiment].

Jin X., Katsuura T., Iwanaga K., Shimomura Y. and Inoue M. (2005). Effects of different lighting on the amount of saliva and taste threshold in Japanese and Chinese. *Japanese Journal of Physiological Anthropology* **10**(1), 9-16. [This presents the effects of color temperature and illuminance of lighting on the taste threshold]

Katsuura T. (2000). Physio-anthropological themes in the 21st century –the natural and artificial environments. . *Current topics in physiological anthropology* (eds. M. Sato, H. W. Jürgens, N.S. Narancic, P. Rudan), 7-12. Croatian Anthropological Society. [This presents the importance of the concept of physiological anthropology to create a desirable artificial environment].

Kobayashi H., Ishibashi K. and Noguchi H. (1999). Heart rate variability; an index for monitoring and analyzing human autonomic activities. *Journal of Physiological Anthropology and Applied Human Science* **18**(2), 53-59. [This provides the physiological background and measurement procedures of heart rate variability for application in physiological anthropology].

Kruithof A.A. (1941). Tubular luminescence lamps for general illumination. *Philips Technical Review* **6**, 65-96. [This is a historical study to demonstrate the combined effects of color temperature and illuminance of lighting].

Küller R. (2002). The influence of light on circarhythms in humans. *Journal of Physiological Anthropology and Applied Human Science* **21**(2), 87-91. [This presents the biological and psychological effects of light on circadian and circannual rhythms in humans].

Morita T. and Tokura H. (1998). The influence of different wavelengths of light on human biological rhythms. *Journal of Physiological Anthropology and Applied Human Science* **17**(3), 91-96. [This reviews the relation between the quality of light and human biological rhythms].

Morita T. and Tokura H. (1996). Effects of lights of different color temperature on the nocturnal changes in core temperature and melatonin in humans. *Journal of Physiological Anthropology and Applied Human Science* **15**(5), 243-246. [This demonstrates that the light with a high color temperature was more strongly inhibited by nocturnal core temperature fall].

Mukae H. and Sato, M. (1992). The effect of color temperature of lighting sources on the autonomic nervous functions. *Annals of Physiological Anthrop*ology **11**(5), 533-538. [This presents the effects of color temperature and illuminance of lighting sources on heart rate variability].

Sato M. (2000). An intrinsic theme of physiological anthropology. *Current topics in physiological anthropology* (eds. M. Sato, H. W. Jürgens, N.S. Narancic and P. Rudan), 1-6. Croatian Anthropological Society. [This describes the history and the current themes of physiological anthropology].

Sato M. (2005). The development of conceptual framework in physiological anthropology. *Journal of Physiological Anthropology and Applied Human Science* **24**(4), 289-295. [This describes the major events in the course of theoretical development and the meaning of important keywords in physiological anthropology.]

Biographical Sketch

Tetsuo Katsuura was born in Aichi Prefecture in 1950 and grew up in Shizuoka Prefecture, Japan. He graduated in ergonomics at Kyushu University of Design Science in 1972. He started his research career as an assistant at Kyushu University of Design Science in 1974 and transferred to Chiba University as a lecturer in 1980. He proceeded to PhD in science at Kyoto University in 1986. He became a full professor of ergonomics at Chiba University in 1996. His recent research theme is “physiological anthropology on adaptability to artificial environment.”