Healthcare Science for Lifelong Health—Visualizing Biological Rhythms and Regulating Them on One's Own

Hiroshi Nakashima, Michiko Seyama, Takuro Tajima, and Kana Eguchi

Abstract

The COVID-19 pandemic has brought dramatic changes to our daily lives and social activities. Anxiety over one and one's family becoming infected, stress caused by limitations imposed on personal behavior, changes in lifestyle, etc. have greatly affected everyone's mental and physical condition. This article introduces health science that aims for a society of lifelong health by visualizing one's daily data covering basic lifestyle habits (eating, exercising, and sleeping) and self-regulating one's biological rhythms.

Keywords: healthcare science, biosensing, biological rhythm

1. Supporting a society of lifelong health

Physical well-being is one basic element of well-being. It is thought that good maintenance of one's physical and mental condition and keeping healthy is important and that good health can act as a basis for cultivating values (symbiosis, empathy, sustainability, happiness, and affluence) that enhance one's quality of life. However, we are experiencing a pandemic on an unprecedented scale in the form of COVID-19. This pandemic has significantly degraded physical and mental well-being throughout the world.

In November 2020, NTT announced its Medical and Health Vision [1] to support lifelong health by predicting a person's physical and mental conditions and acquiring technology to support well-being. As part of this vision, NTT is developing bio-digital twin technology that can sense a massive amount of diverse biological data in a person's daily life, model human physiological functions, and execute simulations for predicting the future by taking individual features into account [2]. The medical field is currently undergoing a paradigm shift from symptomatic therapy that searches for a cure after a person becomes ill to a world of care to prevent an illness from occurring in the first place (preventive medicine). Against this background, NTT aims to conduct digital mapping of a person's biological data and use advanced biological-information-processing technology to create new value, such as avoiding the risk of disease beforehand, inducing healthy behavior to naturally prevent illness, and supporting an individually appropriate self-reliant life.

Amid social changes, such as the trend toward remote working, there have been reports of increasing burden on people's physical and mental conditions due to working in an environment other than one's workplace. There are concerns that a decrease in physical activity or irregular sleep/awake times can lead to the onset or aggravation of lifestyle-related diseases. To maintain one's health, it is common to demand endurance and tenacity to some extent in

managing one's behavior and establishing regular lifestyle habits. We have therefore entered into joint research with Waseda University on the three topics described below in the field of healthcare science with the aim of searching for a behavior-modification protocol for visualizing biological rhythms and enabling automatic regulation without placing a burden on the individual. We are developing techniques for clarifying an individual's biorhythms by arranging lifestyle habits (eating, exercising, and sleeping)—the basic elements of well-being—along a time axis, accumulating biological sensing data accompanying that person's daily behavior, and analyzing those features. We will combine these techniques with knowledge related to behavioral psychology and behavioral economics to establish a mechanism leading to automatic regulation of biological rhythms. This could lead to the development of a technique for presenting and indexing evidence and providing feedback so that a person's health-related behavior can be modified in a voluntarily, effortless manner.

2. Using circadian rhythm to improve dietary habits (in search of chrono-nutrition)

Core body temperature (CBT) has been attracting attention as one index reflecting the circadian rhythm of a person's body. As shown in **Fig. 1**, CBT refers to the temperature of the body's core including the brain and other organs. To keep these organs functioning, CBT is not easily affected by the outside environment and is the highest temperature in the body. CBT rises as a result of an inflammatory response, such as a heat stroke or infectious disease, and drops at the onset of a condition such as hypothermia; thus, it is used as an important vital sign in medicine. CBT fluctuates slightly by about 1°C within the range of normal body temperature in a daily cycle. This fluctuation is linked to the circadian rhythm of every individual [3].

To visualize circadian rhythm based on CBT, NTT has been researching and developing a high-accuracy wearable CBT sensor that can detect this slight daily fluctuation in CBT without placing an excessive load on the body. Medical settings, such as surgery, use measurement methods that involve directly inserting probes into organs, such as the rectum or ear (eardrum temperature), but these methods can place a heavy burden on the patient. In contrast, NTT is using a mechanism that estimates CBT by measuring the flow of heat radiated from the body core, as shown in Fig. 1, to the skin using a sensor attached to the surface of the body [3]. The way in which heat escapes from the body differs in accordance with the outside environment such as wind, temperature, and human activities, but the CBT sensor under development at NTT is equipped with a function for suppressing the effects of fluctuations in the outside environment when the person is in a restful state.

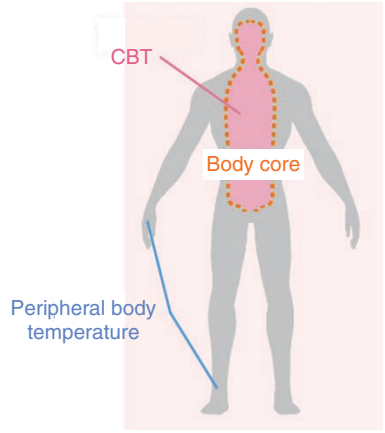

Fig. 1. Peripheral body temperature and CBT.

The biological clock that generates the human circadian rhythm is regulated by the input of information such as external light on a specific brain area (suprachiasmatic nucleus). Recent research has revealed that this biological clock affects the peripheral clocks of various organs such as the liver, kidneys, and muscles, which indicates that the circadian rhythm has a close connection with various states of our body such as metabolism, quality of sleep, exercise, and onset of illness. For example, the level of glucose in the blood when eating can easily increase in the evening hours compared with the afternoon as a circadian rhythm [4]. It is therefore expected that an individual can achieve a healthier dietary lifestyle by ingesting an appropriate meal at the appropriate time given an understanding one's circadian rhythm (chrono-nutrition). In other words, an individual should be able to acquire healthy habits without excessive effort by incorporating nutrition that takes into account this biological clock in one's daily life. Chrono-nutrition has been tested mainly in nocturnal animals such as mice. In our joint research with Waseda University, we are applying NTT's CBT sensor to chrono-nutrition and gathering evidence on the correlation between the diurnal circadian rhythm of humans and a healthy diet.

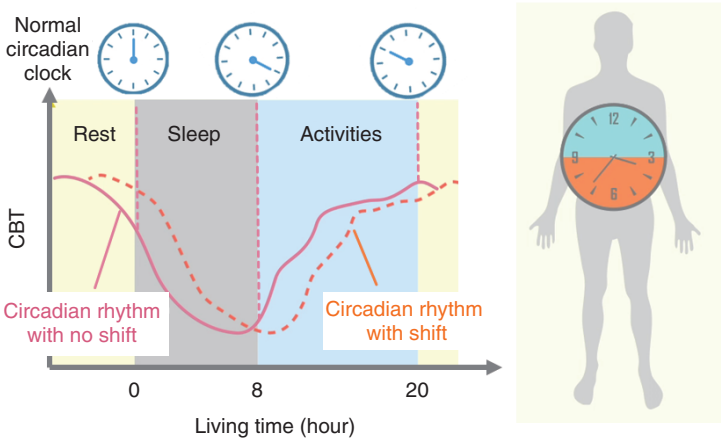

Fig. 2. Circadian rhythm visualized using CBT.

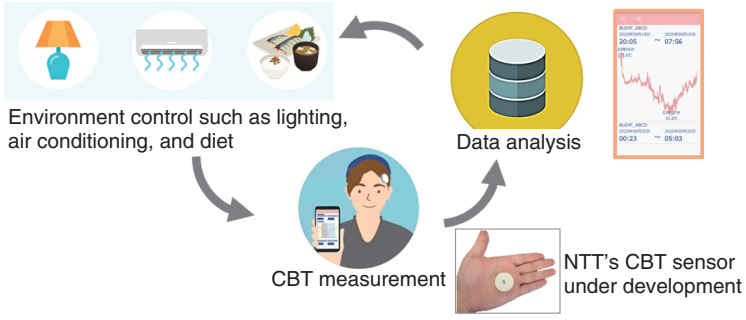

Fig. 3. Example of a healthcare system using CBT measurement.

3. Visualizing circadian rhythm to treat sleep disorders

In today's society in which people's lifestyle habits are becoming increasingly diversified, a shift can easily occur between the circadian rhythm and living time, such as the time that one goes to bed and wakes up, and that this shift is related to the quality of sleep. With no shift between the circadian rhythm and living time, CBT begins to drop several hours before sleep then starts to increase in the latter half of sleep, as shown in **Fig. 2**. However, when a shift does occur between the circadian rhythm and sleep/awake times within one's living time due to an irregular lifestyle, the quality of sleep deteriorates. This state is called *social jet lag*, which is similar to ordinary jet lag to some extent. If left unchecked, this state can lead to sleep disorders such as difficulty falling asleep, light sleep, difficulty in getting out of bed, and sleepiness during the day, which can have a negative effect on one's mental and physical health and social activities [5]. To enable an individual to easily regulate and improve one's quality of sleep, it is important to acquire a technique for one to effortlessly carry out sleep self-management while understanding their circadian rhythm. Applying such a technique should make it possible to construct a healthcare system oriented to the individual, as shown in **Fig. 3**.

We are conducting pilot research on how knowledge of the circadian rhythm obtained from NTT's CBT sensor can help improve sleep quality. We are conducting long-term CBT measurements regarding daily life, and in addition to evaluating biological rhythms obtained from data on the diurnal variation of body temperature, we are conducting correlation analyses with data obtained from a sleep-evaluation wristband, stress-marker tests (cortisol and amylase in saliva), and stress-check questionnaires. Our aim is

to closely track any correlations between temperature patterns obtained from the CBT sensor and stress-marker concentrations or stress indicators, which we hope will lead to methods for evaluating sleep quality and guidelines for improving life.

4. Testing effects of online health and hygiene guidelines on remote workers

Remote working has been expanding since 2020 in the midst of the COVID-19 pandemic. However, a decrease in daytime activities, insufficient exercise, and disruption in one's sleep/awake rhythm due to a life centered on the home can be associated with lifestyle-related diseases and poor mental health. As reflected by comments such as "I can sleep well on days that I move around a lot" and "I feel well-rested with no fatigue after a good night's sleep," nocturnal sleep and daytime exercise are closely related lifestyle habits. Consequently, in this new normal era, it is thought that each person should change their attitude and behavior toward sleep and exercise and that the need for ongoing healthy behavior will increase.

Against this social background, we have begun to study awareness-raising and behavior modification centered on sleep and exercise. As the first step of this study, we are conducting online health and hygiene education seminars targeting remote workers in collaboration with a board certified physician of the Japanese Society of Sleep Research and analyzing their effects. We are using subjective evaluations related to sleep, exercise, and work conditions (commuting to the office or working at home) obtained from questionnaires as well as objective indices related to personal activity (number of steps, calories burned) and body composition (weight, body mass index) obtained from wearable devices or other means. Our aim is to gain a multifaceted understanding of changes in the daily behavior of remote workers. We are also attempting to clarify the changes in daily behavior induced by online health and hygiene education seminars and the relationship between daytime activities and nocturnal sleep. We plan to use the knowledge gained through these studies to investigate techniques for increasing awareness and changing daily behavior for the better in an effortless and sustainable manner. We will also strive to explain any ripple effects of changes in daytime activities and nocturnal sleep in preventing lifestyle-related diseases.

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