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REVIEW ARTICLE

Neuroarchitecture From the Perspective of Circadian Rhythm, Physical, and Mental Health

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The field of neuroarchitecture explores how various architectural elements impact human physical and mental health, based on neuroscience principles. With the development of functional neuroimaging and electroencephalogram studies, researchers can now visualize and quantify how different architectural factors affect brain activity, emotions, and cognition. Mobile Brain/Body Imaging is a new research methodology that records a moving person's brain activity and bodily sensations in real time, promising to be a useful tool for space and urban design. In this article, we discuss neuroarchitecture from the perspective of circadian rhythm, physical health, and mental health. Studies have shown that artificial light at night disrupts the circadian rhythm, leading to acute and chronic negative health effects. Conversely, creating a person-centered light environment or incorporating nature-like elements can have a positive impact on health. Research has also shown that exposure to nature reduces self-rumination and contributes to psychological well-being. Neuroarchitecture studies on other factors, such as ceiling height, wall colors, and the movement of people in the building, should be expanded to gain greater insights and practical applications. The convergence of neuroscience and architecture has the potential to identify architectural elements that benefit human physical and mental health.

Keywords: Circadian rhythm; Mental health; Nature experience; Neuroarchitecture; Physical health

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INTRODUCTION

Neuroarchitecture is a field that explores which architectural elements are beneficial or harmful to the physical and mental health of humans based on neuroscience principles [1-3]. In the past 20 years, functional neuroimaging or electroencephalogram studies have been conducted in neuroscience, which has made it possible to visualize and quantify various perceptions experienced by humans [4,5]. Furthermore, studies have been conducted to confirm how human emotion and cognition are associated with a specific brain area or neural circuit [6-8]. In addition, studies in system neuroscience and computational neuroscience, which have recently increased in number, have helped understand human sensory perception at the molecular and microcircuit levels [9-12]. An interesting new research methodology is Mobile Brain/Body Imaging (MoBI), which records a moving person's brain activity and bodily sensations in real time [13,14]. MoBI has superior ecological validity compared to existing research methods, and since it is possible to see in real time how the brain and body react when a human is staying or moving in a specific space, it promises to be a highly useful method in the area of space and urban design.

As neuroscience research techniques improve, enabling the measurement, visualization, and quantification of human brain activity, we are now able to investigate the influence of different architectural elements (e.g., room height, lighting brightness, scenery outside the window, space temperature change, etc.) on brain activity. Through such studies, we can gain insights into how these factors impact human emotions and cognition, and how they may promote or undermine physical and mental well-being. Neuroarchitecture can be used for various purposes in various fields such as future space design, architectural design, indoor environment, and landscaping. Until now, scientific research in neuroarchitecture has been relatively scant; thus, there is a need for further research and expansion.

NEUROARCHITECTURE FROM THE PERSPECTIVE OF CIRCADIAN RHYTHM AND PHYSICAL HEALTH

In the early days of neuroarchitecture research, indoor environment designs in harmony with the circadian rhythm were proposed. Circadian rhythm is a cellular, biochemical, and behavioral rhythm in living organisms that allows them to adapt to the 24-hour solar cycle. It is an adaptation mechanism that helps living organisms achieve synchronization between internal and external environments [15-17]. One of the important ideas when considering circadian rhythm in neuroarchitecture research is the view that the human body has an optimized circadian rhythm that adapts to nature through the evolutionary process [18,19]. From this point of view, rapid environmental changes or cultural factors that exceed the natural evolutionary rate have the potential to negatively affect human physical and mental health [20]. A simple example of rapid environmental change is the artificial light that floods modern residential or urban environments. Modern light profiles, which are a mixture of natural daylight and artificial light, show a pattern in which the distinction between day and night is unclear to the body, and light of various wavelengths and intensities appears and disappears irregularly and unpredictably. The mismatch between the endogenous circadian rhythm and the light environment produced by modern light profiles causes circadian rhythm disturbances in individuals, potentially leading to acute and chronic negative health effects [21-23]. In fact, the harmful health effects of artificial light exposure at night have been discussed in several papers [24-26].

The effect of artificial light on circadian rhythm disturbance and sleep has been a frequent research topic [27,28]. Many studies show that exposure to light, especially at night, suppresses melatonin secretion and brings about changes in sleep profiles [29,30]. Other studies reveal that a high amount of exposure to artificial light at night leads to difficulties in sleep initiation and maintenance, causing sleep phase delay, and even increased depressive symptoms resulting from decrease in sleep quality [31-33]. The influence of artificial light exposure at night on physical health has also been studied. Some studies propose an increase in the incidence of breast cancer, and associations with obesity, hyperlipidemia, and hypertension risk have been suggested [24,34,35]. However, since nighttime artificial light exposure itself cannot act as a direct toxicity factor for cancer, obesity, or hypertension, these associations are thought to be effects determined by critical mediating factors. Currently, circadian rhythm and sleep are considered the most important mediators, and many previous studies have suggested that circadian disturbance, circadian misalignment, and insomnia can be associated with the development of various physical diseases such as breast cancer, liver cancer, and obesity [36-38]. In addition, recent next-generation sequencing studies have shown that various organs of the human body, such as the liver and large intestine, have a circadian transcriptomic landscape, proposing that each organ has an optimal time to function or rest [39-41]. In the case of the liver, which has been studied the most from the perspective of the circadian clock, about 15% of genes are reported to have circadian gene expression, and major liver functions such as glucose homeostasis, lipids and mitochondrial dynamics, and detoxification show different patterns during the day and at night [41,42]. It is known that the central nervous system and the brain also have unique day and night circadian neural activity patterns and circadian gene expression [43]. As such, humans have developed endogenous circadian rhythms through a long evolutionary process; hence, the modern light profile, especially artificial light exposure at night, has implications for physical and mental health and can be regarded as a potentially significant risk factor.

IMPACT OF PERSON-CENTERED LIGHT ENVIRONMENT AND NATURE EXPERIENCE ON MENTAL HEALTH

Neuroarchitecture studies have investigated not only the negative effects of artificial light at night, but also the positive effects of a nature-like light environment on the human body. In one study, when a large window was installed on the ceiling and the natural light inflow was maximized in a common living space of older adults with cognitive impairment, it was shown to increase day-night orientation and decrease abnormal behavior [44]. Research has also been conducted on scenarios where it is difficult to create a natural lighting environment, such as in an intensive care unit [45]. A study suggested that melatonin secretion and rhythm can be restored in patients when a personalized patient-centered light environment is created in an intensive care unit [46,47]. In addition, a study was conducted on the light environment of shift workers and the resulting cognition and depressive symptoms [48]. In this study, a dynamic light environment was created using channel light-emitting diodes, and the shift workers carried out their work in this experimental lighting for a month. It was found that the month-long exposure to the modified light environment had a positive effect on the circadian rhythm, cognitive performance, and mood status of shift workers. Overall, creating an environment that uses or mimics natural light can have a positive effect on health, and in situations where circadian mismatch is unavoidable, such as shift work, the external environment can be modified to create a residential ambience and minimize circadian mismatch.

In architecture, there have been recent attempts to maximize the individual's nature experience in the process of architectural design or urban design. These attempts have been made based on the intuitive assumption that humans feel physically and mentally stable when they are in nature. An interesting study that is considered important from the perspective of neuroarchitecture drew attention by revealing what kind of brain changes occur when humans experience nature [49]. At the time, the study proposed a hypothesis that urbanization could increase individual self-rumination and cause mental illness such as depression. In this study, participants were asked to walk for 90 minutes in an urban or natural environment and functional neuroimaging was performed. Self-rumination decreased only when they experienced the natural environment. In addition, the activity of the subgenual prefrontal cortex, known as a brain region related to self-rumination, also decreased only when walking in a natural environment, but did not change when walking in an urban environment [50]. Many previous studies have shown that the subgenual prefrontal cortex shows elevated levels of activity in depressed patients, and the activity reduces after depression treatment [51-53]. In summary, recent attempts to introduce the natural environment into a building or urban environment in the process of architectural design or urban design have the potential to reduce human self-rumination and contribute to psychological well-being.

In neuroarchitecture, not only the contents of the light environment or proximity to nature discussed above, but also factors such as ceiling height, the size or direction of doors, wall colors, passage width, the movement of people in the building, and the positional relationship between buildings could be studied to analyze their effect on emotion and cognition. In fact, such studies are being conducted, but they are few in number [54,55]. The research on these topics needs to be significantly expanded to obtain greater insights and practical applications.

CONCLUSION

Neuroarchitecture is the convergence of neuroscience and architecture. With the rapid development of neuroscience research methodologies in recent years, it has become possible to more broadly study how various architectural elements affect human perception, emotion, and cognition. In addition to functional neuroimaging and electroencephalogram, which are widely used, latest research methodologies such as computational neuroscience and MoBI have the potential to further enrich neuroarchitecture studies. Big data analysis and artificial intelligence technology, which are rapidly advancing at present, will also help analyze the collected body-based information. In the future, it is necessary to conduct many studies linking neuroscience and architecture, and in particular, many scientific studies should be conducted to identify architectural elements that are beneficial to the physical and mental health of humans.

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Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

Availability of Data and Material

Data sharing is not applicable to this article as no datasets were generated or analyzed during the study.

Author Contributions

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