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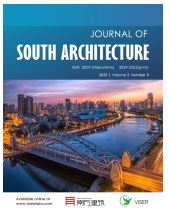

The Healing Benefits and Application of the Virtual Natural Environment

ZHANG Zhen[1], XU Leiqing[2]

Author Affiliations 1PhD students; 2Professor, corresponding author, email: leiqingxu@163.com; 1&2School of Architecture and Urban Planning, Tongji University

ABSTRACT: During the COVID-19 epidemic, many people developed negative emotions and stress from staying at home and being separated from normal life for long periods. Virtual reality technology provides the possibility for people to enter into the natural environment and experience physical and mental healing during home isolation. The healing benefits of virtual natural environments and biophilic design, including perceived restorative effects, improved cognitive performance, improved emotional health and physiological stress recovery, were evaluated by analyzing and summarizing existing empirical research. It was found that both 360° photos/videos and computer-generated virtual nature experiences can significantly improve the perceived restorative effects of these experiences regardless of whether the subject is in motion or resting state. There is insufficient evidence to prove that virtual nature technology can significantly affect cognitive ability. However, some research showed that it could effectively stimulate creative thinking related to cognitive ability. Virtual nature can significantly alleviate negative emotions and improve positive emotions. Such positive effects are regulated by the usability of equipment. Although virtual nature technology can effectively mitigate physiological stress, the influence of time factors must be clarified. The healing benefits of biophilic design are related to the configuration, type and layout of natural elements. For example, indoor greening can generate better healing benefits than biophilic materials and natural windowscapes. In conclusion, both virtual nature and biophilic design can be used as potential healing scenarios. The former can be combined with personal, public space and social network scenes to heal both individuals and groups and repair social relations. These findings provide a new direction for environmental construction.

KEY WORDS: virtual reality technology; restorative environment; virtual natural environment; virtual biophilic design; healing benefits; healing environment; place-making; restorative urban design

Introduction

At the end of 2019, the COVID-19epidemic broke out on a large scale in China and other parts of the world. In order to effectively control the spread of the epidemic, many countries and regions have issued stay-at-home orders. Extended periods of home confinement and disruption of normal routines have led to negative emotions such as tension, anxiety, and depression. How to pull people out of this negative state and effectively improve their mental and physical health has become a common fight against the epidemic while working from home and teaching online, and it is also a public health issue that urgently needs a response.

The natural environment has good physical and psychological healing effects[1]. At the physical health level, the natural environment helps prevent chronic diseases [2] and improves the physical health of the groups [3]. In terms of mental health, the natural environment can effectively repair attention [4], relieve stress [5], and improve

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negative emotions and mental fatigue [6]. However, the lack of restorative living environments in cities limits people's opportunities to get close to nature in space. Now that epidemic prevention and control has become the norm, people are eager to experience nature at home to achieve physical and mental recovery. In recent years, the rapid development of virtual reality technology has made this possible. Virtual reality technology is a technology that uses computer simulation to create a digital, three-dimensional world, giving users an immersive experience [7]. The scenes constructed by virtual reality technology have better performance in terms of immersion, realism, stereoscopic sense, depth of field, and even comfort than photos and videos [8]. This technology provides people with the opportunity to escape from the present moment into the natural environment and enjoy the healing power of nature during home isolation and in between busy lives. Virtual reality technology has been widely used in the field of clinical psychology and has been proven to effectively affect people's perceptions and emotions, thereby affecting their psychological and physical health [9,10].

Based on the above background, the healing performance of natural scenes presented in virtual reality and whether they can achieve healing benefits equivalent to those of real natural environments have become important issues of concern to people. This study collects relevant literature on the effects of short-term immersion in the virtual natural environment on people's physical and mental health, summarizes and analyzes its empirical research results, and attempts to evaluate the healing benefits of the virtual natural environment experience from a more comprehensive and complete perspective, providing a theoretical basis for its future development and application.

1 The healing benefits of the natural environment

People have long explored the healing benefits of natural environments. The "Biophilia Hypothesis" proposed by Harvard University biologist E.O. Wilson in 1984 believes that there is a natural biological connection between humans and nature. Humans have lived in natural environments for a long time, so their bodies can better adapt to the natural environment. The widespread prevalence of urban diseases stems from the fact that the human body has not yet fully adapted to the urban environment due to the short history of living in cities. Humans need to get close to nature to alleviate the physical and mental damage caused by the urban environment [11]. Subsequently, two core classic theories of restorative environment, Attention Restoration Theory (ART) and Stress Reduction Theory (SRT), emerged one after another. Among them, the "Attention Restoration Theory" proposed by Kaplans takes cognitive psychology as its perspective and regards direct attention as the medium of environmental cognition. Excessive consumption of direct attention will lead to mental fatigue. Being in a natural environment can effectively repair attention as a cognitive resource [12]. Based on this theory, Harting et al. developed a perceived restorative effect scale to measure people's subjective feelings of recovery. The "stress reduction theory" proposed by Roger Ulrich is based on the perspective of psychological evolution. It believes that people in daily life are stimulated by various social and environmental factors, which will produce different degrees of psychological and physical stress reactions. Long-term stimulation will cause people to have negative emotions such as stress, anxiety, tension, etc., and induce mental fatigue. The natural environment can promote physiological recovery and psychological relaxation, while most urban environments will hinder people from relieving stress [13].

Based on different research perspectives, the two core theories of environmental restoration deeply explain the mechanism of the restorative effect of the natural environment, and define the healing benefits of the natural environment on people in four aspects: perceived restorative effects, cognitiveperformance, emotional regulation, and physiological stress recovery, providing a basic framework for subsequent empirical research.

2 Assessment methods and indicators

Based on the basic theoretical framework, empirical research often uses multipleassessment methods at the same time to comprehensively assess the healing benefits of the natural environment. The investigation method integrates classic research paradigms and methods from multiple research fields, such as restorative environment theory, psychology, and neuroscience.

2.1 Perceived restorative effects

The Perceived Restorative Scale (PRS), developed from the restorative environment theory, is the main method forassessing perceived restorative effects. It focuses on the four major restorative environment characteristics of Being away, Fascination, Extension, and Compatibility to conduct a subjective assessment of the environmental experience.

2.2 Cognitive performance

Cognitive ability is primarily assessed using classical experimental paradigms in cognitive psychology, including the Digital Span Forward/Backward test (DSF/DSB), the Sustained Attention to Response Task (SART), the Necker Cube Pattern Control Task (NCPCT), the Symbol Digit Modalities Test (SDMT), etc.; cognitive neuroscience assessing methods such as electroencephalograph (EEG) and magnetic resonance imaging (MRI) can also be used.

2.3 Emotional regulation

The mainassessment methods for the natural environment's effect on emotional regulation are self-report scales, such as the Profile of Mood States (POMS), the Positive and Negative Affect Scale (PANAS), and the State-Anxiety Inventory (SAI), Zuckerman Inventory of Personal Reactions (ZIPERS), Achievement Emotions Adjective List (AEAL), etc.

2.4 Physiological stress recovery

With the rapid rise of neuroscience in the 1990s, this technicalassessment method can measure environmental experience more objectively and accurately. Physiological assessment methods are used to examine the physiological stress response of the human body under environmental stimulation. Specific indicators include skin conductivity levels (SCL), stress hormone levels, heart rate (HR), heart rate variability (HRV), respiratory rate, diastolic blood pressure (DBP), systolic blood pressure (SBP), etc.

3 The healing benefits of virtual natural environments

In existing research, virtual natural environments (forests, beaches, etc.) have been discussed as a potential healing tool. The study compared the healing benefits of real and virtual natural scenes, and virtual natural and urban scenes, to verify the effectiveness of the virtual natural environment as a healing tool; compared natural media with different levels of immersion, such as photos, videos, and VR scenes, to verify the superiority of virtual natural environment healing; explored the additional healing benefits of combining the virtual natural environment with physical activity scenes (walking, cycling) to expand its application scenarios; and verified whether the virtual natural environment is suitable for the healing of special groups, such as the elderly with varying degrees of cognitive or physical impairment, cancer patients, and the elderly with depressive tendencies, to expand its application population. Virtual natural scene materials are mainly 360-degree photos or videos taken on site. They are simple to obtain and closer to the original natural appearance, and forest scenes are the most widely used. In order to more clearly analyze the healing benefits of the virtual natural environment, the existing empirical research results were integrated into four aspects according to the theoretical framework, namely, perceived restorative effects, cognitive performance, emotional regulation, and physiological stress recovery.

3.1 Perceived restorative effects

Based on the results of various studies, it is found that static immersion in 360-degree photos/videos[14,15] or computer-generated [16] virtual natural scenes can significantly improve the perceived restorative effects, and the virtual natural environment based on 360-degree video is proven to be able to obtain the same perceived restorative results as the real natural environment[15]. During physical activities, although the perceived restorative evaluation was significantly improved after virtual natural environment immersion, the results of open questions showed that the experience was not pleasant, and simulator sickness and poor image quality were the main reasons for the poor experience[17]. The combination of the virtual natural environment and physical activities requires further improvement in picture quality and stability.

3.2 Cognitive performance

Cognitive ability (mainly attention) is one of the important manifestations of the benefits of natural healing. After analyzing existing research results, it was found that most studies failed to prove that short-term virtual nature

immersion has a significant impact on the subjects' cognitive abilities. Herman LM et al.[14] used the Necker Cube Pattern Control Task (NCPCT), the Digit Span Test (DSB) in reverse order, and the Remote Association Test (RAT) as the assessment tools, Valtchanov D [16] et al. employed the scores and time of mental arithmetic test as the assessment method and indicators, and Menardo E et al. [18] adopted the Sustained Attention to Response Task (SART) as the assessment tool. All of these studies found no significant differences in the cognitive levels of subjects before and after virtual natural environment immersion. AUT (Alternate Uses Test) is used to measure creative thinking related to cognitive function. Studies using AUT as an assessment method have shown that both real natural and urban scenes can stimulate subjects' creative thinking, while only natural scenes in virtual environments can stimulate creative thinking[19]. Virtual natural environment experience has no significant effect on cognitive abilities mainly related to attention, but it can significantly stimulate creative thinking.

3.3 Emotional regulation

The virtual natural environment has been found to be comparably effective to real nature in alleviating negative emotions. The study found that the anxiety levels[14] and stress levels [16] of the subjects reported before and after virtual natural environment immersion significantly decreased. Compared with the virtual urban environment, the virtual natural environment can significantly alleviate negative emotions such as confusion, fatigue, anger, hostility, tension, and depression [20]; the virtual natural environment is just as effective as real nature in alleviating negative emotions [15]. In terms of enhancing positive emotions, after virtual natural environment immersion, participants' scores for positive emotions on the ZIPERS Emotional Seeking Scale [16] and the Achievement Emotional Adjective List (AEAL) [18] significantly increased. After engaging in mindfulness exercises in the virtual natural environment, both mindfulness states and positive emotions were significantly improved [21]. Compared to virtual urban environments, the virtual natural environment can effectively enhance positive emotions such as vitality. However, in comparison to real natural environments, the virtual natural environment does not lead to a significant increase in positive emotions as real nature does [15], indicating that the emotional healing benefits of the virtual natural environment still fall short compared to real nature. The virtual natural environment not only has emotional healing benefits for healthy people, but is also effective for special groups such as the elderly and the sick. After virtual natural environment immersion, most elderly people with different degrees of cognitive or physical impairment felt more relaxed and adventurous[22]. Cancer patients experienced reduced stress and significant improvements in positive emotions and overall well-being following virtual natural environment-based therapeutic interventions[23-24].

In addition, the study found that device usability is an important factor affecting the emotional healing effect of the virtual natural environment. Only those who perceive high usability have significant differences in emotions before and after immersion in a virtual natural environment [18]. The discomfort caused by the heaviness of the virtual head-mounted display, visual deviation, and low scene refresh rate leading to simulator sickness [25], as well as other device usability issues, can significantly increase negative emotions and fatigue while significantly decreasing positive emotions [26,17].

3.4 Physiological stress recovery

Skin conductance level (EDA/SCL), heart rate, heart rate variability (HRV), respiratory rate, blood pressure, salivary α-amylase, etc., are used as physiological indicators to characterize the physiological recovery effect of the virtual natural environment on stress stimulation. After virtual natural environment immersion, the subjects' skin conductivity levels decreased significantly compared to the baseline [16, 27], which is basically the same as the impact of the real natural environment [20]. Compared with virtual urban scenes or two-dimensional natural media (PPT pictures, videos), the heart rate [28, 16] and breathing rate [28] of the subjects significantly decreased after immersion in the virtual natural environment; descriptive statistics showed that the subjects' diastolic blood pressure, systolic blood pressure, and salivary α-amylase all dropped.[20], but this decrease was not statisti-

cally significant [20, 28]. In addition, the analysis found time is an important factor that interferes with the benefits of physiological stress recovery. Analyzing time as a factor, it was found that regardless of the scenes, the subjects' systolic blood pressure [20] and heart rate [29, 20] decreased significantly over time. In summary, the virtual natural environment has significant physiological restorative healing benefits, but the establishment of these benefits should be based on clarifying the impact of time factors on the physiological restorative effects of the virtual natural environment.

4 The healing benefits of biophilic design

4.1 Biophilic urban design

Unlike the natural environment, the urban environment is mostly designed and constructed by humans. How to utilize limited space in cities to enable people to obtain the best health and healing benefits is one of the core issues in the field of environmental design. Public spaces such as parks, squares, green spaces, and streets are the focus of environmental designers.

The configuration, layout, and type of natural elements in urban public spaces all have an impact on the healing benefits. For the virtual park, the moregreen-enclosed edges and the denser vegetation on each boundary, the lower the subjects' perceived restorative effects and sense of safety[30]. After the park added water features, the evaluation of "fascination" and "being away" in the perceived restorative effects was significantly improved [31]. For the virtual square, the more green-enclosed edges, the higher the subjects' perceived restorative effects [30]. Any form of virtual urban green space has a significant restorative effect on attention fatigue and negative emotions. Among them, the semi-open green space has the best healing benefit, with the greatest effect on alleviating negative emotions and the highest leisure preference score, while the closed green space has the worst healing benefit [32]. The street green view index was controlled below 25% in the virtual environment. It was found that the street green view index was positively correlated with the perceived restorative effects in the two dimensions of "fascination" and "compatibility"; that is, as the green view index increased, the restorative potential of the street increased[33]. (Figure 1). Compared with concrete paving, both lawn and tree courtyard spaces are more conducive to the recovery of subjects' physiological stress and the improvement of positive emotions, and lawn has better healing effects[34].

Figure 1 VR scenes of streets with different green view index

4.2 Indoor biophilic design

Indoor biophilic design is to bring nature indoors, including arranging natural elements such as vegetation and water features indoors, using natural materials, introducing natural light, natural windowscapes, etc. The healing benefits of authentic interior biophilic design have been widely

demonstrated [35,36]. In a virtual environment, Yin Jie et al. from Harvard University and Xu Leiqing et al. from Tongji University conducted a series of experiments to explore the healing benefits of virtual interior biophilic design.

Yin Jie et al. compared the healing benefits of virtual and real biophilic design, and the healing benefits of different degrees of biophilic design and different forms of biophilic design in virtual office spaces. Comparative studies on the healing benefits of virtual and real biophilic design have confirmed that short-term immersion in real or virtual biophilic office environments has similar physiological, cognitive, and emotional performances. Compared with non-biophilic design environments, the diastolic blood pressure, systolic blood pressure, and skinconductance level of the subjects who experienced biophilic design environments decreased more significantly, and their short-term memory improved, negative emotions decreased, and positive emotions increased[37]. This study provides strong evidence that virtual indoor biophilic design environments can achieve healing benefits comparable to real environments. A comparative study on the healing benefits of different degrees of biophilic design showed that compared with the control group without biophilic design, the three experimental groups that used biophilic analogues (wood textures and plant-patterned wallpaper), introduced natural elements (natural light and green plants), and used the first two in combination had lower values of physiological indicators such as blood pressure, heart rate, heart rate variability, and skin conductance level, and higher scores on creative thinking tests. Among the three experimental groups, the use of biophilic analogues had the worst healing performance in terms of physiological recovery (diastolic blood pressure, heart rate), cognitive performance (Stroop color word test reaction time and Alternative Uses test scores), and self-reported connection with nature[38]. (Figure 2). A study comparing the healing benefits of different forms of biophilic design showed that compared with the control group without biophilic design, three types of indoor biophilic design, namely natural windowscapes, indoor greenery, and the combination of the first two, can effectively reduce physiological stress and anxiety levels; among the three types of biophilic designs, indoor green has the best effect on restoring physiological stress, and the combination of natural windowscapes and indoor green has the greatest effect on restoring anxiety[39] (Figure 3).

Figure 2 Different degrees of biophilic design

Figure 3 Different forms of biophilic design

In China, Xu Leiqing and others compared the healing benefits of four types of living room environments, created by combining two indoor design variables (wood-based design and white design) with two types of outdoor windowscapes (park view and urban view). The results showed that both indoor wood-based design and natural windowscapes had healing benefits. Specifically, the wood-based design helped alleviate participants' anxiety, while the white design even triggered higher levels of anxiety[40] (Figure 4).

Figure 4 Two levels of interior design: wood color vs. white, and two levels of windowscapes: nature vs. city

In summary, both urban and indoor biophilic designs in virtual environments have healing benefits, and their healing benefits are related to the type, configuration, and layout of natural elements. In interior biophilic design, indoor greening can bring better healing benefits compared to the use of biophilicanalogues, natural windowscapes, etc. Good spatial design is the prerequisite for ensuring that people can achieve physical and psychological restoration in virtual biophilic design.

5 Application trends of virtual natural environment healing

5.1 The virtual natural environment and individuals

The upcoming deployment of 5G mobile communication technology enables individuals to access high-quality, smoothly streamed VR video content via mobile devices such as smartphones and computers. This offers opportunities for people living in closed and isolated environments (e.g., the Arctic, Antarctic, submarines), those unable to go outside due to physical limitations (e.g.,mobility-impaired elderly, patients), as well as those under home quarantine during major public health crises (e.g., the COVID-19 epidemic), to connect with nature and gain physical and psychological restoration. In order to prevent adverse reactions such as dizziness and eye fatigue caused by long-term immersion in a virtual natural environment, it is recommended that each immersion last for 5 to 10 minutes. A study using virtual natural scenes for healing found that after 4-5 minutes of natural environment immersion, the subjects' physiological stress dropped significantly and was close to the baseline level[34, 39]. Research on green physical activities also shows that 5 minutes of natural exposure is most beneficial for improving mood and self-esteem [41]. Short periods of virtual nature exposure are sufficient to achieve good healing benefits.

5.2 The virtual natural environment and public spaces

The presentation of the virtual natural environment is not limited to personal devices such as VR helmets and VR glasses. The rapid development of digital media technology and immersive display technology has made naked-eye VR a reality. South Korea's D'strict company uses a giant LED curved screen 20m high and 80m long to present a 3D, immersive and dynamic picture of surging waves on the building's facade, like a giant waterfall (Figure 5) floating in the air. The combination of digital media technology and powerful design creativity enables natural scenes to be presented in the city in a very realistic and supernatural state. Combining the virtual natural environment with urban public spaces is conducive to enhancing the intentionality of public spaces, stimulating the vitality of public spaces, increasing people's public interactions, effectively expanding and promoting new environmental perceptions, emotions, and health experiences, and achieving collective healing in urban public spaces.

Figure 5 Aerial waterfall designed by D'strict Company in South Korea

5.3 The virtual natural environment and social restoration

"Cyberspace" is a utopian fictional space created by digital means, where humans live in the form of avatars and reorganize social relationships that are different from reality. Companies such as Facebook and Sansar are actively integrating social dimensions into their virtual worlds, which has the potential to transform cyberspace from a fictional dream expressed in words into a realistic virtual world. Research finds people feel lonely and lack social support when they live in an environment lacking

green space [42], the quantity and quality of urban green space and water space are important factors affecting social interaction [43], and social loneliness causes mental and physical health problems [44,45]. The integration of the virtual natural environment and social networks will help combat social loneliness and repair social disconnection and inequality caused by urban isolation. In 2019, Xu Leiqing and Yan Yu restored the connection network as a form of social linkage and spatial restoration, and proposed an urban design model to promote mental health and social recovery. The model includes five types of connections: people-people, people-space, people-nature, people-mobility, and people-data interactions[46] (Figure 6). According to this model, combining the virtual natural environment experiences with social networks will help break down spatial and social segregation embedded in the physical urban fabric, promote social integration, reduce feelings of loneliness, and contribute to the recovery of the entire society.

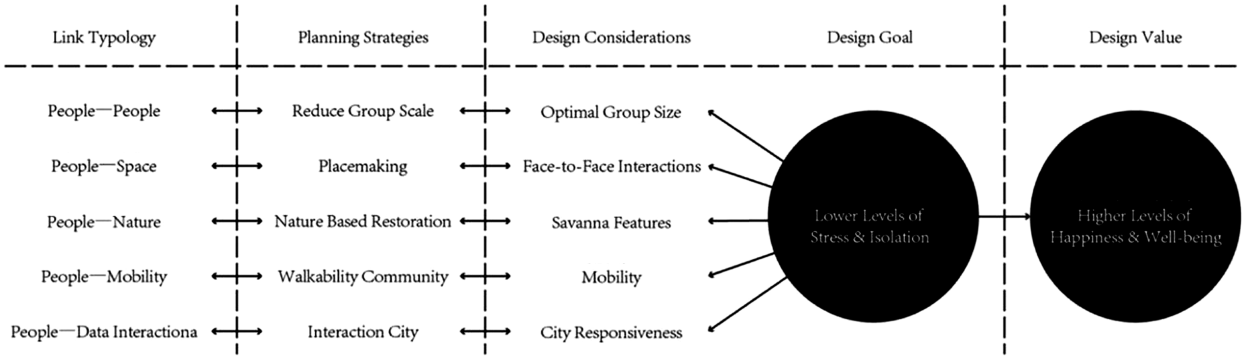

Figure 6 Restorative urban design model

Conclusion

Against the backdrop of the rapid advancement of globalization and the rapid development of network technology, high pressure, fast pace, high load and multi-tasking have become typical characteristics of modern urban life.The virtual natural environment has the potential to become an effective scene tool for people to obtain natural healing benefits in the gaps between busy work and life, providing a new direction for environmental creation. The epidemic has promoted the development of virtual healing. The combination of virtual reality technology and natural scenes has created a new healing environment under public crisis. Virtual healing can become a new healing fashion to respond to public health crises. Researchers and environmental designers in the field of environmental health should pay more attention to the design and development of virtual healing scenes to provide people with more personalized, humane and emotional natural healing environments and experiences to meet and adapt to people's changes in consciousness and spiritual needs.

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