ORIGINAL RESEARCH

Psychological recovery effects of 3D virtual tourism with real scenes -- a comparative study

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Abstract

Objective This study explores the psychological recovery effects of virtual tourism on individuals.

Methods Relevant research usually tends to examine the psychological recovery effects through traditional media entailing a lesser immersive experience. Few studies focus on the psychological recovery effects of virtual tourism, and even fewer on exploring response differences depending on different landscape types. Based on a series of empirical tests and electroencephalogram (EEG) data, this study investigates the impacts of a more immersive 3D virtual tourism with real scenes on people's relaxation (Pm), concentration (Pa), and positive and negative emotions (PA and NA). Additionally, it clarifies the differences in the psychological recovery effects of four landscape types on the abovementioned attributes.

Conclusions The psychological recovery effects did vary according to the type of tourist attractions. There were a few differences based on gender. For instance, men's relaxation level changed significantly after touring lake-oriented virtual tourist attraction. Individual differences in recovery were also observed.

Implications These findings contribute to our knowledge about environmental restoration and its role in alleviating people's anxiety, especially during situations like the COVID-19 pandemic.

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1 Introduction

In a fast-paced modern society, people, especially those who work in urban areas, are always under immense pressure. Owing to the deteriorating urban environment, people also have to cope with negative factors like smog, heavy traffic, polluted air, and loud noises. This causes annual growth in the incidence of psychological burn out, depression, and even emotional exhaustion. Therefore, an increasing number of psychologists have been discussing the issue of people's psychological recovery (Yang 2018). Due to the huge public and personal costs of traditional medical methods, public health agencies have been seeking preventive solutions to promote health and prevent disease, and nature and landscape are increasingly being considered crucial to achieving this goal (Wolf 2017). Mounting evidence suggests that natural environment is important because it offers a valuable resource for human health. Many studies indicated that appreciating nature can reduce stress (Verderber 1986; Ulrich et al. 1991; Hansmann et al. 2007; Shin and Won 2007), improve subjective well-being (Johansson et al. 2011; Luck et al. 2011; White et al. 2017), enhance cognitive functions (Mayer et al. 2009; Richardson et al. 2016), and strengthen connections between individuals and their relationship with natural environment (Mayer et al. 2009; Netta et al. 2015; Richardson et al. 2016). The resilience of natural environment is reflected in the way it reduces stress-related negative emotions and boosts positive feelings (Fredrickson 1998; Sluiter et al. 2000; Takayama et al. 2014).

However, for those with limited time or money or with disabilities, it is inconvenient to enjoy the benefits of the natural environment. Thus, they choose virtual tourism to relieve their physical and mental stress. Especially during the COVID-19 pandemic, people were stranded at home for a long time, sometimes far from nature. They also had their routine disrupted and felt less productive. This situation triggered multiple negative emotions and mental stress. As physical travelling was restricted, people urgently needed to find an effective way to relieve their stress. Thus, virtual tourism emerged and became instantly popular (Yung and Khoo-Lattimore 2017). Additionally, current research tends to explore the recovery effects of natural environments or virtual tourism on people by using photos and videos. There is little research on the recovery effects of the more immersive 3D virtual tourism with real scenes.

3D virtual tourism with real scenes is a tourism model based on 3D panoramic VR technology. This entails presenting realistic scenarios are presented based on VR technology and panoramic photography. Photos are taken using an omnidirectional camera, which has a visual field that covers approximately the entire sphere and is combined with computer technology. Thus, the full screen mode and the interaction provide the audiences with a sense of immersion (Wu et al. 2014). It is also interpreted as a tourism model that uses 3D panoramic virtual technology based on still images. It also refers to the tourism model which uses still image-based 3D panoramic virtual technology, stitches the scenic views taken by the camera into a panoramic image, carries out 3D, detailed, and realistic simulation and reproduction as well as provides travel experience for tourists through a network or other related carriers. There are two main characteristics of 3D virtual tourism with real scenes in terms of its impact on visitor experiences: One, the immersive experience for visitors is supported by a

picturesque scenery and high-resolution 3D panoramic photographs. Two, the interactive experience for visitors is provided by selecting their preferred perspectives with the mouse combined with the tourist navigation map, so that the visitors can look around, look down, and look up the sceneries as if they were physically present (Zhang and Kou 2021). Therefore, compared with viewing pictures and videos, 3D virtual tourism with real scenes is a more immersive way to travel, as it heightens the experience and interaction for visitors.

The current situation in China that involves prevention and control measures for COVID-19 provides tourism with an appropriate chance for innovation and promotion through 3D virtual tourism with real scenes. There are many well-known tourist attractions in China that have launched 3D virtual tourism services, such as the Wulingyuan Scenic Area of Zhangjiajie in Hunan Province, an important natural world heritage site, and the Longmen Grottoes of Luoyang in Henan Province, an important world cultural heritage site. There is a virtual tourism service named 'Smart Wulingyuan', which utilizes 3D virtual tourism technology and provides visitors a chance to enjoy the landscapes online. The visitors can customize their own travel route and destinations with a click of the mouse. By zooming in and zooming out, they can experience the charm of landscapes from every corner and every angle as they were there. As for the Longmen Grottoes, their 3D virtual tourism project, known as 'Longmen on the Cloud', allows visitors to travel whenever and wherever they want. More specifically, both the operating system and the interface display can provide the visitors with an immersive experience, combining digital technology and traditional culture. A full-scale 3D virtual tourism program was launched by the Shanghai Expo, which allowed visitors to visit all the pavilions at home through an entirely 3D spatial and interactive experience.

Although some scholars have conducted studies on the recovery effects of virtual tourism, there still are limitations. Firstly, in terms of research topic and contents, the current scholars mainly focus on the impact of computer virtual scenes on people (Valtchanov et al. 2010; Felnhofer et al. 2015; Cheng and Li 2020; Omab et al. 2020). Few scholars have studied the impact of real scenes based on 3D panoramic virtual reality (VR) on human psychology. This kind of research has become increasingly important with the development of 3D virtual tourism with real scenes. Besides, the psychological restorative effects of 3D virtual tourism with real scenes of different landscape types have not been proven. Secondly, in terms of research instrument selection, scholars tend to use scales to measure psychological recovery of the participants (Priolo et al. 2017; Tussyadiah et al. 2018; Bogicevic et al. 2019). However, this method is comparatively subjective, and it is difficult to accurately measure the psychological condition of participants. There is a series of physiological reflective indicators; for instance, increased heart rate when one is excited or terrified and sweaty palms when one is nervous or anxious (Carlson and Hatfield 1992). Therefore, more precise research is needed with the assistance of methods and tools normally used in psychology to measure physiological differences caused by psychological changes. EEG can measure the brain's potential changes non-invasively by placing electrode points on a subject's head as well as the potential changes when the subject engages in cognitive tasks, thus reflecting mental changes. Thirdly, in terms of research methods, most scholars adopt a comparative experimental approach (Kjell-

gren and Buhrkall 2010; Annerstedt et al. 2013). With changing experimental scenes, less consideration of the psychological impact of the previous scenes on participants may lead to inaccuracy of experimental data. Hence, repetitive stress stimulation is required to keep the subject in the same psychological stress level when entering into the following scene. Finally, in terms of experimental control, as people's psychological state is easily influenced by external factors, such as light, temperature and other environmental conditions (Bell et al. 1996), more attention should be paid to controlling them. However, the current relevant studies rarely mention this (Lu et al. 2019; Cheng and Li 2020). To complement the research gap of existing publications, this study examines the psychological restorative effects of 3D virtual tourism with real scenes and verifies the different restorative effect with different landscape types. Seventy college students were selected as the participants. Under strict compliance with the experimental procedures and the control of the experimental environment, the data obtained through the positive and negative emotion scales and EEG were analyzed in depth through a comparative experiment to determine the psychological changes in the participants more comprehensively. Therefore, additional analysis was conducted regarding the effects of different landscapes of 3D virtual tourism on participants' psychology.

According to our findings, 3D virtual tourism with real scenes is a restorative experience, which is especially vital for those who find it inconvenient to travel. The results of this study help heighten the appeal of virtual tourism. This study emphasizes that people can experience rapid significant improvement with a few minutes of virtual tourism, without leaving their space while working or studying. It examines the psychological recovery effects of 3D virtual tourism across four main landscape types; the participants could choose the landscape type for their virtual tourism. Although we do not argue that virtual tourism can replace real tourism, we are convinced that it offers the possibility of enjoying benefits similar to real tourism. This is especially true in the case of disabled people, where it provides them with positive and memorable experiences, which can help them connect with nature and real environments.

2 Literature review

2.1 Virtual reality and virtual tourism

As one of the most important technological breakthroughs of the late 20th century, VR is a computer-generated medium that allows people to feel like they have moved from the physical to an imaginary world (Perry Hobson and Williams 1995). In recent years, spherical panoramic images and videos of the real world have also come to be known as 3D VR (Mel and Sanchez-Vives 2016). As a technology, VR presents images and sensory inputs interactively, and it can create a realistic audio-visual experience that cannot be found in regular photos and videos (Phillips et al. 2012). The dual stimulation of virtual landscapes and virtual experience allows users to perceive the entertainment and enjoyment as well as satisfy their own emotional needs as well (Oleksy and Wnuk 2017). Moreover, it not only allows users to escape from

routine life, but also stimulates their senses and provides opportunities for virtual interaction (Özdemir and Kılıç 2018).

Virtual tourism is built on the basis of the real tourism landscape, by using innovative three-dimensional technology and the combination of visual, dynamic and audio elements to simulate the real landscape, so that the tourists in the virtual environment feel like they are physically present there (Zhao et al. 2017). The advantage of virtual tourism is that it saves time and money. Although it is exclusive of physical movement (Paolo Mura et al. 2017), it allows people to visit landscapes thousands of miles away without leaving their homes (Williams and Hobson 1995; Xu et al. 2001). Virtual tourism provides consumers the opportunity to feast their eyes on VR destinations and plays an important role in encouraging visits to and participation in specific tourist attractions for particular events or activities (Kim and Hall 2019). 3D virtual tourism with real scenes is a more immersive form of virtual tourism based on the real tourism landscape, which uses 3D VR technology. It relies on the 3D virtual tourism platform to build a 3D virtual tourism environment by simulating or restoring the reality of the tourist attractions. Visitors can personalize the 3D virtual presence as well as explore the realistic, detailed, and vivid scenery that lies thousands of miles away through the 3D virtual environment. Such tourism with real scenes makes it possible for people to healing physically and mentally despite staying indoors; through 3D virtual tourism, visitors can enjoy the magic of nature and experience the history of a given place (Nong 2016).

2.2 Recovery effects of virtual tourism

There is still limited research on the recovery of virtual tourism, and major interest lies in the recovery effects of virtual environments. The virtual approaches, mainly include virtual technologies, such as 360° roaming, video images, slideshows, and VR (Yu et al. 2018; Bogicevic et al. 2019). The study conducted by Valtchanov et al. (2010) compared the differences in recovery effects between slideshows and natural environments in VR. They concluded that the participants who were immersed in VR had more positive emotions, and their stress levels were simultaneously reduced. The primary environmental types include virtual forest-oriented environments (Omab et al. 2020), virtual indoor environments (Jie et al. 2020), and virtual urban green environments (Tsunetsugu et al. 2013; Annerstedt et al. 2013) studied the physiological recovery of 30 male participants in a forest-oriented VR. They found that a simulated natural environment with natural sounds contributed to their recovery. In contrast, neither the control group nor the participants immersed in a simulated natural environment without sound showed a significant improvement. Baños et al. (2013) explored the relationship between simulated natural environments and the emotions of 19 cancer patients. They concluded that after viewing a computer-generated forest landscape, the patients experienced a decrease in negative emotion and an increase in their positive mood. Omab et al. (2020) examined restorative experiences in an immersive forest-oriented VR environment. Comparing the participants' perceived recovery, vitality, and mood after using VR to the same attributes of those who visited the actual forest indicated that VR environments had the same restorative effect, were more engaging, and were as coherent as the authentic forest environments. Kjellgren

& Buhrkall (2010) similarly compared the restorative effects of natural and simulated environments and found that both natural and simulated natural environments contributed to stress reduction. Other scholars compared the effects of forest-oriented VR and urban environments on physiological and psychological responses. They found that both the systolic blood pressure and heart rate of participants decreased over time. Regarding psychological responses, increased levels of fatigue and decreased levels of self-esteem were observed in cases of simulated urban environment. On the contrary, an increase in vigor levels and a decrease in negative mood levels were observed in cases of simulated forest environment. In conclusion, immersion in a virtual forest environment would be of greater benefit (Yu et al. 2018). Wong et al. (2022) used a qualitative research method to demonstrate the effect of virtual tourism on attention recovery. The effects of virtual marine environments on psychological recovery and mental fatigue were tested using a comparative experiment. The results showed that the 3-minute virtual tourism experience can improve the attention of employees and promote their mental health (Walters et al. 2022). Using a mixed research approach, Fiocco et al. (2021) studied the psychological recovery of elderly people in nursing homes after VR tours. The results showed that VR tours reduced their anxiety and fatigue, improved their social engagement and quality of life, and enhanced their sense of well-being.

Some scholars studied the recovery effects of virtual tourism from the perspective of perceived value. They argued that virtual tourism generates tourism experiences by stimulating users' senses (Kim et al. 2020), in which visual perception plays a staple role (Paolo Mura et al. 2017). Additionally, the generation of experience value is related to aesthetic appreciation processes (Chung et al. 2018). All three dimensions of the perceived experience value of virtual tourism, namely escape, visual aesthetics, and entertainment and enjoyment significantly and positively affect virtual attachment, and users' attachment to virtual tourism helps to enhance local attachment to real tourism places and significantly and positively affects people's willingness to physically travel to those places (Zheng et al. 2022; Cheng and Li 2020) concluded that virtual travel experiences help to alleviate stress and negative emotions in homebound people and can induce positive emotions. A four-level research model was constructed to examine how 360° virtual tours can reduce people's psychological stress during the special period of COVID-19 epidemic through two modes of presence (presence and remote presence) and affective movement states (enjoyment and engagement) (Yang et al. 2021). By constructing a webcam travel dream model, Lee et al. (2022) investigated how digital virtual experiences add to improve viewers' psychological well-being. McLean et al. (2023) revealed the positive impact of virtual tourism on individuals' subjective well-being through a multiple quantitative research design and based on presence theory and effort recovery theory. The findings suggested that virtual tourism may not only provide important social and health benefits in restoring and improving individual well-being, but also bring benefits from an economic perspective.

2.3 Environmental restoration theories

A short taste of nearby nature, or even just a look at the landscapes around you, will help the brain recover from mental fatigue, which is the restorative effect of the natural environment (Wolf 2017). Currently, the research on the resilience of virtual environments mainly includes the Attention Restoration Theory ('ART') and Stress Reduction Theory ('SRT'). ART was first proposed by Kaplan (1995) based on his own research and the experience of previous studies. The theory is considered as a landmark in the study of human recovery from interactions with nature. In ART, attention is divided into two components based on previous researches: undirected attention, where attention is captured by intrinsic triggers or important stimulation; and directed attention, where attention is guided by cognitive control processes (Kaplan and Kaplan 1989; Fan et al. 2002; Marc et al. 2008; Yung and Khoo-Lattimore 2017). Directed attention is a key factor for humans to enhance productivity. Directed attention fatigue can bring in stress, anxiety, and other psychological problems, and even endanger life.

Therefore, it is essential to find an effective way to restore directed attention. It is the natural environment that can restore directed attention by increasing human undirected attention, thus reducing stress, and improving learning or work efficiency. Kaplan and Talbot (1983) referred to this environment as a restorative environment and defined it as an environment that can help people better recover from psychological fatigue and negative emotions associated with stress. Based on this concept, this study defines psychological recovery as the recovery of individuals from psychological fatigue and negative emotions associated with stress under certain specific environmental conditions.

SRT known as psychological evolutionary theory was first proposed by Ulrich (1991). The theory assumes that the premise of recovery is that individuals are under pressure, and when people face an event or situation, their first judge depends on whether their health is affected. And if they feel unfavorable, threatened, or challenged, which means, when the individual perceives that the environment is out of control, they are stimulated to stress, and psychological resistance is generated. Such stress will result in negative emotions, short-term physiological changes, and behavioral responses such as the appearance of avoidance or behavioral disorders. This theory complements previous stress theories that focused on stimulation causing stress, while stress recovery or reduction seemed to be spontaneous only if people are away from their stressors. Based on SRT, people believe that in certain natural environments, changes in the natural environment like bird calls, which are not common in daily life, can easily attract individual attentions, and temporarily blocks their negative thoughts and generates positive emotions so that the disturbed dysfunctional physiological operation is going to restore. Ulrich (1983a) argued that improvements in positive emotions and attention are the result of interest in and positive affective assessment of certain natural environments, and the arousal of positive evaluations of natural environments and the subsequent reduction of negative emotions may lead to people's recovery from stress. The human-nature relationship is proved in both theories from different views, and the resilience brought by the natural environment is emphasized as well.

3 Methods

3.1 Participants

Seventy participants were selected through volunteer recruitment. This kind of recruitment follows standard steps. The first step is formulating a recruitment plan. The recruitment plan was formulated according to the purpose, content, and requirements of the experiment, and the recruitment time, number of volunteers, work arrangement, and recruitment requirements were determined. The second step is the announcement of recruitment. Interested eligible students could visit the registration link to sign up and fill in the relevant information. The third step is preliminary selection. It is the preliminary review process of the registered participants. Those who had been to any of the four chosen tourist destinations, who provided incomplete information, or who filled-in false information were excluded. The fourth step is on-site confirmation. Volunteers' health status and experimental time were confirmed in this step, and those who met the requirements were enrolled and included in the trial procedures. Those who did not satisfy the requirements were explained why they were excluded and were thanked for their effort. The participants had to be physically healthy, not normally addicted to smoking, not have undergone any recent major emotional changes, and not have a history of psychological disorders, allergic diseases, or psychotropic drugs. The participants' educational background was the same (undergraduate students), and their age ranged from 19 to 22 years. Thus, their average age was 20 ± 0.5 years. The ratio of men to women was 1:1. The main considerations for choosing university students were as follows: (1) Academic, emotional, and professional pressures faced by university students may lead to severe psychological problems and serious consequences if not addressed (Tao 2019). Besides, the outbreak of COVID-19 epidemic aggravated their mental health problems (Li et al. 2021; Huang et al. 2022; Wu et al. 2022). A mental health status survey indicated that during COVID-19, 36,865 out of 89,588 Chinese college students experienced anxiety, and the positive anxiety detection rate was 41% (Fu et al. 2021). Therefore, it is of great relevance to regard university students as the subject of this study. (2) College students are more curious and capable of learning new things, and they can understand the experiment content and steps. Hence, the experiments could be accomplished effectively and efficiently. (3) During the pandemic, transportation was restricted, and it was hard to recruit volunteers nationwide. Therefore, recruiting students from nearby universities was a stopgap measure to facilitate the recruitment process and complete the experiment. (4) When conditions permit, other age and vocational volunteers could be considered in future studies to gain broader sample data and execute more convincing experiments. Prior to the experiment, our participants were trained to ensure they understood the contents, rules, and precautions. Informed consent was then obtained from each one of them.

3.2 Materials

The Panorama Guest (Panorama Guest Virtual Tourism Network) was established in 2009. It is one of the leading intelligent tourism solutions providers in China, and

China's largest virtual tourism e-commerce platform, with a high degree of professionalism (Tang and Yuan 2019). On this platform, there are more than 400 cities at home and abroad, more than 10,000 tourism spots with HD 720-degree 3D panoramic view, enabling original panoramic virtual photo taking, one-click microblog sharing, and other functions. It provides tourist information as well, such as attraction books, destination guides, panoramic routes, cloud panorama, and other vertical tourism services.

In this study, the selected experimental landscapes included the Zhangjiajie National Forest Park, the Lugu Lake, the Supohan Steppe Tourism Region, and the Mingsha Mountain and Moonlight Spring Scenic Spot (Fig. 1). They are located in the central, southwestern, northern, and northwestern regions of China, and all of them represent the main landscape types in their regions. To the best of our knowledge, among all the virtual tourist attractions provided by the Panorama Guest, these four types are the most representative. There is another reason why we selected these spots. According to the Chinese national standard 'Classification, Survey and Evaluation of Tourism Resources' (GB/T 18972−2017), these four types of tourist attractions are the most dominant and common types of tourist attractions in China and are also the frequently visited ones by tourists. Furthermore, these tourism attractions are with both uniqueness and representativeness worldwide.

The chosen forest-oriented tourist attraction is Zhangjiajie National Forest Park. It is located in the Wulingyuan District of Zhangjiajie in Hunan Province. It is known for its unique 'Zhangjiajie landform' in the world, and it is regarded as a utopia away from the usual din and bustle of the city. Besides, planet Pandora in the movie Avatar was set in this park. In December 1992, the park was listed on the World Natural Heritage List by the United Nations for its quartz sandstone forest peak gorges. In February 2004, it was included as a Global Geopark. In 2007, it was included in the

Fig. 1 3D virtual tourism attractions provided by Panorama Guest (①②③④ represent Zhangjiajie, Lugu Lake, Supohan and Mingsha Mountain-Lunar Crescent Spring respectively)

first batch of the National 5 A Tourist Attractions in China. With a total area of 4,810 hectares, the park is located in a central subtropical climate zone, with high mountain valleys and dense forests. It has a forest coverage rate of 98% and has received 4,295,500 visitors in 2019. It is a typical forest-based tourism area in central China.

The selected typical lake-oriented tourist attraction is the Lugu Lake tourist attraction, which is famous for being the 'land of the women' in novel *Lost Horizon* written by James Hilton. The lake is located on the border of the Yunnan Province and Sichuan Province and is under the common domination of the two provinces. The lake spans from the northwest to southeast. Precisely, the length from north to south is 9.5 km, and the width from east to west is 5.2 km. Moreover, the length of the shoreline is about 44 km, and the lake area is 50.1 square kilometers, with 247.6 square kilometers of water catchment area. It is a national 4 A-level tourist attraction and is regarded as the 'mother lake' by the local Mosuo people. The area is famous for its natural and cultural landscapes, especially for its typical plateau lake scenery and unique Mosuo matrilineal ethnic culture, which is representative of the lake-based tourism area in southwest China and worldwide.

The selected grassland-oriented tourist attraction is the Subohan Steppe tourist attraction in the west of the Erdos Iginhoro Banner covering 153 square kilometers. It is a large grassland scenery suited for sightseeing, relaxation vacation, and business exhibitions. The Supohan Steppe Tourism Region is known as the living museum of the history of Ikezhao League, which was the resting place of Genghis Khan during his western expedition. Here, the 13th century Mongolian nomadic life scenes can be recreated completely and the world's largest Yurt Expo can be seen. As one of the national 4 A-level tourism spots, it has a historical and nomadic prairie culture. It is a good choice for people to enjoy the nomadic-styled romantic and leisure time of Inner Mongolia. The grassland is also an ecological museum of the western grassland, with diverse ecological landscapes of grassland, lakes, rivers, wetlands, and mountains. Meanwhile, rare birds can be spotted here as well. With its diverse seasonal scenery, it is regarded as the best place for photography tourism in central and western Inner Mongolia. It is a typical grassland tourism area in northern China and even the world.

The desert-oriented tourist attraction is the Ming Sha Mountain-Lunar Crescent Spring tourist attraction. It lies 5 km south from Dunhuang of the Gansu Province, covering an area of 31,200 square kilometers. The length of Ming Sha Mountain is more than 40 km from east to west and its width is about 20 km from north to south. The crescent moon spring is surrounded by the Mingsha Mountains and is named after its resemblance to a crescent moon, while the Mingsha Mountain is named for the sound of the sand moving and it is 5 km from the southern suburbs of Dunhuang City. It is a mountain of sand that is made up of red, yellow, green, white, and black colors. As one of China national 5 A-level tourist attraction, the scenic spot was designated as a national key scenic spot in 1994 and won the honorary title of "one of the five most beautiful deserts in China" and other honorary titles. It is a typical desert-type tourism area in northwest China, and it is unique in the world.

3.3 Equipment

3.3.1 EEG monitoring

EEG has been used for many years and is considered a safe procedure that does not cause any discomfort (Herman et al. 2021). EEG has been used for many years and is considered a safe procedure without causing discomfort. We use Mind wave, an EEG acquisition device with Think Gear ASIC Module (TGAM) as the core from Neurosky, which is famous for its stable performance and wearability. It has numerous development platforms. It is suitable for personal computers (PCs), Androids, the iPhone operating system (iOS), microprocessors, and so on. In the EEG, more applications have currently been used for mind control games to train attention, brainwave recording, and analysis. Meanwhile, it is a single-channel acquisition device. The EEG signal acquisition device is placed on the forehead. The frequency band collected ranges from 0 to 100 Hz, which means it covers the 4 types of brain wave bands, namely α, β, θ, and δ. The signal sampling frequency in this study was 512 Hz, and the effective distance of wireless transmission was 10 m. The collected EEG data were processed to obtain the eSense index, which was used to describe the degree of attention and relaxation state of the participants. When people's attention is focused on, the y-wave and Y-wave account for a larger proportion of EEG signal energy. In a fatigued state, the proportion of EEG energy accounted for by EEG waves and δ waves is larger. Therefore, the methods to calculate the concentration and relaxation indices can be obtained, and the formula of eSense concentration index is as follows:

$$Pa = (mY + n\beta + t\alpha) \times 100 \tag{1}$$

where Pa is the concentration level; Y, β and α are the percentages of Y, β and α waves in EEG energy respectively; m, n and t are the weighting coefficients of Y, β and α waves respectively, which can be obtained by the hierarchical analysis method (AHP). The eSense concentration index indicates the intensity of one's mental concentration level or attention level. The index value ranges from 0 to 100, and a higher score means a higher concentration level of the subject.

The formula for the eSense Relaxation Index is as follows.

$$Pm = (x\theta + y\delta + z\alpha) \times 100 \tag{2}$$

where Pm represents the relaxation level; θ, δ and α represent the percentages of θ, δ and α waves in the EEG signal energy; x, y and z represent the weighting coefficients of θ, δ and α waves respectively, which can be obtained from AHP. The eSense relaxation index indicates the level of mental calmness or relaxation of the experimental participants. The index value ranges from 0 to 100, and a higher score means a higher relaxation level of the subject.

3.3.2 Emotion measurement

Emotions occupy an important position in psychological research, and researchers often use emotions as a criterion to test people's psychological health (Guo and Gan 2010). With the emergence of positive psychology research, scholars turned to focus on positive emotions and research instruments, such as subjective sense of happiness and emotional intelligence emerged. Watson et al. (1988) complied with the Positive Affect and Negative Affect Scales (PANAS) to measure positive and negative emotions, which was largely used by many scholars to conduct psychological research (Valtchanov et al. 2010; Martens et al. 2011; Tyrväinen et al. 2014; Takayama et al. 2017). Accordingly, this study used the said scale to measure the psychological changes of participants. Emotions were measured using the self-reported PANAS with 10 words representing positive affect (PA) and another 10 words representing negative affect (NA). All the results were positively scored on a five-point scale ranging from 'almost none', 'relatively little', 'moderately', 'more', to 'very much'. The result of positive emotions was derived by adding together the scores of numbers 1, 3, 5, 9, 10, 12, 14, 16, 17, and 19 entries. The higher the value, the more positive the emotion. Similarly, the results of negative emotions were calculated by summing-up of the scores of numbers 2, 4, 6, 7, 8, 11, 13, 15, 18, and 20 entries. The higher the value, the more negative the emotion. A high positive emotion score indicates that the individual is energetic and is able to pay full attention and is filled with joy, while a low score indicates indifference. A high negative mood score indicates an emotional state in which the individual feels subjectively confused and distressed, while a low score indicates calmness. The participants scored the indicators according to their actual emotional state on a five-point Likert scale. Higher scores indicated higher emotional state.

3.3.3 Display and Workstation

The model of the monitor used was MG32A2Q2 produced by HKC, which is a 31.5 inches liquid-crystal display (LCD) monitor, with 1920*1080 resolution. This ensured exquisite images and high-quality performance. Dell Precision T5820 tower graphics workstation was also used, with an Intel Xeon/Core processor. Its central processing unit (CPU) cache can go up to 15 M, and its CPU frequency is 2.6/2.9/3.0 GHz. Both the display and workstation offer fluidity and clarity.

3.3.4 Stress stimulation

The pressure application method included a numerical reasoning task and an oral calculation task. The former requires participants to complete a numerical reasoning task with 10 questions, and 30s is the time limit for each question. The participants should answer the questions carefully, as the next question automatically pops up after 30s. The latter requires the participants to subtract 13 from 1022, and the task should be finished as quickly and accurately as possible. Once the participant reports an error, the experimental assistant immediately says 'Stop, and restart from 1022'. The stress stimulation ends when three errors occur. The participants were told in advance that

they would be punished if they selected 5 incorrect answers or did the wrong math thrice within 15 s. However, the nature of the punishment was not revealed.

3.4 Environmental control

To minimize the influence of the experimental participants on their physiological and psychological conditions due to extraneous variables like the experimental environment, we controlled the experimental environmental conditions. The experiments were completed intensively in October and November. For the light, the laboratory curtains were drawn to avoid the interference of external environmental lighting, and the laboratory's fluorescent lights was under unified control. As for the temperature of each indoor experiment, it was kept within 23℃-26℃ using air conditioners. The display of indoor items was kept the same. To avoid interference with the results, especially by the experimental participants in terms of mood (caused by hungry, thirsty, going to bathroom, insufficient rest, and so on), the experiments were chosen to be conducted about two hours after lunch and dinner. Additionally, the participants were required to eat normally on that day, drink an appropriate amount of water before the experiment, go to the bathroom, and get enough sleep the day before the experiment.

3.5 Procedure

The experimenter prepared the experimental apparatus in advance and explained the purpose, process, and use of the experimental apparatus to the participants. After they entered the laboratory, the apparatus was worn and tested to ensure it could be used properly. According to the requirements, the participants filled in the informed consent form and recent health status form. The experiment was divided into four steps (Fig. 2).

Step 1:   The participants entered the laboratory and sat quietly for 10 min to familiarize themselves with the laboratory environment and regulate their emotions.

Fig. 2 Flow chart of experimental design

Step 2: Stress stimulation was performed initially, and then the participants were asked to wear the EEG equipment to measure and fill in the positive and negative emotion scale.

Step 3: The participants were randomized visited the forest-oriented, lake-oriented, grassland-oriented, and desert-oriented tourist attractions under the guidance of experimental assistants, and the visiting time arranged for each type of tourist attraction was 10 min. After touring the four tourist attractions, the participants were asked to wear EEG equipment to measure and fill in the positive and negative emotion scale. The following stress stimulation was conducted after a five-minute break. The participants were asked to perform stress stimulation four times in total, and they were stimulated every time before visiting a tourist attraction (Fig. 3).

Step 3: Step 4: The experimenter packed and kept the experimental apparatus after the experiment, saved the experimental data in time, and organized and archived the experimental records.
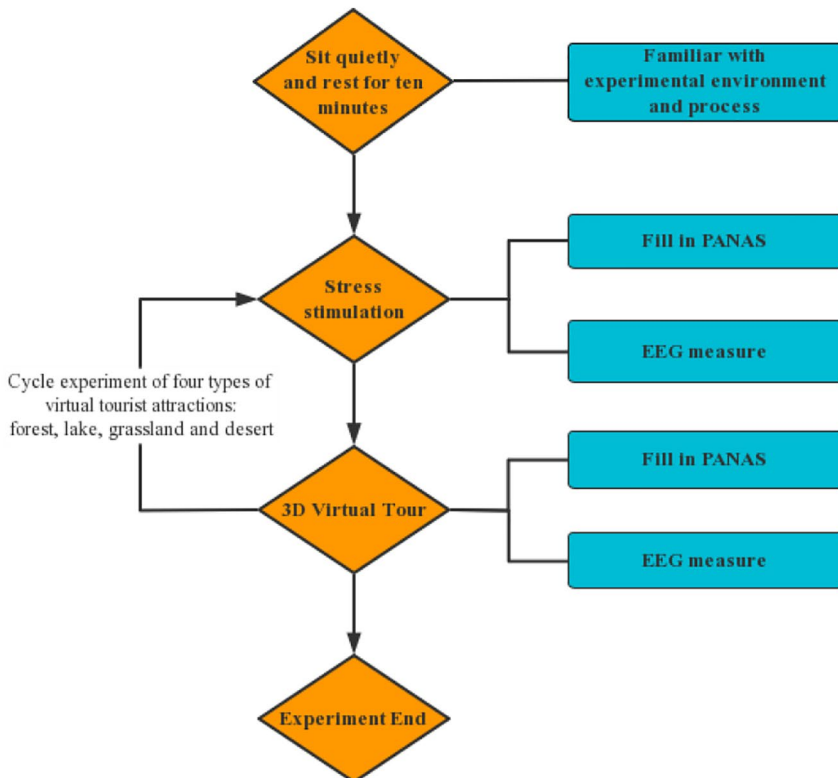

Fig. 3 Experimental environment

3.6 Data analysis

At the end of the experiment, the data collected using the EEG wading pen were exported through a cell phone app to generate an Excel sheet (2021 version), and the data obtained from the positive and negative emotion scales were imported to SPSS 26.0 for further analysis. After collecting and organizing the collected EEG data and scales, paired samples were analyzed after the stress stimulation and 3D virtual tourism with real scenes processes. The impact of 3D virtual tourism with real scenes on the participants' psychology and the differences in the psychological impact of different landscape types could be clarified.

4 Results

4.1 Differences in pm

4.1.1 Paired sample test for pm

The Shapiro-Wilk test was carried out, the Wilcoxon test was used to test the difference for the data that did not meet the normal distribution, and the Paired-samples t-test was used to test the difference between the data after the stress stimulation and that after visiting the virtual tourist attraction for the data that met the normal distribution.

A paired-samples t-test was used to verify whether there was a significant Pm difference after stress stimulation and visiting the four kinds of 3D real scene virtual tourist attractions (Fig. 4). A 0.001 level of significance (p=0.000<0.001) was presented between Pm after the stress stimulation and Pm after visiting the forest-oriented virtual tourist attraction. Additionally, a 0.001 level of significance (p=0.000 <0.001) was shown between Pm after the stress stimulation and the Pm after visiting the lake-oriented virtual tourist attraction. Besides, a 0.001 level of significance (p=0.000<0.001) was shown between Pm after the stress stimulation and Pm after visiting the grassland-oriented virtual tourist attraction. Eventually, a 0.001 level of significance (p=0.000<0.001) was presented between Pm after the stress stimulation and Pm after visiting the desert-oriented virtual tourist attraction.

To further explore the differences in Pm after stress stimulation and after visiting virtual tourist attractions with different landscape types, the effect size was used to investigate the magnitude of the differences. The Cohen's *d* value for the paired sample t-test indicated the effect size, and the threshold points for differentiating the small, medium, and large effect sizes were 0.20, 0.50, and 0.80, respectively. The Cohen's *d* value between Pm after the stress stimulation and Pm after visiting the forest-oriented virtual tourist attraction was 1.342, and its effect size was large. The Cohen's *d* value between Pm after the stress stimulation and Pm after visiting the lake-oriented virtual tourist attraction was 1.013, and it turned out to be a large effect size. The Cohen's *d* value between Pm after the stress stimulation and Pm after visiting the grassland-oriented virtual tourist attraction was 1.891, which means a large effect size. The Cohen's *d* value between Pm after the stress stimulation and Pm after
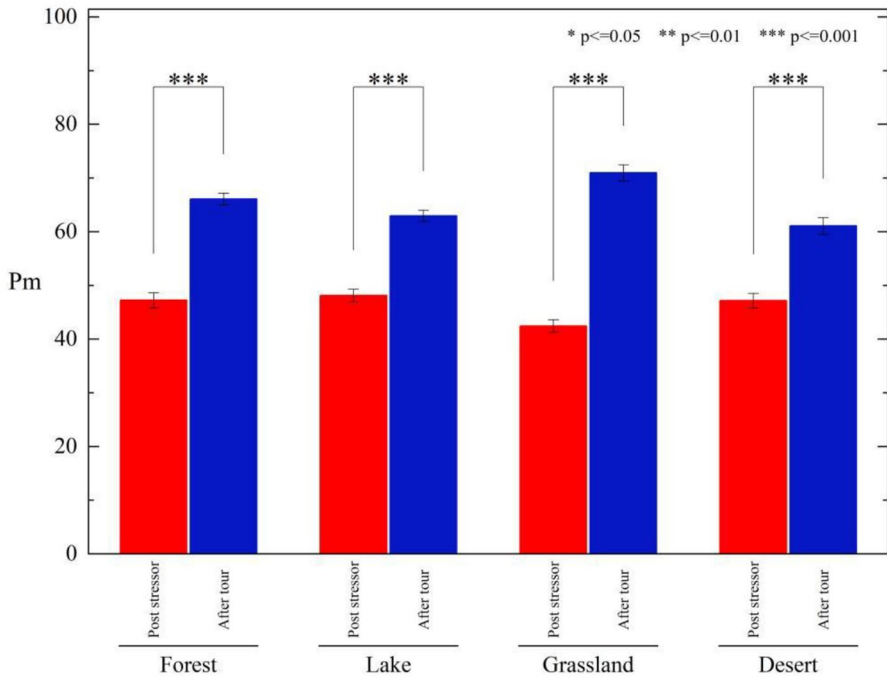
Fig. 4 Pm difference of participants after visiting four types of 3D real scene virtual tourist attractions

visiting the desert-oriented virtual tourist attraction was 1.019, which was a large effect size as well. Above all, there was a significant effect on Pm improvement of visiting the four types of virtual tourist attractions. What contributed the most was the grassland-oriented tourist attraction, followed by the forest-oriented, desert-oriented and lake-oriented areas.

4.1.2 Pm differences in individual and gender

After visiting the forest-oriented virtual tourist attraction, 2 participants had a decreased Pm, 6 had an unchanged Pm, and 62 had an increased Pm. After travelling to the lake-oriented virtual tourist attraction, 11 participants showed a decreased Pm, 3 had an unchanged Pm, and the remaining 56 showed an increased Pm. As for those who visited the grassland-oriented virtual tourist attraction, 7 experienced a decline, 3 showed no change, and 60 experienced an increase. After touring the desert-oriented virtual tourist attraction, 6 participants experienced a decreased Pm, 3 showed no changes, and 61 experienced an increased Pm.

The significance did not appear between different genders ($p > 0.05$) for difference values 1, 3, and 4 (Table 1). This implied that different genders showed consistency for different values 1, 3, and 4. Therefore, there was no significant effect of gender on Pm changes before and after visiting the abovementioned three types of virtual tourist attractions. There was a 0.05 level of significance for the difference value

Table 1 One-way ANOVA of gender and Pm before and after visiting three types of virtual tourist attractions: forest, grassland and desert

Differences of Pm	Gender (Standard deviation)		F	p
	1.0(n=35)	2.0(n=35)		
Difference value 1: visiting forest-oriented virtual tourist attraction − 1st stress stimulation	17.33±12.96	17.83±11.74	0.051	0.749
Difference value 3: visiting grassland-oriented virtual tourist attraction − 3rd stress stimulation	26.75±15.62	29.01±14.83	0.311	0.642
Difference value 4: visiting desert-oriented virtual tourist attraction − 4th stress stimulation	13.30±16.49	20.02±14.78	1.910	0.174

Note: * $p<0.05$ (one-tailed), ** $p<0.01$ (one-tailed),*** $p<0.00$ 1(one-tailed)

Table 2 Dunn, s t nonparametric test of gender and the change of Pm before and after visiting lake-oriented virtual tourist attraction

Difference value of Pm	Gender Median M(P25, P75)		MannWhitney Test statistic U-value	MannWhitney Test statistic Z-value	p
	1.0(n=35)	2.0(n=35)			
Difference value 2: visiting lake-oriented virtual tourist attraction −2nd stress stimulation	11.965(-2.3,21.2)	19.002(13.6,24.8)	179.510	-2.621	0.021*

Note: * $p<0.05$ (one-tailed), ** $p<0.01$ (one-tailed),*** $p<0.00$ 1(one-tailed)

2 (p=0.012<0.05) (Table 2). Thus, there was a significant effect of gender on Pm changes before and after visiting the lake-oriented virtual tourist attraction.

To investigate the specific effect of gender on the difference value 2, gender was converted into a continuous variable and then a stepwise regression analysis of the continuous variable was conducted. To be precise, gender was regarded as the independent variable, while the difference value 2 was used as the dependent variable for stepwise regression analysis. After the automatic identification of the model, 1 item of male was finally left in the model, and the model equation was as follows: difference value 2=20.112–10.305*male, and the R-squared value was 0.146. That is to say, being male can significantly affect Pm changes before and after visiting the lake-oriented virtual tourist attraction, and the reason for the change of 14.6% could be accounted for as well.

4.2 Differences in Pa

4.2.1 Paired sample test of Pa

The Wilcoxon test was conducted to examine whether there was a significant difference in Pa after stress stimulation and visiting the virtual tourist attractions. Meanwhile, the paired sample t-test verified whether there was a significant difference in Pa after stress stimulation and visiting the desert-oriented attraction. A 0.001 level of significance (p=0.000<0.001) was proven between Pa after the stress stimulation and Pa after visiting the forest-oriented attraction (Fig. 5). There was a 0.001 level significance (p=0.000<0.001) between Pa after the stress stimulation and Pa after
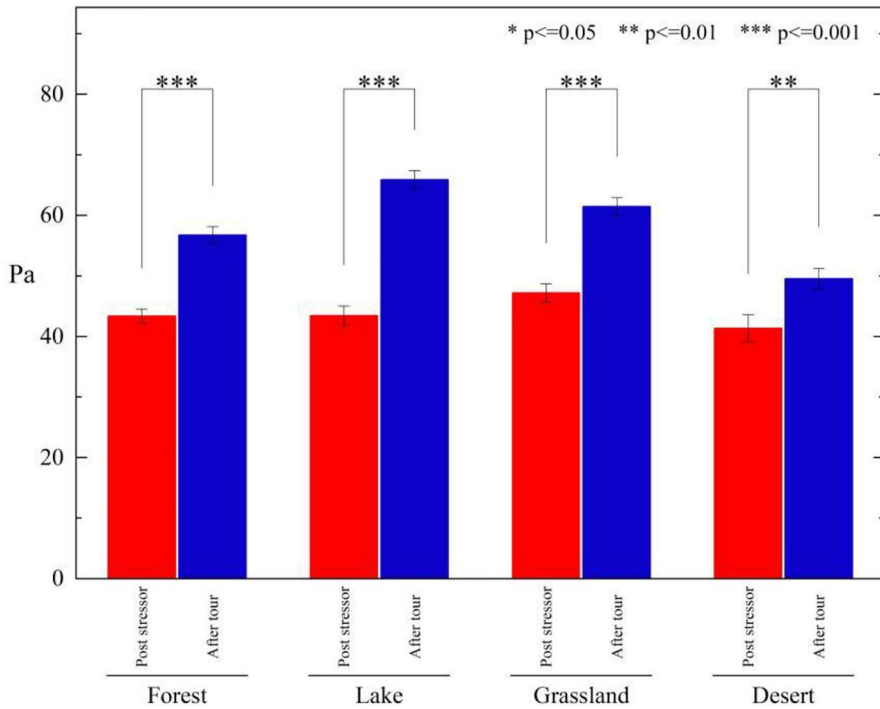
Fig. 5 Pa difference of participants after visiting four kinds of 3D real scene virtual tourist attractions

visiting the lake-oriented attraction. As for Pa after the stress stimulation and visiting the grassland-oriented virtual tourist attraction, there was a 0.001 level significance ($p=0.000<0.001$). There was a 0.01 level significance ($p=0.000<0.01$) between Pa after the stress stimulation and Pa after visiting the desert-oriented virtual tourist attraction. Cohen's d value between stress stimulation and touring the forest-oriented virtual tourist attraction was 0.825, whose effect size was large. Cohen's d value between stress stimulation and touring the lake-oriented attraction was 0.920, whose effect size was large. As for Cohen's d value between stress stimulation and travelling the grassland-oriented attraction, it was 0.719, whose effect size was still large. Cohen's d value between stress stimulation and touring the desert-oriented virtual tourist attraction was 0.810, whose effect size was large. Thus, there was a significant Pa improvement after visiting the virtual tourist attractions. Besides, what influenced Pa the most was the grassland-oriented virtual tourist attraction, followed by the lake-oriented and forest-oriented virtual tourist attractions.

4.2.2 Pa differences in individuals and gender

After travelling to the forest-oriented virtual tourist attraction, 8 participants experienced a decreased Pa, and 60 participants' Pa increased, and 2 participants' Pa remained unchanged. After visiting the lake-oriented virtual tourist attraction, 9 participants' Pa decreased, and 61 participants' Pa heightened. After visiting the

grassland-oriented virtual tourist attraction, 8 participants' Pa decreased, 3 participants' Pa remained unchanged, and 59 participants' Pa improved. After visiting the desert-oriented virtual tourist attraction, 20 participants' Pa lessened, 2 participants' Pa remained the same, and 48 participants' Pa increased. To examine the influence on Pa changes based on gender, one-way analysis of variance (ANOVA) was conducted. There was little significance in terms of gender-based differences for difference values 1, 2, 3, and 4 ($p > 0.05$) (Table 3). This means that no consistent significance existed, and gender was minimally-significant.
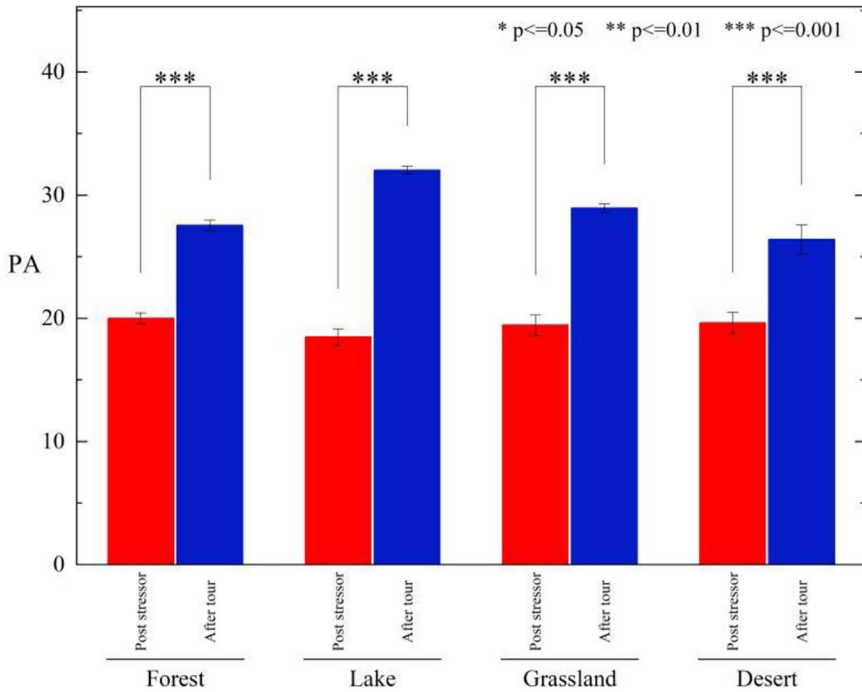
4.3 Changes in PA

4.3.1 Paired sample test for PA

The Wilcoxon test was utilized for paired samples to verify if there was a significant difference in PA after stress stimulation and travelling to the four destinations. There was a 0.001 level significance ($p = 0.000 < 0.001$) between PA after stress stimulation and PA after visiting the forest-oriented virtual tourist attraction (Fig. 6). There was a 0.001 level significance ($p = 0.000 < 0.001$) between PA after stress stimulation and PA after visiting the lake-oriented virtual tourist attraction. There was a 0.001 level significance of PA ($p = 0.000 < 0.001$) between stress stimulation and visiting the grassland-oriented virtual tourist attraction. Furthermore, there was a 0.001 level significance of PA between stress stimulation and visiting the desert-oriented virtual tourist attraction as well ($p = 0.000 < 0.001$). Cohen's d value of PA after stress stimulation and visiting the forest-oriented attraction was 1.511, whose effect size was large. Cohen's d value of PA after stress stimulation and viewing the lake-oriented attraction was 1.927, which meant a large effect size. Cohen's d value of PA after stress stimulation and touring the grassland-oriented virtual tourist attraction was 1.143, whose effect size was large, while Cohen's d value of PA after stress stimulation and visiting the desert-oriented virtual tourist attraction was 0.497, whose effect size was between medium and small. Above all, there was a significant enhancement of PA by travelling to the attractions. What promoted PA the most was the lake-oriented virtual tourist attraction, followed by the forest, grassland, and desert-oriented virtual tourist attractions.

Table 3 One-way ANOVA of the changes of Pa before and after visiting four types of virtual tourist attractions

Difference value of Pa	Gender (Standard deviation)		F	p
	1.0(n=35)	2.0(n=35)		
Difference value 1: visiting forest-oriented virtual tourist attraction − 1st stress stimulation	13.84±14.55	11.98±16.13	0.061	0.718
Difference value 2: visiting lake-oriented virtual tourist attraction − 2nd stress stimulation	21.54±23.11	18.65±20.11	0.318	0.571
Difference value 3: visiting grassland-oriented virtual tourist attraction − 3rd stress stimulation	11.01±13.20	17.33±13.65	2.661	0.112
Difference value 4: visiting desert-oriented virtual tourist attraction − 4th stress stimulation	8.91±23.33	0.96±23.29	1.329	0.238

Note: * $p < 0.05$ (one-tailed), ** $p < 0.01$ (one-tailed),*** $p < 0.00$ 1(one-tailed)

Fig. 6 PA difference of participants after visiting four kinds of 3D real scene virtual tourist attractions

4.3.2 PA changes in individuals and gender

After visiting the forest-oriented virtual tourist attraction, 5 participants' PA decreased, 3 participants' PA did not change, and 62 participants' PA increased. After visiting the lake-oriented virtual tourist attraction, 4 participants' PA declined, 2 participants' PA remained unchanged, and 64 participants' PA increased. After visiting the grassland-oriented virtual tourist attraction, 9 participants' PA dropped, 1 participants' PA remained unchanged, and 60 experienced an increased PA. Moreover, after travelling to the desert-oriented virtual tourist attraction, 20 participants' PA decreased, 6 participants' PA stayed consistent, and 44 participants' PA increased. One-way ANOVA indicated that there was little gender-based for difference values 1, 2, and 4 ($p > 0.05$), indicating consistency for those values (Table 4). Meanwhile, the Dunn, s, t, non-parametric test (Table 5) indicated that the consistency existed for different genders for the difference value 3 ($p > 0.05$). Therefore, gender was of little significance to PA changes.

Table 4 One-way ANOVA of changes in gender and PA

Difference value of PA	Gender (Standard deviation)		F	p
	1.0(n=35)	2.0(n=35)		
Difference value 1: visiting forest-oriented virtual tourist attraction − 1st stress stimulation	7.68±4.55	7.10±6.32	0.429	0.524
Difference value 2: visiting lake-oriented virtual tourist attraction − 2nd stress stimulation	12.65±8.14	12.01±5.78	0.387	0.533
Difference value 4: visiting desert-oriented virtual tourist attraction − 4th stress stimulation	6.18±11.27	6.11±12.41	0.023	0.948

Note: * $p < 0.05$ (one-tailed), ** $p < 0.01$ (one-tailed),*** $p < 0.00$ 1(one-tailed)

Table 5 Dunn, s, t nonparametric test of PA change values before and after gender and visiting grassland-oriented virtual tourist attraction

Difference value of PA	Gender Median M(P35, P90)		MannWhitney Test statistic U-value	MannWhitney Test statistic Z-value	p
	1.0(n=35)	2.0(n=35)			
Difference value 3: visiting grassland-oriented virtual tourist attraction − 3rd stress stimulation	15.000(6.0,14.0)	15.000(7.5,16.0)	350.500	-0.621	0.912

Note: * p<0.05(one-tailed), ** p<0.01(one-tailed)

4.4 Changes in NA

4.4.1 Paired sample test of NA

The Wilcoxon test was conducted for the PA of paired samples to examine whether there was a significant difference of PA after stress stimulation and visiting the attractions. Meanwhile, the paired t-test was required to verify whether there was significant PA difference pertaining to the visits to the lake-oriented and desert-oriented virtual tourist attractions. There was a 0.001 level significance of NA between stress stimulation and visiting the lake-oriented virtual tourist attraction (p=0.000＜0.001) (Fig. 7). There was a 0.001 level significance of NA between stress stimulation and after touring the desert-oriented virtual tourist attraction (p=0.000＜0.001). There was a 0.001 level significance of NA between stress stimulation and visiting the forest-oriented virtual tourist attraction (p=0.000<0.001). The 0.001 level significance of NA existed as well between stress stimulation and viewing the grassland-oriented virtual tourist attraction (p=0.000<0.001). Cohen's *d* value between stress stimulation and visiting the forest-oriented virtual tourist attraction was 0.821, whose effect size was between medium and large. Cohen's *d* value between the stimulation and touring the lake-oriented virtual tourist attraction was 0.691, whose effect size was large. Cohen's *d* value between stress stimulation and travelling the grassland-oriented virtual tourist attraction was 1.362, whose effect size was large. Cohen's *d* value between stress stimulation and visiting the desert-oriented virtual tourist attraction was 0.723, whose effect size was between medium and large. Above all, there was a significant influence on the decrease of NA of touring the virtual tourist attrac-
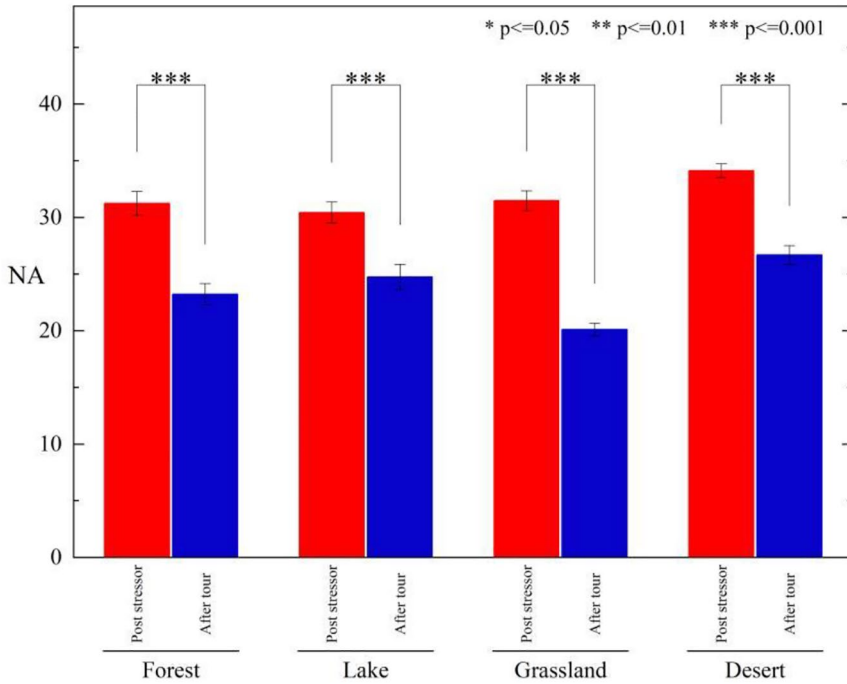
Fig. 7 NA difference of participants after visiting four kinds of 3D real scene virtual tourist attractions

tions. The grassland-oriented attraction impacted NA the most, followed by the lake, forest, and desert-oriented attractions.

4.4.2 NA differences in individuals and gender

After visiting the forest-oriented virtual tourist attraction, 9 participants' NA increased, 3 participants' NA remained the same, and 58 participants' NA declined. After visiting the lake-oriented virtual tourist attraction, 21 participants' NA increased, 4 participants' NA stayed the same, and 45 participants' NA decreased. After touring the grassland-oriented attraction, 7 participants' NA increased, 4 participants' NA remained the same, and 59 participants' NA decreased. After visiting the desert-oriented attraction, 17 participants' NA increased, 2 participants' NA remained unchanged, and 51 participants' NA decreased.

The one-way ANOVA indicated that there was little significance for different genders with difference values 2, 3, and 4 ($p > 0.05$), indicating consistency for those values (Table 6). Meanwhile, Table 7 indicated that consistency existed for different genders for the difference value 1 ($p > 0.05$). Therefore, gender was minimally significant to changes in NA.

Table 6 One-way ANOVA of changes in gender and NA

Differences of NA	Gender (Standard deviation)		F	p
	1.0(n=35)	2.0(n=35)		
Difference value 2: visiting lake-oriented virtual tourist attraction − 2nd stress stimulation	-3.77±12.64	-3.56±12.21	0.001	0.886
Difference value 3: visiting grassland-oriented virtual tourist attraction − 3rd stress stimulation	-11.94±9.12	-12.01±7.99	0.022	0.901
Difference value 4: visiting desert-oriented virtual tourist attraction − 4th stress stimulation	-5.24±7.69	-6.35±10.46	0.191	0.682

Note: * $p<0.05$ (one-tailed), ** $p<0.01$ (one-tailed),*** $p<0.00$ 1(one-tailed)

Table 7 Dunn, s t nonparametric test of gender and NA change value before and after visiting forest-oriented tourist attraction

Difference value of NA	Gender Median M(P25, P75)		MannWhit-ney Test statistic U-value	MannWhit-ney Test statis-tic Z-value	p
	1.0(n=35)	2.0(n=35)			
Difference value 1:visiting forest-oriented virtual tourist attraction − 1st stress stimulation	-13.000(-16.5,-7.5)	-14.000(-17.0,-0.2)	369.000	-0.077	0.951

Note: * $p<0.05$ (one-tailed), ** $p<0.01$ (one-tailed),*** $p<0.00$ 1(one-tailed)

5 Discussions and implications

5.1 Discussions

This study provides a new perspective on the relationship between 3D virtual tourism with real scenes and psychological health under particular circumstances. It also verifies the role of 3D virtual tourism in psychological recovery. The experimental results indicated the psychological recovery effects of four types of 3D virtual tourist attractions: forest, lake, grassland, and desert.

The psychological recovery effects of different types of 3D virtual tourist attractions varied. In detail, there was a significant effect on Pm by touring in all the four types of virtual tourist attractions, while the most effective way is to visit grassland-oriented virtual tourist attraction, followed by forest, desert and lake-oriented areas in order. Compared with forest, desert and lake-oriented attractions, the most distinctive feature of grassland-oriented virtual tourist attraction is its vastness, which gives people a feeling of freedom, and that is why grassland-oriented attraction relaxes people. Specifically, touring forest, lake, grassland and desert-oriented virtual tourist attractions can significantly improve the level of Pa. And what impacted Pa most was lake-oriented virtual tourist attraction, and forest, desert and grassland-oriented virtual tourist attractions followed in order. Compared to the other types of virtual tourism attractions, the sky and lake of the lake-oriented virtual tourism attraction merged into one color. Specifically, when visiting the Lugu Lake virtual tourism area, the scenery of reflection on water and sky enabled the participants to find inner peace. These features helped alleviate people's distraction and vexation, thus help-

ing them focus on their work. The four attractions helped improve the PA. However, the lake-oriented attraction promoted PA the most, followed by the forest, grassland, and desert-oriented areas. The difference in the impact was not significant. Deserts may trigger a magnificent feeling, and it may trigger a feeling of desolation, terror, or even despair. Compared to the other areas, there are quite distinct feelings that desert-oriented virtual tourism areas trigger in visitors. In this study, we discovered that although the impact of such an area on the PA was less than other types of areas, it also significantly boosted PA. It always had a positive effect in terms of recovery impact. As for the reduction of NA, all the four attractions exerted an influence on them. The grassland-oriented attraction impacted this aspect the most, followed by the forest, desert, and lake-oriented areas. This is also consistent with previous findings wherein grasslands were found to be more relaxing and therefore more capable of reducing negative emotions.

There was little significant difference between the two genders in terms of recoverability after visiting the four different types of 3D virtual tourist attractions. There is no significant effect on Pm changes before and after visiting forest, grassland, and desert oriented virtual tourist attractions, while visiting lake-oriented virtual tourist attraction had little significant impact on Pm changes. In particular, Pm changes can be significantly influenced by males after touring lake-oriented virtual tourist attraction, which can illustrate the 14.6% reasons of Pm changes. As for Pa, PA and NA changes, genders can hardly lead to them converted after travelling forest, lake, grassland, and desert-oriented virtual tourist attractions.

There were individual differences in psychological recovery effects of touring different types of 3D virtual tourist attractions. In terms of Pm, the number of samples who visited four kinds of 3D virtual tourist attractions and improved Pm was 56 or more. As for Pa, the sample size of visiting four kinds of 3D virtual tourist attractions and improved Pm was 48 or more. When mentioned PA, the number of PA rose after four kinds of 3D virtual tourist attractions was 44 or more. Besides, for those whose NA declined, there were 45 or more samples who visited four kinds of 3D virtual tourist attractions.

Although the sceneries presented in the virtual environment cannot exactly replicate the natural sceneries, VR is able to restore the audiovisual stimulation in real natural scenes better and offer a more immersive experience because it covers the multisensory of the individual and it is equipped with the three elements of immersion, imagination, and interaction. Research outcomes confirmed that immersion in a natural forest environment can help individuals relax and recover (Miyazaki 2003; Annerstedt et al. 2013), and virtual forest environments are considered as more coherent, fascinating, and compatible ones. As a complete forest environment, it provides a sense of leaving urban areas (Kotze 2012). Our study shows that forest-oriented virtual tourism is helpful in enhancing the Pm, Pa, and PA, as well as reducing the NA. Nevertheless, among all types of virtual tourist attractions, it was not the best-suited for all participants. The grassland-oriented virtual tourism attraction worked the best in heightening Pm and reducing NA. This is because the expansiveness of grasslands can soothe and relax people. Lake-oriented virtual tourism promoted the Pa and PA the most because it can cheer people up. Although there was a significant influence on changes in the Pm among males, there were few significant differences in terms of the

Pa, PA, and NA after visiting all kinds of virtual tourist attractions. Thus, the effect of gender on resilience after visiting the four attractions can be ignored.

Tyrväinen et al. (2014) argued that it takes more than 15 min in a natural environment to enhance subjective energy. Our findings suggested that a 10-minute virtual tourism can significantly increase people's Pa and Pm, along with increasing PA and decreasing NA. Studies suggested that a 5-minute stay in a VR forest environment can significantly enhance subjective activation, as well as mood and resilience. This may be because wearing a VR headset may provide a high contrast to the authentic environment in the laboratory, resulting in a faster recovery (Omab et al. 2020). Our study did not require wearing a helmet, thus, this sense of contrast was smaller and thus recovery was slower.

This study utilized EEG, combined with scales, to evaluate the effects of virtual tourism on participants' psychological recovery. EEG is suitable for measuring brain responses to external visual stimuli, and because it is non-invasive and relatively inexpensive, EEG can be used with a large number of non-clinical participants. However, some scholars believe that electromyogram (EMG) is more reflective of the neural and muscle processes driven by emotional changes, so they actively support the use of EMG to study the changes in human emotions (Furuta and Urbina 2002; Cacioppo et al. 2007). Other scholars have also emphasized the important role of infrared thermography (IRT) in the study of emotions (Zajonc et al. 1989; N. McIntosh R. B. Zajonc Peter S. V 1997; Mizuno et al. 2016). In a word, the use of either technology has the potential to promote the related research of psychological recovery. In addition, attention needs to be paid to the influence of the experimental environment on the psychology of participants, and strict experimental control is a guarantee for the success of psychological recovery-related research.

Virtual tourism has brought a subversive experience change of 'moving scenic spots home' to people, and has become an important issue in the high-quality development of tourism. Virtual tourism experience will stimulate people's interest in the tourism destination, affect the perception of the overall image of the tourism destination, and thus affect the literal tourism intention, with an optimistic development prospect (Zhao et al. 2022; Ye et al. 2022). In addition, virtual tourism can also play an important role in the promotion of tourism destinations as an important marketing method (Cho et al. 2002; Huang et al. 2016; Wang et al. 2022; Adachi et al. 2022). In these ways, virtual tourism can facilitate the flow of tourists to real tourism destinations and has a catalytic effect on literal tourism development in tourism destinations. It has also been shown that virtual tourism can help promote sustainable tourism by reducing unnecessary transportation greenhouse gas emissions (Lu et al. 2022).

5.2 Theoretical contributions

This study investigates the effects of 3D virtual tourism with real scenes on human psychology by utilizing an experimental approach. It has several potential theoretical contributions. This study is an extension of the Attention Recovery Theory (ART) produced by Kaplan (1995). Based on previous studies, the ART divided attention into two parts: undirected attention, where attention is captured by intrinsic triggers or important stimuli; and directed attention, where attention is guided by cognitive

control processes. Directed attention is a crucial factor in improving human productivity. Its fatigue may produce stress, anxiety, and other psychological problems and even cause some fatal problems. Therefore, it is essential to seek an effective method for recovery. Natural environment can restore directed attention by increasing undirected attention, thus serving to reduce stress and improve learning or working productivity (Fan et al. 2002; Marc et al. 2008). This study examines the psychological recovery effects of 3D virtual tourism with real scenes, proving that not only the natural environment but also 3D virtual tourism can increase people's attention and heightens concentration.

Additionally, this study confirms the stress-reducing effects of virtual tourism with real scenes, which expands the Stress Reduction Theory (STR). Traditional SRT assumes that changes in some certain natural environment can easily attract the attention of individuals, especially owing to those uncommon factors, like bird sounds, which temporarily blocks their negative thoughts and emotions and generates positive feelings, so that the disturbed and disordered physiological operation gradually recovers. SRT emphasizes that the primary and immediate response to environmental stimuli is emotional, which does not need to be regulated by cognition, and these preferences for environments are unlearned tendencies and positive responses, as a result of long-term evolution (Ulrich 1983b; Ulrich et al. 1991)proposed that improvements in positive emotion and attention are the result of interest in certain natural environments, and positive evaluations of natural environments and the subsequent reductions in negative emotions may lead to stress bounce back. This paper confirmed the stress-reducing effects of 3D virtual tourism by playing the same role as natural environments in increasing people's positive emotions, reducing their negative emotions, relax them, and improving concentration.

Moreover, this study provides a new approach to environmental restorative research. Kaplan (1995) analyzed the relationship between nature and recovery, described the relevant components of natural and restorative environments, and also proposed four requirements of restorative environments, namely Being away, soft fascination, extent, and compatibility. He then developed the Perceived Restorativeness Scale (PRS), which has been refined and revised by subsequent scholars (Hartig et al. 1996, 1997; Korpela et al. 2001). Although the scale has been adopted by many scholars, there still exist some limitations. As participants respond to the scale themselves, the reliability and validity of the data can be influenced. That is why the results are more reliable when an experimental approach combining psychological and physiological monitoring devices and the scale is used.

Finally, this study expands the field and depth of tourism experience research. Based on the historiographical perspective, Boorstin (1992) argued that modern travelers do not travel in 'real' life situations. Travelers consider the travel experience as a popular and stereotypical way of consuming in a large number of 'fake events', which are personal experiences of pleasure, relaxation, and are different from the regular environment (Cohen 1979). Current research on tourism experience is mainly undertaken by obtaining data from tourists who travel in real environments (Xie et al. 2017; Tang et al. 2018). In contrast, there are fewer studies on tourist experiences in virtual environments. Most of the studies are carried out using qualitative methods, and experimental methods are rarely used. This study extends the scope of tourism

experience research to the virtual environment and obtains data on psychological indicators through an experimental method to analyze the tourist experience more precisely.

5.3 Practical implications

The results of this study support that 3D virtual tourism with real scenes is a substitute for realistic tourism to some extent, thus advancing the application of virtual technology in tourism and yielding benefits for the public, especially for those who cannot access the natural environment easily and directly. It provides theoretical support and practical channels for relieving people's tension and stimulating positive emotions during the ongoing pandemic. COVID-19 brought tourism industry's development to a standstill, with tourist attractions and cultural and entertainment places suspending their operations. Travel agencies, hotels, farmhouses, restaurants, and tourism shopping have been severely affected as a result, and the offline tourism industry has incurred huge losses. During this 'cold winter' of the tourism industry, online tourism should seize the opportunity to play its alternative role in relieving people's anxiety owing to COVID-19.

The staff in tourism enterprises and tourist attractions should expand their ideas and models about product development and develop virtual tourism products by using new technologies to expand the online tourism business and provide people with abundant virtual tourism products. Furthermore, various types of virtual tourism products can be designed based on their own resource characteristics and advantages to satisfy the needs of different people. More specifically, the mode of virtual tourism products can no longer be limited to traditional pictures or videos. New technologies like 3D panoramic VR should be introduced to enhance tourist experience and encourage them to purchase online tourism products and services.

For tourist attractions, compared to VR-based virtual tourism, the sunk costs of 3D virtual tourism with real scenes are less in producing and promoting. VR-based virtual tourism requires visitors to wear helmets, which increases the cost for the public as well. To achieve the goal of visiting a picturesque scenery from the comfort of one's home, 3D virtual tourism with real scenes is a more valuable choice in terms of promotion and use.

According to our research, psychological recovery effects take shape after a 10-minute 3D virtual tourism session. This means that it is appropriate to produce a 3D virtual tourism product of approximately 10 minutes' duration. Meanwhile, our government should pay more attention to people's mental health, and they can guide people to actively participate in 3D virtual tourism during COVID-19.

The results of this study enhance the appeal of virtual tourism because they prove that people experience significant improvements within only a few minutes of indulging in the same, without having to leave their space. We studied the psychological recovery effects of 3D virtual tourism in the context of four main landscape types, which entails the opportunity for people to choose their preferred scenery for the virtual tourism. Although we do not believe that virtual tourism can replace field tourism, we believe it offers the possibility, especially for some special groups, to

enjoy similar benefits as offered by field tourism. It provides positive and memorable experiences and connects people with the natural and real environments.

6 Conclusions and future research

Based on the relevant theories and methods in environmental psychology, this study verified the psychological recovery effects of 3D virtual tourism with real scene on individual psychological recovery through an experimental approach using EEG and PANAS, and verified the effect of virtual tourism with different major landscape types on individual psychological recovery. It was found that 3D virtual tourism with real scenes have the same psychological recovery effects as natural environments. The psychological recovery effects of 3D virtual tourism with real scenes of different major landscape types were different. There were a few psychological recovery differences based on gender when visiting the four virtual tourist attractions. The Pm of males changed significantly after touring lake-oriented virtual tourist attraction. There were also individual differences in psychological recovery. The results of this study are still an extension of the ART and STR. In addition, this study confirms the psychological recovery effects of virtual tourism, providing a new means of psychological recovery for people who, for one reason or another, are unable to travel out.

An experimental approach was applied to four types of 3D virtual tourism with real scenes to explore people's recoveries. The results provided evidence to support that virtual tourism relieves pressure. These also enriched the theories of environmental restoration. However, there still are some limitations. In terms of experimental control, although we controlled related factors as much as possible (e.g., constraints on subject behavior, personal preferences, environmental conditions, such as air temperature and humidity, and data missing or discredited due to possible dislodgement of experimental apparatus), the results may have still been affected by the subjectivity of the participants and unknown changes in conditions. To gain more accurate data, experimental conditions should be controlled more strictly, and the number of participants should be increased. The measurement of participants' physiological indicators is also essential, and the number of psychological and physiological indicators should be increased in future studies to arrive at more accurate conclusions. Although 3D virtual tourism with real scenes is more immersive, it is also limited by many technical conditions. Some landscape features cannot be fully presented, such as color, sound, or specific micro-environmental factors, for instance, negative air ions and atmospheric environmental quality. The resilience after adding these elements needs further study. Moreover, a comparative study can be conducted in future research to determine the psychological recovery effects of 3D virtual tourism with real scenes, such as comparing the psychological recovery effects among natural environments, VR environments, and 3D virtual tourism with real scenes, or comparing the psychological recovery effects between urban virtual environments and natural virtual environments. Additionally, in future research, while continuing to focus on the psychological recovery effects of virtual tourism, attention should also be paid to the impact of virtual tourism as a marketing tool on tourism destinations and its contribution to literal tourism.

Data Availability Data will be made available upon request from the corresponding author.

Declarations

Conflict of interest statement The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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