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Original article

The effect of virtual reality forest and urban environments on physiological and psychological responses

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ABSTRACT

Previous studies used pictures or movies to investigate the impact of virtual nature environments on physiological and psychological health, providing inferior immersive experiences. The latest virtual reality (VR), launched in 2016, allows users to be fully immersed in simulated surroundings. However, the effects of the simulated environments created by the latest VR technology on health were not yet known. This study employed both cross-over and pretest-posttest design to examine the influence of forest and urban VR environments on restoration (N = 30). Both physiological and psychological responses were collected. The results show that participants' systolic blood pressure and heart rate decreased with time, regardless of environmental differences. About psychological responses, an increased level of fatigue and a decreased level of self-esteem were reported in simulated urban environments. In contrast, an increased level of vigor and a decreased level of negative emotions (i.e., confusion, fatigue, anger-hostility, tension, and depression) were observed in simulated forest environments. In sum, greater benefits were found when immersing in forest settings. The latest VR technology can serve as an alternative way to access nature environments for restoration.

1. Introduction

With the rapid development of urbanization, a large percent of population is living under stress, which is associated with poor health (Karjalainen et al., 2010). Previous studies have demonstrated the positive association between green exposure and individuals' health that highlights visiting natural environment as a cost-effective approach for restoration and public health (Hartig et al., 1991; Powell and Blair, 1994; Nielsen and Hansen, 2007; Hartig et al., 2014). Powell and Blair (1994) indicate that individuals' physiological health could be improved if living in an environment surrounded by more green space, mediated by higher motivation to exercise. Nielsen and Hansen (2007) conducted research in Denmark and concluded that individuals' physiological and psychological health were improved if their living environment was covered with more green space where people could visit for physical activities and stress release. Studies of nature surroundings and human health have found that forests have been found to have a great impact on health promotion and disease prevention (Li et al., 2008; Park et al., 2008; Park et al., 2009; Lee et al., 2009; Li, 2010; Tsunetsugu et al., 2010; Lee et al., 2011; Morita et al., 2011; Beil and Hanes, 2013; Tsunetsugu et al., 2013). In terms of physical health, visiting forests have been found to contribute to a decrease in sympathetic activities and an increase in parasympathetic activities, indicating its function in reducing stress levels (Park et al., 2008; Park et al., 2009; Lee et al., 2011; Tsunetsugu et al., 2013). Additionally, a reduction of other physiological stress indicators (e.g., heart rate, blood pressure, and salivary cortisol level) were observed when visiting forests, confirming the impact of forests in restoration (Lee et al., 2009; Tsunetsugu et al., 2010; Beil and Hanes, 2013). Regarding psychological effects, previous studies found an association between positive emotions and forest visits. Individuals felt more relaxed, dynamic, and rested after visiting forests (Tsunetsugu et al., 2007; Lee et al., 2011; Mao et al.,2012; Tsunetsugu et al., 2013). In contrast, a decrease in levels of stress, fatigue, and irritation were reported after their visit to forests (Lee et al., 2011; Mao et al.,2012; Tsunetsugu et al., 2013). Other than improving physiological and psychological health, forests also play a role in disease prevention (Li et al., 2008; Li, 2010; Morita et al., 2011). Li (2010) indicates that taking a forest bath could enhance immune system by increasing nature killer cells (NK cells), and the activities of NK cells could last for more than a month after visiting forests. In sum, with the substantial evidences showing the effects of forest in improving public health, the benefits of visiting forests should be promoted. Two major theories were highlighted in nature and human health studies, Kaplan & Kaplan's Attention Restoration Theory

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(Kaplan and Kaplan, 1989) and Ulrich's Stress Recovery Theory (SRT, 1991). Based on the principle of ART (1989), natural environments are more restorative than urban environments because of their ability to catch involuntary attention (Berto, 2014). SRT is a psycho-evolutionary theory that considers non-threatening natural settings as restorative environments, leading to a more positive emotional state and a decreased level of physiological arousal (Ulrich et al., 1991). The difference between these two theories is that ART emphasizes cognition while SRT focuses on affective responses.

One motivation to develop virtual reality (VR) environments is to benefit those who are not able to go outside, by offering them virtual nature exposure (Berto, 2014). The virtual forest environments provide an opportunity to people who are unable to frequent a real forest and enjoy beneficial effects from forest landscapes. Virtual reality is an advanced technology combining a high degree of control with ecological validity that can simulate highly realistic environments, leveraging basic neuroscience research and therapeutic applications (Bohil et al., 2011). The content in VR can be produced by either computer-generated imagery (CGI) or a 360-degree panorama camera. The former features great interactivity; however, it requires specialized skills for 3D modeling, texturing and programming. In contrast, although the interactivity of 360-degree video is limited because it is pre-recorded, the sensory vividness of the physical environment has led to an increasing popularity in environmental simulations (Jacobs, 2004; Bishop and Rohrmann, 2003). Given the capability of VR in helping users immerse themselves in the created environment and interact with the simulated world in real time (Burdea and Coiffet, 2003; Stanovsky, 2004), VR has been applied in many fields for skill training or dealing with problems in the real world. For example, VR could be used in medical education to help surgeons hone their skills before real operations. Despite early virtual equipment being limited by numerous obstacles, such as cost, software skills, bulkiness of equipment and cybersickness (Bohil et al., 2011), the applications of VR on human health practices were never stopped. For example, in the late 1990s the virtual forest rehabilitation system and Bedside Wellness Systems were designed to simulate a virtual forest walk with sounds and smells to reduce patients' stress levels and to improve their quality of life (Ohsuga et al., 1998; Oyama et al., 1999). Additionally, along with therapists' assistance, VR could help patients overcome mental disorders such as anxiety disorder and posttraumatic stress disorder (PTSD) by teaching them techniques for dealing with triggering situations (Botella et al., 2015; Reger et al., 2016). Whether the simulated nature environments have a positive impact on individuals' health gives rise to other questions. A few studies investigating the association between simulated environments and health have been conducted. Annerstedt et al. (2013) examined 30 male participants' physiological recovery in a virtual reality forest. They found simulated nature environments with sounds of nature helped participants' recovery. In contrast, neither the control group nor participants immersed in the simulated nature environments without sounds showed significant improvement. Baños et al. (2013) studied the relationship between simulated nature environments and emotions among 19 cancer patients. They concluded patients had a decrease in negative emotions and an increase in positive emotions after watching a computer-generated forest environment. Another study conducted by Valtchanov et al. (2010) compared the difference in regards to restorative effects between a slide show and virtual reality nature settings. They concluded that participants who were immersed in VR nature settings had an increased positive affect and coinciding decrease in stress levels. As more studies were conducted whose results suggested the effectiveness of simulated nature environments on health improvement, there arose another question of whether or not a simulated nature environment has the same effect as an actual natural environment. Kjellgren and Buhrkall (2010) made a comparison between a natural environment and a simulated one in terms of restorative effect and found that both natural and simulated nature environments helped reduce stress. Nonetheless, the simulated nature setting did not increase participants' states of consciousness and energy when compared to the natural environment. This may be because the effect of simulated settings is mediated by the level of immersion, diminishing its effect on health.

Although the impacts of virtual nature environments on individuals' physiological and psychological health have been studied (Oyama et al., 1999; Hoffman et al., 2000; Valtchanov et al., 2010; Annerstedt et al., 2013; Baños et al., 2013), most studies investigate the abovementioned relationships by using pictures, 2D movies, or 3D movies on a flat screen to simulate environments, which provide inferior immersive experiences. A new generation of immersive VR system with Head-Mounted Display (HMD) has been launched that is able to support 360-degree videos and allows users to be fully immersed in the simulated surroundings, as well as provides experiences extremely close to those in the real world. The immersive VR environments incorporate highly sensitive head-and-body tracking systems to provide a first-person perspective. The virtual reality experience is vivid and real, enhancing a sense of "presence" that influences the emotional responses and levels of relaxation (Berto, 2014). Studies of VR pain analgesia for burn victims find that more highly immersive VR equipment could enhance the sense of presence in virtual environments, corresponding with greater levels of relief (Bohil et al., 2011). These arguments highlight that the greater immersive experiences the individuals perceived, the greater health improvements they obtained from simulated natural environments. In other words, the level of immersion plays an important role in studying benefits of virtual environments. Due to the short history of the latest immersive VR technology, only a few studies have examined the individual health benefits of virtual environments utilizing this technology. So, the effects of simulated environments created by the latest immersive VR technology on psychological and physiological responses are not yet known. Accordingly, this study is concerned with understanding individuals' perceived restorativeness on physiological and psychological responses, with a particular interest in virtual restorative environments. From both ART and SRT perspectives, it's not surprising that virtual reality natural environments have more restorative value than do urban settings. Additionally, there are two types of virtual environments, the virtual environments on videos and those on computer-generated environments (Valtchanov et al., 2010). Given the former type of simulated environments provides a better immersive experience with sensory vividness in a real world, this study aims to explore the effects of simulated environments on individuals' psychological and physiological responses by applying a cutting edge VR technology with 360-degree videos. The research tasks of this study are (1) to investigate the effects of simulated urban and forest environments on individuals' physiological responses and psychological effects by using a newer-generation HMD VR device than previous studies and (2) to compare the differences in the change of psychological responses and psychological effects between urban and forest environments.

2. Materials and methods

2.1. Participants

Participant recruitment was announced through Internet and social network websites (e.g. Facebook) in September 2016. Participants aged between 20 and 35 with sound wellbeing were eligible to attend this study. Those with a history of neuropsychiatric disorder, cardiovascular disease, or who were taking disqualifying medicine were excluded from the study. In total, 30 participants were retained for the experiment. Among them, 13 were male and 17 were female. The majority of them (93.3%) were aged between 20-29. The study was approved by IRB review at the authors' institution (NTU-REC No. 201607HS008).

2.2. Research design

This study employed both cross-over and pretest-posttest design to examine the influence of virtual reality forest and urban environments on individuals' restoration. Participants were randomly assigned to two groups (Group 1 and Group 2). Group 1 was exposed to the simulated urban environment in the first week and then was exposed to the simulated forest environment in the second week. Group 2 was exposed to the simulated forest environment in the first week and then was exposed to the simulated urban environment in the second week. The reason not to let participants immerse in two environments on the same day is to avoid carry-over effect.

Regarding environment settings, a famous shopping district at Taipei, Taiwan-Ximending, was chosen to represent the urban environment. On the other hand, The Aowanda National Forest Recreation Area at Nantao, Taiwan, famous for its forest and waterfalls, was chosen to represent the nature environment.

2.3. Environments

2.3.1. Equipment

This study used HTC Vive VR system (see Fig. 1a), which is a head-mounted display (HMD), developed by HTC and Valve Corporation, to simulate environments. The feature of this room-scale VR system is to provide 360-degree panorama video and to track users' motions by 32 sensors on two screens. Each screen is equipped with an active-matrix organic light-emitting diode, supporting the video's high resolution and smooth movement. This study employed a HMD to play 360-degree videos recorded by researchers. Unlike a traditional 360-degree panorama system, participants of this study were isolated from noise and visual distractions due to the fully-immersive surroundings created by the system, in addition to the fact participants were immersed in a more vivid surrounding because videos were recorded from real environments. Participants could enjoy each aspect of the video by turning their heads to look around (see Fig. 1b).

2.3.2. Videos

Fig. 2 shows selected photos of two environmental settings in virtual reality videos. Regarding the urban setting, researchers chose Ximending at Taipei, Taiwan, to record video. Ximending is known as a shopping heaven. Video recorded in Ximending contains urban elements such as crowds, noise, traffic, and low green space coverage. For a forest environment, researchers shot video at the Aowanda National Forest Recreation Area at Nantao, Taiwan. This National Forest Recreation Area includes an area for water conservation and features coniferous and broadleaf trees as well as a variety of wild life. The video took in Aowanda's natural elements such as double waterfalls, a maple tree trail, a pine tree zone, cypress trees, a fir forest observatory, and the Cingshuei River.

(a) (b)

Fig. 1. (a) HTC Vive VR system; (b) A player is immersed in the simulated setting by using HTC Vive VR system.

Kodak pixpro SP 360-degrees 4 K was used to record videos for this experiment. The notable feature of this camera is its ability to record 360-degrees of the surroundings at a very high resolution. This camera is composed of two lenses, and each lens captures 235 degrees (Kodak Pixpro, 2017). By using two lenses simultaneously, researchers were able to make 360-degree videos by applying video stitching software provided by the Kodak company. In total, two videos were produced to simulate urban and forest environments, respectively. Each video enclosed seven clips including the aforementioned elements with sounds (e.g., cicadas, rivers, cars). Each clip lasted about 1 min and 10 s. The total viewing time of each video is about 9 min and 30 s.

2.4. Procedure

Regarding the experiment procedure, participants were told not to consume food containing alcohol or caffeine at least 12 h before the experiment. Upon participants' arrival, they were asked to take a short rest first and to drink a cup of water during their rest. Meanwhile, researchers explained the procedures of the experiment and the purpose of the study to them. Participants who agreed to participate in the experiment were asked to sign a consent form and provide their demographic information. The total time of orientation took about 20 min.

The experiment was divided into 5 stages: (1) before the experiment, participants' physiological indicators such as blood pressure, HRV, and salivary α amylase were measured and recorded as baseline information; (2) Paced Auditory Serial Addition Test (PASAT) was applied to stimulate participants' stress level; (3) participants were asked to complete a profile of mood states (POMS), and their physiological indicators were measured again; (4) participants were exposed to virtual reality of either forest environment or urban environment; (5) participants were asked to complete POMS with their physiological indicators were measured again (see Fig. 3). The participants were allowed to watch videos in any position they found comfortable and were informed of the right to drop out of the experiment at any time.

Regarding PASAT, a test that has been broadly used to stimulate individual's negative emotion by neuropsychologist (Deary et al., 1994), was adopted in this study to stimulate participants' stress level. PASAT is composed of several questions related to mental mathematic calculation skills. A siren will be triggered to increase participants' stress if they answered incorrectly. After the participants' levels of stress were increased by PASAT, participants were asked to immerse in either an urban environment or a forest environment to examine the restorative effect of environments. This study employed Inquisit software designed by Millisecond to conduct PASAT.

2.5. Measures

2.5.1. Heart rate variability

An HRV monitor (V1.89, Yangying Company) was used to measure heart rate using both high-frequency (HF: 0.15–0.40 Hz) and low-frequency (LF: 0.04–0.15 Hz) bands (Camm et al., 1996). The high-frequency band reflects parasympathetic nervous system activity while the LF/HF ratio is an indicator of sympathetic nerve activity (Camm et al., 1996). Three methods were available for measurement: (1) hand grip, (2) patch, and (3) wrist-worn ring. Considering cost and efficiency, wrist-worn rings were chosen for this study. Participants were asked to take off all accessories beforehand to avoid interferences of measurement. The sampling frequency of the device could be up to 512 Hz.

2.5.2. Salivary α amylase activity

Alpha amylase, one of the salivary enzymes, can reflect the activity of the sympathetic nervous system (Nater and Rohleder, 2009). Further, sympathetic nervous system activity induced by psychological stress

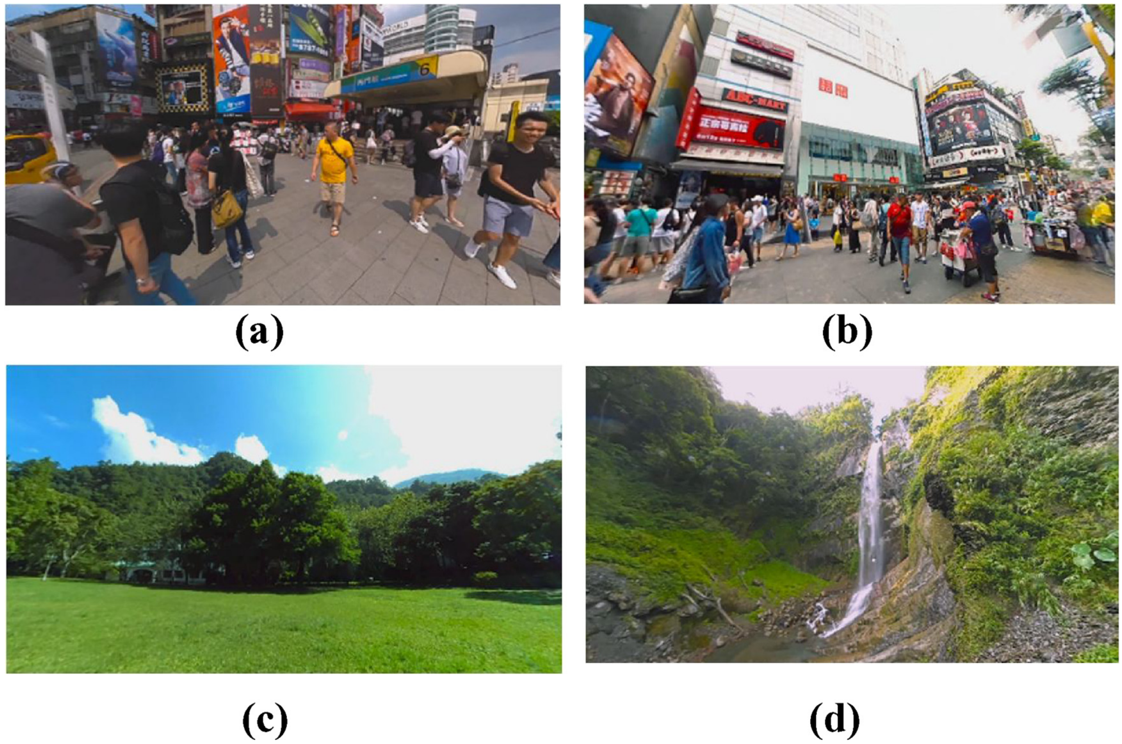

Fig. 2. Selected photos of two environmental settings in Taiwan in virtual reality videos: (a) Subway station of Ximending; (b)Shopping plaza of Ximending; (c) Nature forest of The Aowanda National Forest Recreation Area; (d) Waterfall of The Aowanda National Forest Recreation Area.

can be discerned by the increased level of α amylase activity in saliva. Using salivary amylase activity (sAA) to quantify stress levels has been validated in previous research (Nater et al., 2005; Yamaguchi et al., 2006). In this study, salivary α amylase activity was measured by salivary amylase monitor DM-3.1 (NIPRO, Japan). Saliva was collected by using sublingual regent paper. The regent paper contains 2-chloro-4-nitrophenyl-4-o-b-D-galactopyranosylmaltoside that can be hydrolyzed by amylase (Arai et al., 2008). Participants were asked to leave the regent paper in their mouth for 60 s and then put the test paper into the monitor. The activity of salivary α-amylase is assessed by the hydrolyzing reaction time. The more time that is needed to complete the hydrolyzing reaction, the higher the level of amylase activity a participant has (Arai et al., 2008).

2.5.3. Blood pressure

Participants' blood pressure was measured by blood pressure monitor HEM-1000 (Omron, Taiwan). This monitor was able to detect the position of participants' arm. A warning will be given if the participant's arm is not in the right position or if movement is detected during the measurement.

2.5.4. Profile of mood state

POMS was adapted to measure participants' mood state. A questionnaire revised by Chang and Lu was translated into Mandarin for this study (Chang and Lu, 2001). Back translation was applied to ensure that the questionnaire was translated correctly. Considering culture differences, the questionnaire was revised in this study and Exploratory Factor Analysis was employed to validate its reliability. The revised questionnaire was composited of 7 constructs with 37 questions. The 7 constructs were confusion, vigor, fatigue, anger-hostility, self-esteem, tension, and depression. A five-point Likert scale ranging from 1 to 5 was used for each item. Participants were asked to indicate the level of agreement or if the word can be used to describe them. The higher the score, the higher agreement participants had.

2.6. Statistical analysis

First, descriptive analysis was performed to examine participants' demographic characteristics. Second, a two-way repeated measures ANOVA was conducted to investigate the physiological effects influenced by measuring time points and environments. After that, a one-way repeated measures ANOVA was used as a post-hoc test to further discern the difference in significant factors. Regarding psychological responses, a two-way repeated measures ANOVA was performed with a paired-sample *t*-test as the post-hoc to investigate participants' mood states and levels of restoration as influenced by the two environmental settings. All analyses were executed by SPSS 20.0.

3. Results

3.1. Influence of virtual environments on physiological responses

Table 1 lists the descriptive results of physiological responses. Compared to the pretest, participants' SBP, DBP, and SAA in forest environments declined in the posttest. In contrast, participants' SBP, DBP, and SAA in urban environments increased in the posttest. The result of two-way repeated measures ANOVA is shown in Table 2 to illustrate whether the change in physiological responses is the result of the interaction between the environments and time. The result illustrates that none of the interactions were significant. However, a significant difference was found in time factors of systolic blood pressure and heart rate. Hence, follow-up one-way repeated measures ANOVA with Bonferroni adjustment were conducted to examine the influence of time on participants' systolic blood pressures and heart rates, respectively. The results of the post hoc tests show there was a significant difference in the three time points of measuring systolic blood pressure ($F = 10.32$, $p < 0.001$, $\eta_p^2 = 0.149$). Further, participants' baseline systolic blood pressure was significantly higher than in the pretest ($M_{diff} = 3.98$, $SD = 1.13$, $p = 0.003$) and in the posttest ($M_{diff} = 5.30$, $SD = 1.40$, $p = 0.001$). In terms of heart rate, the results show there

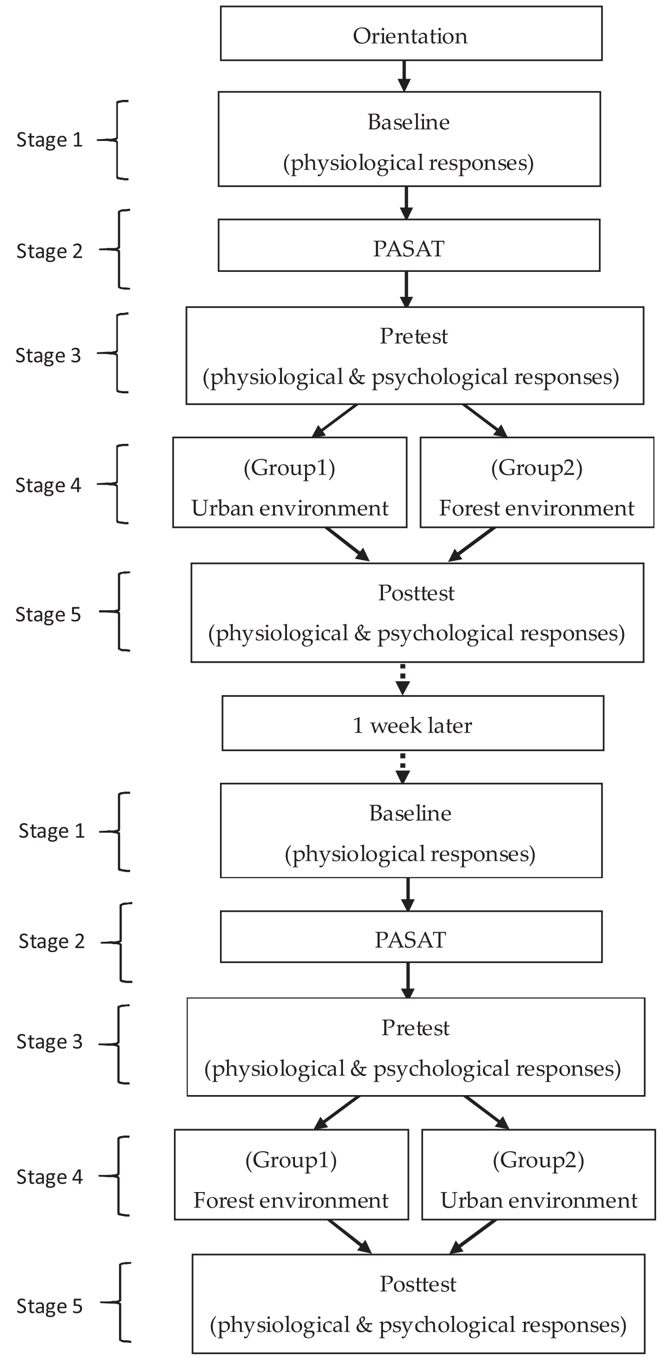

Fig. 3. Flow diagram of the experiment procedure. (PASAT- Paced Auditory Serial Addition Test).

was a significant difference in the three measuring time points ($F = 31.35$, $p < 0.001$, $\eta_p^2 = 0.347$). Participants' heart rates in the baseline ($M_{diff} = 3.73$, $SD = 0.52$, $p < 0.001$) and the pretest ($M_{diff} = 2.83$, $SD = 0.49$, $p < 0.001$) were significantly higher than in the posttest.

3.2. Influence of virtual environments on psychological effect

Table 3 shows the result of another two-way repeated measures ANOVA examining the effect of environments and time on psychological responses. The result shows that, excluding depression, there was a significant interaction between the effects of time and environment on all psychological responses. To further discern the influence of the two simulated environments on participants' psychological responses, respectively, two paired sample t-tests were performed, and the results are shown in Table 4. In the simulated urban environment, participants' fatigue levels were significantly increased ($t = 2.749$, $p = 0.01$) and their self-esteem was significantly decreased ($t = -2.351$, $p = 0.026$) in the posttest. For the simulated forest environment, there was a significant difference between pretest and posttest in all psychological responses except for self-esteem. The forest environment significantly decreased participants' negative psychological responses, including

Table 1
Descriptive analysis of physiological responses.

	Total		Urban		Forest	
	Mean	SD	Mean	SD	Mean	SD
SBP						
Baseline	108.72	16.35	108.33	16.04	109.10	16.92
Pretest	104.73	16.06	104.97	16.76	104.50	14.60
Posttest	103.42	15.24	105.50	15.10	101.33	15.35
DBP						
Baseline	64.50	9.75	64.20	9.54	64.80	10.11
Pretest	63.23	9.07	64.10	8.84	62.37	9.36
Posttest	63.53	10.09	64.73	11.00	62.33	9.13
HR						
Baseline	77.40	11.00	78.43	11.14	76.37	10.95
Pretest	76.50	10.75	77.53	11.07	75.47	10.50
Posttest	73.67	10.37	74.70	10.65	72.63	10.15
SAA						
Baseline	21.00	17.03	23.17	20.53	18.83	12.58
Pretest	21.08	15.68	21.00	17.42	21.17	14.02
Posttest	19.75	12.37	21.17	11.06	18.33	13.60
HF						
Baseline	315.12	356.42	300.90	400.45	329.33	312.53
Pretest	325.48	309.16	331.63	350.51	319.33	267.44
Posttest	395.30	314.70	362.23	316.56	428.37	314.68
LF/HF						
Baseline	2.79	2.49	2.67	2.08	2.91	2.87
Pretest	3.01	2.30	3.20	2.56	2.83	2.04
Posttest	2.88	2.32	3.15	2.58	2.61	2.04

Abbreviations: SBP = systolic blood pressure; DBP = diastolic blood pressure; HR = heart rate; SAA = salivary α amylase; HF = high frequency; LF/HF = ratio of low frequency and high frequency.

Table 2
Physiological results of two-way repeated measures ANOVA.

	(df)	F	P	η_p^2
SBP				
Time	(2,28)	7.461	0.003**	0.348
Environment	(1,29)	1.110	0.301	0.037
T x E	(2,28)	2.007	0.153	0.125
DBP				
Time	(2,28)	1.095	0.349	0.073
Environment	(1,29)	2.081	0.160	0.067
T x E	(2,28)	0.974	0.390	0.065
HR				
Time	(2,28)	19.655	< 0.001***	0.584
Environment	(1,29)	1.676	0.206	0.055
T x E	(2,28)	< 0.001	1.000	< 0.001
SAA				
Time	(2,28)	0.588	0.562	0.040
Environment	(1,29)	1.098	0.303	0.036
T x E	(2,28)	0.997	0.382	0.066
HF				
Time	(2,28)	2.305	0.118	0.141
Environment	(1,29)	0.231	0.634	0.008
T x E	(2,28)	2.305	0.290	0.085
LF/HF				
Time	(2,28)	0.814	0.453	0.055
Environment	(1,29)	1.472	0.235	0.048
T x E	(2,28)	1.281	0.294	0.084

Note: **:$p < 0.01$; ***:$p < 0.001$.

Table 3
Psychological results of two-way repeated measures ANOVA.

	(df)	F	P	η_p^2
Confusion				
Time	(1,29)	10.967	0.002**	0.274
Environment	(1,29)	4.449	0.044*	0.133
T x E	(1,29)	10.019	0.004**	0.257
Vigor				
Time	(1,29)	1.274	0.268	0.042
Environment	(1,29)	10.713	0.003**	0.270
T x E	(1,29)	11.417	0.002**	0.282
Fatigue				
Time	(1,29)	0.016	0.901	0.001
Environment	(1,29)	5.550	0.025*	0.161
T x E	(1,29)	19.226	< 0.001***	0.399
Anger-hostility				
Time	(1,29)	3.808	0.061	0.116
Environment	(1,29)	3.148	0.087	0.098
T x E	(1,29)	5.979	0.021*	0.171
Self-esteem				
Time	(1,29)	1.294	0.265	0.043
Environment	(1,29)	8.910	0.006**	0.235
T x E	(1,29)	9.869	0.004**	0.254
Tension				
Time	(1,29)	27.045	< 0.001***	0.483
Environment	(1,29)	4.708	0.038*	0.140
T x E	(1,29)	12.724	0.001**	0.305
Depression				
Time	(1,29)	1.680	0.205	0.055
Environment	(1,29)	0.685	0.415	0.023
T x E	(1,29)	2.208	0.148	0.071

Note: *p < 0.05 ; **:p < 0.01 ; ***:p < 0.001.

Table 4
The influence of virtual reality urban and forest environments on psychological conditions.

Variables	Pretest	Posttest	t-value	p-value
Urban				
Confusion	13.17 ± 6.32	12.80 ± 5.3	−0.360	0.722
Vigor	20.23 ± 6.75	18.23 ± 7.34	−1.912	0.066
Fatigue	13.13 ± 6.32	15.80 ± 6.57	2.749	0.010*
Anger-hostility	8.80 ± 4.75	8.93 ± 4.39	0.360	0.722
Self-esteem	13.63 ± 3.51	12.20 ± 3.42	−2.351	0.026*
Tension	8.47 ± 3.03	7.13 ± 3.05	−2.021	0.053
Depression	4.20 ± 1.97	4.13 ± 1.66	−0.242	0.810
Forest				
Confusion	12.53 ± 5.61	9.37 ± 3.58	−3.641	0.001**
Vigor	20.27 ± 7.22	24.60 ± 5.94	2.870	0.008**
Fatigue	13.60 ± 6.34	10.30 ± 5.13	−2.716	0.011*
Anger-hostility	8.27 ± 3.49	7.00 ± 2.15	−2.867	0.008**
Self-esteem	14.03 ± 3.46	14.5 ± 3.63	1.439	0.161
Tension	9.00 ± 2.79	5.30 ± 1.73	−7.353	0.000***
Depression	4.23 ± 1.65	3.80 ± 1.49	−2.538	0.017*

Note: *p < 0.05 ; **:p < 0.01 ; ***:p < 0.001.

confusion (t = -3.641, p = 0.001), fatigue (t = -2.716, p = 0.011), anger-hostility (t = -2.867, p = 0.008), tension (t = -7.353, p < 0.001) and depression (t = -2.538, p = 0.017). Meanwhile, the forest environment was found to significantly increase participants' positive psychological responses, such as vigor (t = 2.870, p = 0.008).

Fig. 4 illustrates the interaction of time (pretest vs. posttest) and environments (urban vs. forest) on participants' psychological responses. The graph shows that participants' confusion, tension and depression decreased in the posttest in both environments. Nonetheless, the slope of the forest environment was steeper than the urban environment. Regarding other negative psychological responses, the urban environment was found to increase participants' fatigue levels and anger-hostility, while the forest environment lead to the opposite effect. Also, participants' level of vigor and self-esteem increased after immersing themselves in the forest environment, while the urban environment was found to decrease their vigor and self-esteem.

4. Discussion

4.1. The influences of virtual environments on physiological response

Findings of this study show that forest environments and urban environments did not have significant differences in influencing participants' physiological responses. Our findings are not consistent with previous studies that immersion in a forest environment can help individuals' levels of relaxation and restoration (Miyazaki, 2003; Annerstedt et al., 2013). This non-significant impact of simulated forest environments may be attributed to the insufficiency of stimulations. Unlike immersion in the real world, only two senses (i.e., visual and auditory) are stimulated in the virtually-created settings. On the other hand, the impact of the simulated urban environment on physiological responses was not as strong as it was in previous studies (Miyazaki et al., 2004; Tsunetsugu et al., 2013). This may be because previous studies brought participants to real urban surroundings offering more stimulation (i.e., olfactory) than the simulated urban environments in this study. Additionally, the majority of participants of this study live in an urban area, which could decrease the impact of the virtual urban environments because they are accustomed to such an environment.

4.2. The influences of virtual environments on psychological effects

Regarding psychological effects, participants in the virtual forest environment showed more positive psychological effects than in the virtual urban environment. In the simulated forest environment, participants' negative psychological perceptions such as confusion, fatigue, anger-hostility, tension, and depression decreased significantly in the posttest. Conversely, participants' level of vigor had a significant increase in the posttest, supporting the forest's function in restoration. These findings are consistent with those of previous studies that immersion in a natural environment not only could effectively help reduce fatigue, confusion, and tension, but also increase level of vigor (Van den Berg et al., 2003; Park et al., 2010; Lee et al., 2011; Sonntag-Öström et al., 2014). Nonetheless, whether a simulated natural environment has a comparable effect to the real forest is not known. A direct comparison between a simulated natural environment and a real natural environment is needed in future studies.

4.3. The significance of virtual reality forest in improving health

The positive impacts of forests have been demonstrated in previous studies in terms of health improvement (Van den Berg et al., 2003; Park et al., 2010; Sonntag-Öström et al., 2014). Compared to urban environments, forests were found to have positive impacts on both individuals' physiological responses and psychological effects, leading to wellbeing improvement (Miyazaki, 2003; Miyazaki et al., 2004; Tsunetsugu et al., 2013). Despite the extensive evidence showing benefits of visiting forests (Van den Berg et al., 2003; Park et al., 2010; Sonntag-Öström et al., 2014), a large percent of population does not take advantages of forests. The main reasons could be the lack of access or time to visit forests. With the expansion of urbanization, forests are generally located in a remote area. Geographic location, therefore, becomes a barrier to visiting. Moreover, visiting forests may be a time-consuming trip for those living in urban areas. As a result, to motivate the public to visit forests, an approach to eliminate constraints and barriers is necessary.

This study demonstrates the influences of simulated forests in improving individuals' psychological wellbeing, indicating that the application of virtual reality in improving health is possible and feasible. By using immersive VR, individuals are not limited by time and location. In other words, they are able to visit forests anywhere and anytime. Moreover, the use of VR not only benefits the general population

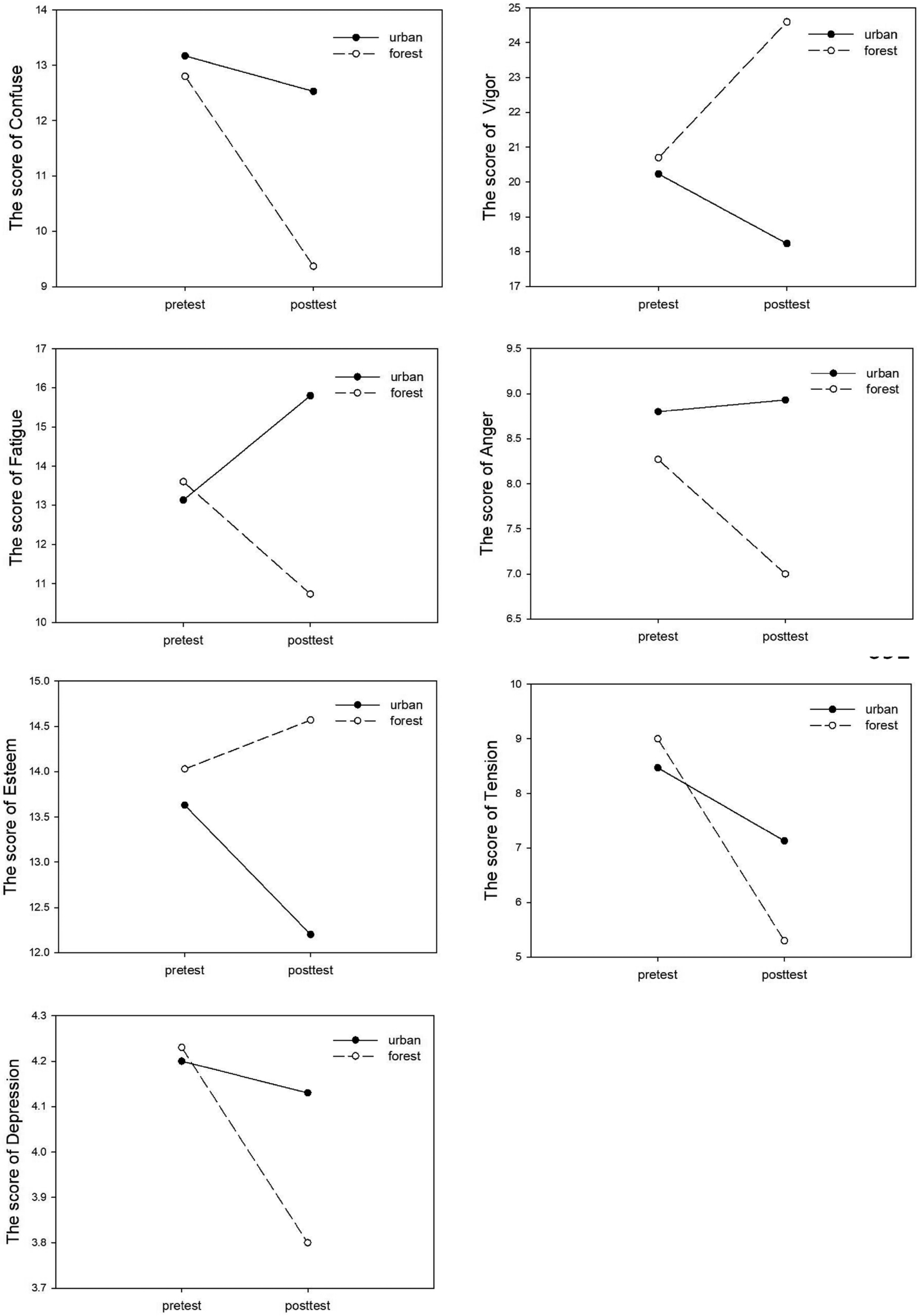

Fig. 4. The interaction of time points and environments on psychological responses.

but also elderly and those with immobility (Delpedge et al., 2011). With the increasing number of aging population in most countries, simulated nature environments could benefit elderly within their care units. Additionally, individuals who are not able to move freely, such as in-patients, could use this technology to take a virtual visit to a forest. The positive impact of simulated nature environments in clinical settings was also examined. In Baños et al.' study (2013) investigating cancer patients' emotional change, patients' positive emotion was found to increase after immersing in a simulated nature surrounding. Another study conducted by Hoffman et al. (2000) focusing on burn patients concluded that patients' level of pain had a significant decrease when doing physical therapy with VR assistance. Although the positive impact of VR may suggest a non-pharmaceutical method in health improvement, it should be further noted that the simulated forests were not designed to replace real forests since the simulated surroundings could not stimulate other senses such as touch and smell (Kjellgren and Buhrkall, 2010). Moreover, real forests provide a place for leisure activities and social networking that the simulated forests were not able to achieve. Nonetheless, given VR's increased approachability, it could be used as an alternative means of restoration for patients restrained by time or location. By immersing in simulated nature, it is expected that individuals' health could be improved as well as visiting real nature environments.

4.4. Limitations

There are limitations to this study. First, PASAT did not effectively induce participants' pressure. This may be because all participants were from a prestigious university. The math questions in PASAT could not increase their level of pressure since all of them did well in solving math questions. Therefore, a more effective approach to induce participants' pressure is needed in future studies. Second, as mentioned above, all participants were college students. Generalizability may be limited, and a selection bias may have confounded study findings. Third, considering the possibility of cybersickness while immersing in simulated environments, participants were free to watch videos in standing position or sitting position. Moreover, they were informed the right to drop out the experiments anytime if they did not feel comfortable. In this study, very few participants indicated their slight dizziness when watching videos but none of them chose to drop out the experiment. Therefore, we consider them are valid subjects. However, it should be further noted that the influence of minor dizziness in affecting the experimental results is unknown. Lastly, the impacts of different positions while watching videos on the results were not considered in this study. Therefore, it is suggested that future study should control cybersickness and positions in order to give a more precise estimates.

5. Conclusions

The simulated forest environments are found to have positive impacts on psychological health, while the simulated urban environments are found to have negative impacts on psychological health. VR technology can serve as an alternative way to access nature environments, especially for those with immobility.

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