Physiological and Affective Responses to Immersion in Virtual Reality: Effects of Nature and Urban Settings

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

With the rapid advancements in technology, researchers are seeking new ways to incorporate modern high-tech solutions such as virtual reality into treatment paradigms for stress. The current experiment explores the beneficial effects of immersing an individual into virtual reality after a stressful encounter. I examined the potential restorative effects of three unique immersive virtual reality environments by inducing stress and negative affect in sixty-nine participants and then randomly assigning them to freely explore one of three environments (a virtual nature setting, a virtual urban cityscape, or a neutral environment composed of solid geometric shapes) for ten minutes. Participants who explored the nature environment were found to have significantly improved affect (as measured by a standardized questionnaire), and significantly lower stress levels (as measured by self-report and skin-conductance levels) compared to those who explored the urban and geometric environments. The results suggest that virtual nature has restorative properties similar to real nature, and that simply immersing participants into a virtual nature setting can reduce stress. These results also suggest that the content of the virtual reality experience (i.e., whether it contains nature) is important in promoting restoration, and that in the absence of nature, stress levels remain unchanged.

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Dedication

This thesis is dedicated to my mother; without her encouragement and support I would not have come this far.

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1.1 Introduction

Over the last thirty years, researchers have provided empirical evidence suggesting that surrounding oneself with nature can have restorative effects on emotional, physiological and cognitive states. The restorative effects of exposure to nature have been classified as a reduction in cognitive fatigue, decreases in both physiological and cognitive stress, a decrease in negative affect, and an increase in positive affect (Gullone, 2000; Hartig, Mang & Evans, 1991; Berman, Jonides & Kaplan, 2008). For example, recent research by Berman, Jonides and Kaplan (2008) comparing the effects of interacting with natural versus urban environments has found that individuals performed better on a working memory task after taking a walk in a local park versus taking a walk in a local downtown area. Furthermore, Berman et al. also found that individuals' executive attention (as measured by the Attention Network Task) improved after viewing pictures of nature when compared to individuals who viewed pictures of urban areas (Berman et al., 2008) which suggests that simply viewing nature pictures can have restorative effects. Other studies by Ulrich et al. (Ulrich, 1981; Ulrich, Simons, & Losito, 1991) as also showed that viewing photographs and videos of nature scenes can promote significant reductions in physiological stress (shown by reductions in skin-conductance level) and improvements in emotional states of individuals (shown through self-report on the Zuckerman Inventory of Personal Reactions).

1.1.1 Theoretical Perspectives

Kaplan (1995, 2001) delineates how and why nature is restorative in his Attention Restoration Theory (ART), which states that when a person is immersed and interacting with a surrounding environment that contains *fascinating* stimuli, the stimuli *modestly* capture attention in an involuntary fashion. The ART further states that while this form of involuntary attention is active, internal mechanisms responsible for directed attention are allowed to recover (Kaplan, 1995; Kaplan, 2001). Attention Restoration Theory attempts to explain the differences between exposure to nature versus environments by contrasting the types of stimuli present in both types of environments: Nature environments contain many stimuli that *modestly* capture attention (such as grass and leaves swaying with the wind), which occupy attention but can also be disengaged from easily, allowing attention to drift from stimulus to stimulus. Conversely, urban environments contain bright lights, neon signs and loud vehicle and construction sounds that *dramatically* capture attention. Thus, directed attention mechanisms are taxed in order to disengage from the stimuli (e.g. ignoring neon advertisements), causing the environments to be less restorative. (Kaplan, 1995; Kaplan, 2001). Recent research by Berto Massacesi, and Pasini (2008) examining eye-movements of participants that viewed urban and nature images provides some support for ART. Berto et al. (2008) found that when participants viewed images of nature scenes, they had fewer long-fixations and visually explored more of the images compared to participants that viewed images of urban settings, providing evidence that nature scenes prompt involuntary attentional drifts from stimulus to stimulus as suggested by ART.

A second theory that stands in contrast to Kaplan's Attention Restoration Theory was proposed by Ulrich et al. (1981; 1991). This theory states that an individual's *initial* response to immersion within an environment is affective instead of cognitive. Ulrich et al. proposed that the structural properties of an environment (such as complexity and how/where objects are clustered) prompt an *automatic affective response* within the individual. Ulrich et al.'s theory proposes that stimuli seen outside of nature are more threatening and thus more physiologically arousing. In contrast to ART where replenishment of directed attention mechanisms is believed to be the source of restoration, Ulrich et al.'s theory proposes that the *initial automatic affective response* to an environment shapes the cognitive events that follow (Valtchanov, Barton, & Ellard, 2010). If the affective response is positive (as when one is exposed to nature), the cognitive and physiological events that follow are also positive: Negative emotions and thoughts are suppressed, resulting in higher levels of positive affect and ability to sustain attention, and reduced levels of negative affect and physiological stress (Valtchanov et al., 2010). Experiments by Ulrich et al. have focused on measuring the affective and physiological states of participants in an attempt to find support for this theory. These authors have shown that exposure to surrogate nature (such as videos and photos of real nature) promoted a decrease in heart-rate and skin-conductance (Ulrich et al., 1991), and even blood pressure (Ulrich, Simons & Miles, 2003) while also improving self-reported affect.

1.1.2 Background Information

Much of the research on the restorative effects of nature has focused on identifying and understanding how the restorative properties of nature may be utilized to improve overall quality of life and well-being, rather than exploring the theories proposed by Kaplan (1995; 2001) and Ulrich et al. (1981; 1991). Some applications include making cityscapes more pleasant and appealing to individuals by adding trees (Sheets & Manzer, 1991) while others include improving workplace satisfaction by providing views of natural scenery within office spaces (be it through the use of windows or posters) (Leather, Pyrgas, Beale, & Lawrence, 1998; Kweon, Ulrich, Walker, & Tassinary, 2008). With the emergence of new technologies such as immersive virtual reality and 3D-video, researchers are investigating new ways to use these technologies to help improve the quality of life both within the home and within clinical settings (Villani, & Riva, 2008; Valtchanov et al., 2010). Part of this line of research has focused on exploring the restorative effects of exposure to nature using immersive virtual reality. Valtchanov, Barton and Ellard (2010) believe that the restorative properties of nature may be captured using computer-generated nature (i.e., the artistic interpretation of nature versus photographs or videos of real nature) which can then be used within virtual reality to create restorative experiences. This notion is supported by research done by Villani and Riva (2008) which has found that immersive 3-D video (which coincidentally contained computer-generated nature) can aid recovery in a stress-management protocol. Furthermore, research by Villani et al. (Villani, Riva, & Riva, 2007; Villani, Luchetta, Preziosa, & Riva 2009) and Freeman, Lessiter, Keogh, Bond & Chapman (2004) that suggests virtual reality may be used to aid relaxation also used computer-generated nature environments. Lastly, Valtchanov et al. (2010) investigated whether computer-generated virtual nature had restorative effects, and found that exploring a virtual forest promoted reductions in physiological stress, and an improvement in emotional state when compared to viewing abstract paintings. While this research supports the idea that computer-generated nature may possess some of the properties of real nature to produce restoration, it does not definitively answer the question of whether it is the nature scenery or the immersive virtual reality experience that is responsible for the observed restorative effects. Such is the case partially due to the lack of controlled comparison groups. As acknowledged by Valtchanov et al. (2010) it is currently unclear whether the restoration produced by virtual nature shares a mechanism with restoration produced by real nature, or whether virtual reality in general may provide an ‘escape’ from one’s current mindset and situation, resulting in psychological distance from stressors and thus restoration.

1.1.3 The Current Study

The goal of the present study was to build on the previous research by Valtchanov et al. (2010). Using improved methodology and measures, I aspired to test the effects of a variety of virtual environments on physiological stress, ability to sustain attention, and affect: One environment was a virtual nature environment, another was a virtual urban environment modelled after the Shibuya area in Tokyo Japan, and the last was a geometric virtual environment featuring only regular geometric shapes (such as cubes, cylinders, spheres, etc). Similar measures to Valtchanov et al. (2010) were used in order to examine whether their previously reported restorative effects of virtual nature settings could be reproduced using a more complicated and realistic nature environment conforming to the current computing power. This was also done to compare physiological and affective reactions of participants to three distinctly different virtual environments to clarify whether virtual reality provides an 'escape' which may cause restoration, or whether it is virtual nature that has been responsible for the restoration observed in previous literature (Freeman et al., 2004; Villani, Riva & Riva, 2007; Villani & Riva, 2008; Villani et al., 2009; Valtchanov et al., 2010). To ensure that all participants in the experiment were experiencing an equal level of stress prior to immersion in virtual reality, such that between-group comparisons could be made, a stress-induction task similar to that used by Valtchanov et al. (2010) and de Kort et al. (2006) was used to homogenize stress-levels.

Natural and urban environment types were used in order to mirror previous literature on restorative effects in real-world studies (Ulrich, 1981; Ulrich et al., 1991; Sheets & Manzer, 1991; Berman et al., 2008) which have compared exposure to natural environments versus urban environments. The geometric environment was developed as a third comparison in order to examine the question of whether nature environments are neutral and urban environments stressful, or if nature environments are restorative and urban environments neutral (Valtchanov et al, 2010). I wished to address this question because much of the literature on restorative effects of nature has only compared natural versus urban environments, creating an ambiguity as to whether nature is restorative or neutral since urban settings could be either neutral or stressful.

Furthermore, the geometric environment was developed to help test both the Attention Restoration Theory as proposed by Kaplan (1995; 2001) and the ‘affective response’ theory proposed by Ulrich et al., (1981; 1991) since both theories suggest contradictory outcomes when participants are exposed to such an ‘abstract’ environment. Kaplan’s Attention Restoration Theory would suggest that such an environment would be restorative since it lacks elements that *demand* attentional resources (such as advertisements, loud noises, etc), while still containing a new and *fascinating* experience (i.e., virtual reality) to *modestly* capture attention, allowing directed attention to disengage and recover. Meanwhile, according Ulrich et al.’s theory, since the environment is similar to an urban setting in its geometric focus and contains visual patterns that are not found in nature, it should be viewed as threatening and promote stress and deterioration of affect. Lastly, I also aimed to examine whether virtual nature could promote an improvement in ability to focus, similar to that reported by Berman et al. (2008) when participants were immersed in real nature.

Measures of physiological stress consisting of skin-conductance level and heart rate were used as they have been in previous research (de Kort et al., 2006; Villani et al., 2009; Valtchanov et al., 2010). The Zuckerman Inventory of Personal Reactions (Zuckerman,

1977) was used to measure positive and negative affect in accordance with previous research by Ulrich et al. (1981;1991) and Valtchanov et al. (2010). To measure ‘cognitive fatigue’ I employed the Sustain Attention to Response Task (SART), which has been shown to be a sensitive behavioural measure of sustained attention (Cheyne, Solman, Carrier, & Smilek, 2009) and has previously been used to test individuals suffering from stress (Van Der Linden, Keijers, Eling, & Van Schaijk, 2005). Individuals suffering from (chronic) stress have been shown to have trouble using executive attention to inhibit the automatized response in the SART (Van Der Linden, et al., (2005).

I predicted that there would be a similar pattern of results to that observed in research using real-nature, such that the virtual nature environment would promote stronger improvements in physiological, affective, and cognitive states than the urban and geometric environments as shown by a decrease in SCL, reduced heart-rate, higher positive affect and lower negative affect scores on the Zuckerman Invenotry of Personal Reactions (ZIPERS), and fewer errors on the SART. I also predicted that the urban virtual environment would be more stressful than the geometric environment since the urban virtual environment contained features that may cause stress (such as advertisements, various coloured lights, and high levels of various types of noise), potentially elevating physiological stress and having a negative impact on affect and sustained attention. Lastly, I predicted that immersion in the geometric environment would have no effect on all measures (relative to pre-immersion), since both major theories on restoration predicted results going in opposite direction (cancelling each other out) and the environment contained neither threatening stimuli, nor anything resembling nature (aside from colours). Thus it was used as the neutral control group.

1.2 Method

1.2.1 Participants

Prior to recruitment, participants were pre-screened using a mass-testing questionnaire. Participants were required to speak and read English fluently (in order to understand instructions), to not have experienced seizures, vertigo, or motion sickness prior to the study (to reduce risk of simulator sickness during the study), to have corrected-to-normal or normal vision. A random sample of sixty-nine undergraduate students (32 male and 37 female), ages 18 to 26, was recruited to participate in the study in exchange for course credit. Participants were randomly assigned to one of the three conditions (nature, geometric or urban). There were 11 males and 13 females in the nature condition, 10 males and 12 females in the geometric condition, and 11 males and 12 females in the urban condition.

1.2.2 Design

Measures of physiological, affective and cognitive states were taken at the start of the experiment (baseline), post-stress induction, and post immersion in virtual reality. Each participant served as his or her own control on the repeated measures. The virtual reality experience required participants to explore one of the three virtual environments, either the nature setting, the environment full of geometric shapes, or the urban setting. Procedures and measures were identical between all three conditions. The only difference between conditions was the virtual environment participants explored.

1.2.3 Measures

Restorative effects were measured in three different ways (self-report questionnaire, physiological recordings, and behavioural task) in similar fashion to our previous work (Valtchanov et al. (2010). The Zuckerman Inventory of Personal Reactions (ZIPERS)

(Zuckerman, 1977) was adapted from previous experiments exploring restorative effects of nature both in the real world and within virtual reality which have found it to be a reliable measure of restoration.(Ulrich, 1981; Ulrich et al., 1991; Hartig et al., 1991; Valtchanov et al., 2010). The ZIPERS includes twelve items that measure positive affect (happiness, friendliness, playfulness, and affection), negative affect (anger, sadness, and avoidance) and attentiveness on a five-point Likert scale. I incorporated two more items at the end of the questionnaire to measure self-reported stress.

Both skin-conductance level (SCL) and heart-rate (HR) were continuously recorded by a computer from the beginning to the end of the experiment and were used as a measure of physiological stress. Measurements were recorded using the *ADInstruments PowerLab Data Acquisition System* and accompanying *LabChart* software. Both SCL and HR were recorded using a sampling rate of 100 hz. Skin-conductance level was recorded using two finger-tip electrodes attached to the index and middle fingers of the participant's non-dominant hand. Skin conductance level is viewed as a measure of sympathetic nervous system activity (Dawson, Schell & Filion, 2007; Valtchanov et al., 2010). Increases in sympathetic nervous system activity have been associated with increases in activation of epidermal tissue and sweat glands, which results in secretion of sweat and an increase in skin conductivity (Dawson, Schell & Filion, 2007; Valtchanov et al., 2010). I opted to use the tonic skin conductance component (SCL) instead of the phasic component (skin-conductance response: SCR) since SCL has been previously used in research on restorative effects of nature (de Kort et al., 2006; Valtchanov et al., 2010) and is associated with tonic states of sympathetic nervous system arousal (e.g., stress) Dawson et al., 2007; Valtchanov et al., 2010). Heart-rate was recorded using an infrared finger-tip sensor placed on the ring-finger of the participant's non-dominant hand, and served as a secondary measure of physiological stress. Both SCL and HR sensors and wires were secured to the participants' hand using Velcro straps to prevent sensors from moving during the experiment.

The third measure of restoration used was the Sustained Attention to Response Task (SART). The SART is a powerful behavioural measure of sustained attention that gives insight into some of the states of sustained attention (Robertson et al., 1997; Manly et al., 1999, Cheyne et al., 2009). The SART features a rapid display of randomized numbers from 1 to 9. During the SART, participants are instructed to press the "space" key on a keyboard every time they see a number that is not the target, and are told to withhold their response (i.e., refrain from pressing the "space" key) when the target (#3) appears onscreen. This produces an automatized behaviour of pressing the "space" key since eight out of nine responses require the key to be pressed. Attention must be sustained in order to prevent pressing the "space" key when the target randomly appears. The main two measurements that emerge from the task are the number of inhibition errors, where participants have failures of sustained attention and fail to use executive control to inhibit the automatized behaviour of pressing the "space key", and response time. Both inhibition errors and response time have been associated with sustained attention (Robertson et al., 1997; Manly et al., 1999, Cheyne et al., 2009).

Lastly, I measured simulator sickness using the Simulator Sickness Questionnaire developed by Kennedy et al. (1993) which measures sickness induced by simulators (such as virtual reality) using three subscales (nausea, oculomotor, disorientation). The questionnaire asks participants to rate the level various symptoms (nausea, blurred vision, eyestrain, etc) that they may be experiencing on a scale from "none" to "severe". Simulator sickness was measured in order to determine if measures of affect, sustained attention, and stress were being confounded by the simulator sickness that sometimes results from immersion in virtual reality (Kennedy et al., 1993; Valtchanov et al., 2010).

1.2.4 Technical Information About Virtual Reality Setup

Both the virtual nature environment and virtual urban environment were constructed using a combination of the *CryEngine 2* software developer's kit, the *Crysis* level creator, and *Google Sketchup* modelling software. The geometric virtual environment was constructed using a combination of *Google Sketchup* and the *Worldviz* virtual reality software, *Vizard*. All three environments were built to be of similar size and to allow a similar amount of exploration on a grid of 3 km^2. The overall layout of all three environments was kept as consistent as possible while retaining the uniqueness of each type of virtual environment.

The nature island contained two waterfalls (with accompanying rivers flowing toward the ocean), various different palm trees and types of broad-leafed trees, grass, rocks, varied flower bushes and plants, and a long stretch of beach by the ocean. Dirt path networks were clear and easy to follow throughout the island. Ambient nature sounds (such as the ocean, rivers flowing, etc) were also present in the environment. The environment also featured simulated wind and realistic physics, creating a gentle sway of the tree branches and ripples/waves in the water. It should be noted that participants did not physically feel any wind or breeze inside the climate-controlled lab room.

The geometric setting was created using an assortment of 3-dimensional geometric shapes including spheres, cylinders, cones, and rectangular and square boxes of various sizes. Shapes were coloured using the colour palette found within the nature environment (i.e., with a heavy focus on greens, blues, and browns) in order to help control for the potential effects of colour on affect. The geometric environment did not feature any sounds apart from the individuals' virtual footsteps since it was an empty environment (apart from the shapes themselves).

The urban environment was a model (to scale) of the area surrounding Shibuya station in Tokyo, Japan. I did not create a hypothetical urban environment since I wished to capture modern design and architecture accurately. Shibuya was chosen as the urban environment because it is a dense urban center that participants were unfamiliar with. It featured full-scale buildings, streets, sidewalks with realistic ambient lighting and advertisements. All buildings, signs and objects were made using realistic textures taken from photographs of the actual location in Japan. Ambient city sound was also present, giving the impression that people were present but very far away. However, no actual 3d-models of people were present and there were no moving vehicles on the streets. The three environments (nature, geometric, and urban) can be seen in Figure 1.

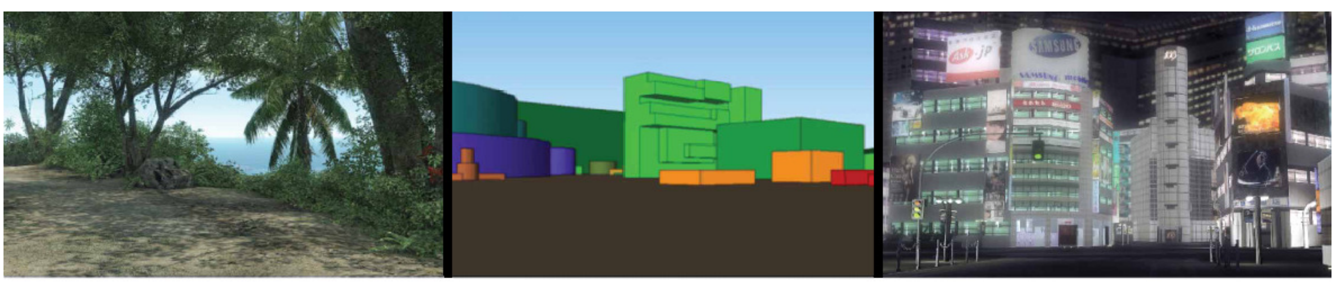

Figure 1. Screen captures of the nature (left), geometric (middle) and urban (right) virtual environments

The three virtual environments were rendered using *CryEngine 2*, a platform available to individuals who have purchased the PC game "*Crysis.*" Environments were rendered using a consumer-grade gaming PC with a 2.4 ghz quad-core processor, 4 GB of ram and two AMD ATI 3870x2 video cards at 1280x1024 pixels per eye with photorealistic shadows and lighting. The rendered scene was then piped in stereo to a *nVIS* head-mounted display that featured a 65-degree field-of-view. The HMD also featured a thick light-blocking cover which prevented participants from seeing the real-world environment around them, allowing them to better focus on the virtual environment. The viewpoint was controlled by an *InterSense InertiaCube2* head-tracking device which was attached to the HMD, allowing the viewpoint to update in real-time with physical head-movements. (i.e., If a participant turned their head toward the right, the viewpoint in virtual reality would update and look toward the right.) Self-locomotion through the virtual environments was achieved through the use of a wireless mouse calibrated to move participants' "virtual bodies" forward and backward with the left and right click respectively. The direction of movement corresponded to the orientation of their head in the physical world. Participants were instructed to orient their body to the direction of movement in order to reduce the mismatch between their physical and virtual bodies.

1.2.5 Procedure

Participants were randomly assigned to one of the three conditions (nature, geometric, or urban). An identical procedure was followed for all three conditions with the exception of the type of virtual environment (nature, geometric, or urban) participants were exposed to. Each participant was met in a central meeting area by appointment and was then escorted to a lab setting where he or she participated in the experiment. Participants were given a cover story stating that the purpose of the experiment was to examine the performance of stress and virtual reality on their performance on the Sustained Attention to Response Task (SART).

At the start of the experiment, participants were seated at a desk in front of a computer monitor with a keyboard and mouse, and were hooked up to skin conductance level (SCL) and heart-rate (HR) sensors on their non-dominant hand in order to measure physiological stress levels. Participants wore the SCL and HR sensors on their non-dominant hand throughout the entire experiment and were asked to keep the hand stationary on the desk while they filled out questionnaires (in order to prevent measurement noise and movement artifacts). In order to acclimatize participants to the equipment prior to obtaining measurements, participants wore the HR and SCL sensors for 5-minutes while sitting at the desk during which the experiment protocol explained. They were then asked to fill out the Zuckerman Inventory of Personal Reactions (ZIPERS) on the computer using the keyboard and their dominant hand, in order to establish a baseline for self-reported affective state (on levels of positive affect, negative affect, ability to focus and stress) during which a SCL and HR baseline was established for 2 minutes. The SART was then administered on the computer for 5 minutes in order to establish baseline performance and ability to sustain attention.

Participants were then given a 10-minute stress-induction task on the computer consisting of a modified version of the Markus & Peters Arithmetic Test (previously found to be an effective stress-induction by de Kort et al.2006). During the task, participants were asked to use mental arithmetic to solve difficult multi-step multiplication questions (e.g., 56 x 37 + 17) within a time limit (a 60-second timer was present for each question). While solving the questions, participants wore stereo headphones that played loud street-traffic noise meant to distract them and make the task more difficult and frustrating. Participants were also given feedback after every incorrect response to induce further stress. A high-level of stress was induced in participants within the controlled lab setting in order to ensure that all participants were experiencing a similar level of stress and negative affect prior to immersion in virtual reality. This was done in order to homogenize stress levels between groups prior to immersion in virtual reality, so that the effectiveness of each virtual environment in helping participants to recover from the same level of stress could be measured.

After the stress induction, the SART was administered again for 5 minutes to measure if participants' ability to sustain attention had changed from baseline. After administration of the SART, participants filled out the ZIPERS for 2 minutes once again while SCL and HR data was collected. The SCL and HR data file was marked with the start and finish of the 2-minute interval. ZIPERS scores and SCL and HR data was collected post stress and administration of the SART in order to have an accurate measure of participants' physiological and affective states just prior to exploring virtual reality.

After participants finished filling out the ZIPERS, they were fitted with a head-mounted-display (with motion tracking) immersing them in one of the three virtual environments (nature, geometric, or urban) seen in Figure 1 based on random assignment. Participants were given 10 minutes to freely explore the virtual environment, with their only goal being to find objects or locations which they found pleasant or interesting.

After the 10-minute virtual reality session was finished, participants were once again given the ZIPERS for 2 minutes to measure the effects of the virtual environments on their emotional state while SCL and HR were once again collected recorded. Finally, the SART was administered for 5 minutes for the final time to measure any changes in ability to sustain attention resulting from immersion in virtual reality.

1.3 Results

1.3.1 Reliability Analysis of ZIPERS

To simplify our analysis, I grouped the questions measuring happiness, friendliness, affection, and playfulness under the broad category of "positive affect." These items were found to have an acceptable Cronbach's alpha of 0.88. Similarly, I grouped the questions measuring fear, anger, and sadness into the broad category of "negative affect." These items were also found to have an acceptable Cronbach's alpha of 0.81.

1.3.2 Stress Manipulation Check

To confirm that the stress induction was successful and that participants were stressed and experiencing a negative emotional state prior to their virtual reality experience such that restoration could take place, baseline scores on the Zuckerman Inventory of Personal Reactions, skin conductance levels, and heart-rate levels obtained prior to stress-induction and post stress-induction were compared using a set of mixed-model repeated measures ANOVAs. As a result of the stress induction, participants reported feeling significantly lower positive affect (M = 2.3, SD = 0.73) than at baseline (M = 2.8, SD = 0.70), $F(1,68) = 32.90$, $p < 0.001$, MSE = 0.234, $\eta_p^2 = 0.326$. Participants also reported a significant increase in negative affect (M = 1.65, SD = 0.73) compared to baseline (M =1.29, SD = 0.42), $F(1,68) = 18.90$, $p < 0.001$, MSE = 0.228, $\eta_p^2 = 0.217$, significantly higher feelings of stress (M = 3.85, SD = 0.96) compared to baseline (M = 2.97, SD = 1.2), $F(1,68) = 37.78$, $p < 0.001$, MSE = 0.714, $\eta_p^2 = 0.357$, and significantly lower attentiveness (M = 2.7, SD = 1.11) compared to baseline (M = 3.28, SD = 0.89), $F(1,68) = 12.39$, $p < 0.001$, MSE = 0.889, $\eta_p^2 = 0.154$. Physiological measures converged with the self-report of feeling stressed. As seen in Table 1, skin-conductance levels increased significantly $F(1,68) > 100$, $p < 0.001$, MSE = 0.621, $\eta_p^2 =$

0.796, and heart-rate trended increase, $F(1,68) = 2.771$, $p = 0.10$, $MSE = 39.577$, $\eta_p^2 = 0.039$. The results suggest that the stress-induction was successful at inducing negative mood, and both self-reported and physiological stress. However, the stress-induction failed to induce cognitive fatigue and lapses in sustained attention, since there was no significant change in SART inhibitory errors, $F(1,68) = 0.072$, $p = 0.789$, n.s., $MSE = 3.599$, $\eta_p^2 = 0.001$, or SART response time, $F(1,68) = 1.085$, $p = 0.301$, n.s., $MSE = 1281.444$, $\eta_p^2 = 0.016$. This suggested that participants' ability to sustain attention remained at baseline despite elevated levels of stress and negative affect.

Table 1

Means and Standard Deviations of Physiological Measures

Physiological measure	Condition	Baseline	Post-stress induction	Post immersion in virtual reality
Heart rate	Nature	M = 82.91 SD = 12.92	M = 86.16 SD = 11.46	M = 78.22 SD = 13.42
	Geometric	M = 81.77 SD = 14.57	M = 82.40 SD = 11.33	M = 76.97 SD = 10.12
	Urban	M = 78.67 SD = 12.66	M = 80.08 SD =12.70	M = 76.78 SD =12.39
Skin conductance level change from baseline (z-score)	Nature	-	M = 2.50 SD = 0.98	M = 1.76 SD = 1.14
	Geometric	-	M = 1.86 SD = 0.95	M = 2.02 SD = 1.40
	Urban	-	M = 2.15 SD = 1.33	M = 2.26 SD = 1.37

1.3.3 Effects of Virtual Reality on ZIPERS Scores

Scores on the Simulator Sickness Questionnaire (SSQ) were used to check if participants were experiencing any simulator sickness which may have influenced scores. Participants reported feeling "none" (1) to "slight" (2) simulator sickness on a scale from 1 to 4 ($M=1.645$, $SD = 0.456$), thus simulator sickness was not believed to be a confound. To examine the effects of immersion into virtual reality (VR) on participants' self-reported affect, ZIPERS scores obtained just prior immersion into VR (but post stress induction) were compared to scores obtained immediately after immersion into VR using a set of mixed-model repeated measures ANOVAs with time (prior to VR, post VR) as the repeated measure and condition (nature, urban, geometric environments) as the between variable.

A significant time by condition interaction on the positive affect dependent variable was found, $F(2,66) = 9.676$, $p < 0.001$, $MSE = 0.328$, $\eta_p^2 = 0.227$, suggesting that the three virtual environments had different effects on positive affect. To test for simple effects, the data was split by condition, and repeated-measures ANOVAs were done. The analysis revealed that the nature virtual environment caused positive affect to increase significantly from a mean of 2.21 (SD = 0.71) prior to VR to a mean of 3.03 (SD = 0.98) post VR, $F(1,23) = 14.304$, $p < 0.001$, $MSE = 0.571$, $\eta_p^2 = 0.383$, meanwhile the geometric virtual environment had no effect (M = 2.39, SD = 0.67 prior to VR to M = 2.27, SD = 0.94 post VR), $F(1,22) = 0.776$, $p = 0.388$, n.s., $MSE = 0.220$ $\eta_p^2 = 0.034$ and the urban environment had no effect (M = 2.40, SD = 0.83 prior to VR to M = 2.38, SD = 0.74 post VR), $F(1,21) = 0.021$, $p = 0.887$, n.s., $MSE = 0.175$, $\eta_p^2 = 0.001$. This data can be seen in Figure 2.

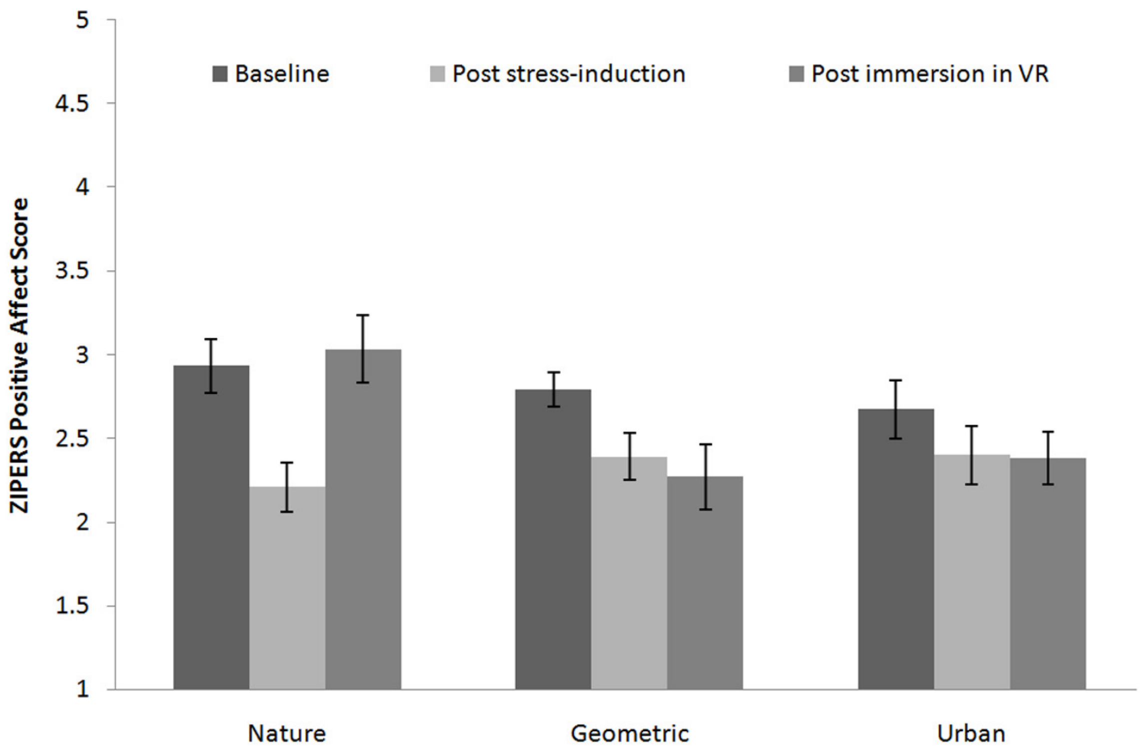

Figure 2. ZIPERS Positive affect scores (scale of 1 to 5). Error bars represent 1 S.E. Mean.

A significant time by condition interaction on the negative affect dependent variable was also found, $F(2,66) = 6.140$, $p < 0.005$, $MSE = 0.180$, $\eta_p^2 = 0.157$, suggesting that the virtual environments had different effects on participants' level of negative affect. To test for simple effects, the data was split by condition and repeated-measures ANOVAs were used. The analysis revealed that the nature virtual environment caused negative affect to decrease significantly from a mean of 1.88 (SD = 0.85) prior to VR to a mean of 1.22 (SD = 0.35) post VR, $F(1,23) = 17.750$, $p < 0.001$, $MSE = 0.293$, $\eta_p^2 = 0.436$. The geometric environment had no effect (M = 1.50, SD = 0.65 prior to VR to M = 1.45, SD = 0.62 post VR), $F(1,22) = 0.268$, $p = 0.610$, n.s., $MSE = 0.117$, $\eta_p^2 = 0.012$ while the urban environment caused a significant decrease in negative affect from a mean of 1.55 (SD = 0.61) prior to VR to a mean of 1.27 (SD = 0.41) post VR, $F(1,21) = 7.205$, $p = 0.014$, $MSE = 0.121$, $\eta_p^2 = 0.255$. This data can be seen in Figure 3. As shown in Figure 3, it appears that there might be a floor effect since scores are near the lower end of the scale.

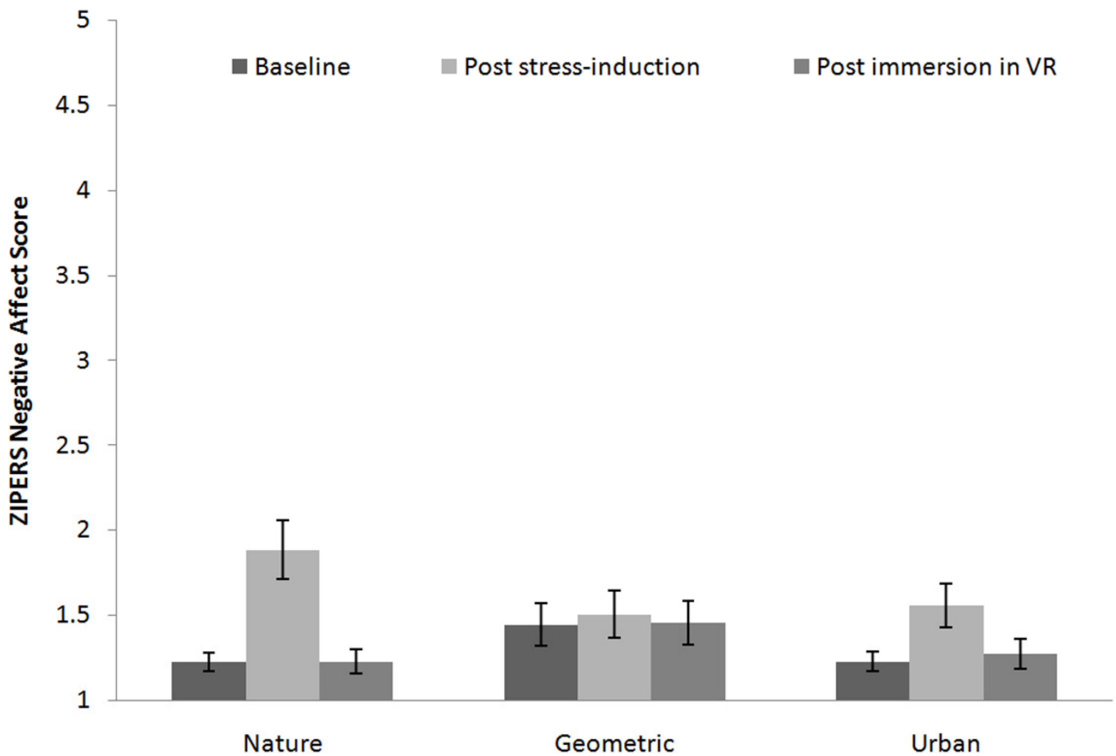

Figure 3. ZIPERS Negative affect scores (scale of 1 to 5). Error bars represent 1 S.E. Mean.

A significant time by condition interaction on self-reported stress was found, $F(2,66) = 12.763$, $p < 0.001$, $MSE = 0.918$, $\eta_p^2 = 0.113$, converging with previous measures and suggesting that the three virtual environments had different effects on perceived stress levels. Simple effects analysis using repeated measures ANOVAs revealed that self-reported stress decreased significantly from a mean of 3.83 (SD = 1.17) to a mean of 2.63 (SD = 1.35) as a result of being immersed in the nature environment, $F(1,23) = 12.219$, $p < 0.005$, $MSE = 1.434$, $\eta_p^2 = 0.347$, but did not change significantly as a result of being immersed in the geometric environment (M = 3.78, SD = 0.74 prior to VR to M = 3.70, SD = 1.11 post VR), F(1,22) = 0.193, p = 0.665, n.s., MSE = 0.451, η_p^2 = 0.009 or the urban environment (M = 3.95, SD = 0.95 prior to VR to 3.50, SD = 0.96 post VR), F(1,21) = 2.692, p = 0.116, n.s., MSE = 0.844, η_p^2 = 0.114. This data can be seen in Figure 4.

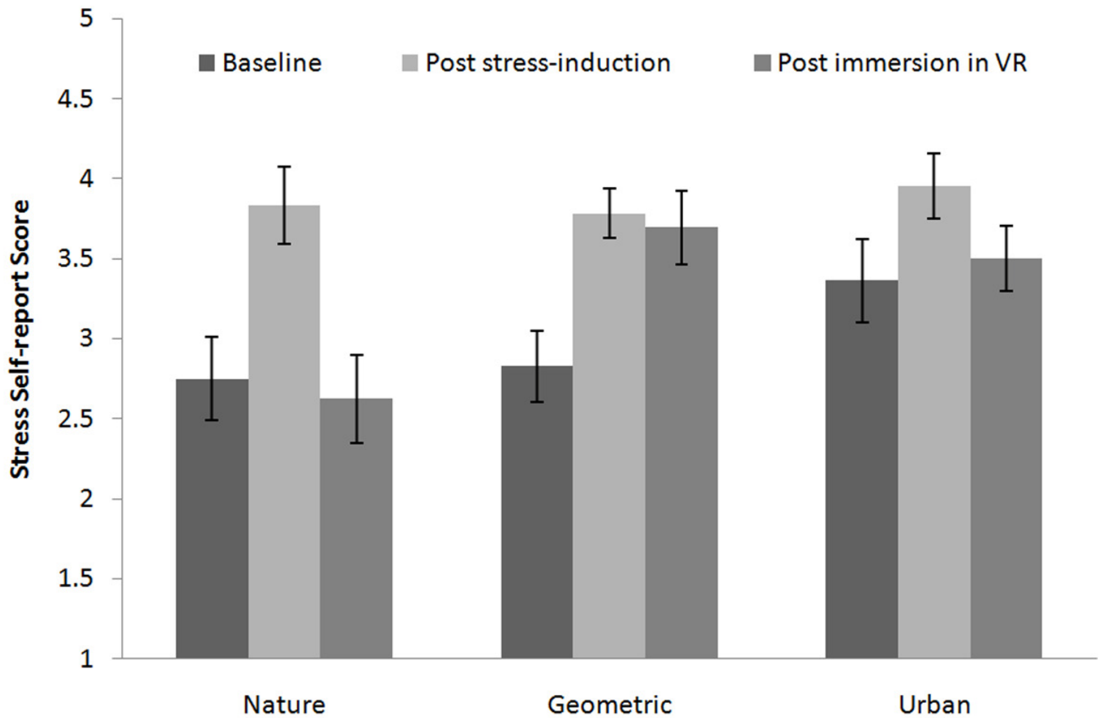

Figure 4. Stress self-report scores (scale of 1 to 5). Error bars represent 1 S.E. Mean.

Lastly, a significant time by condition interaction on the self-reported attentiveness dependent variable was also found, F(2,66) = 3.436, p < 0.05, MSE = 0.638, η_p^2 = 0.094. Simple effects were once again tested using repeated measures ANOVAs. The analysis revealed that self-reported attentiveness (i.e., ability to focus) did not change as a result of immersion in the virtual nature environment (M = 2.63, SD = 1.17 prior to VR to M = 2.67, SD = 0.87 post VR), F(1,23) = 0.038, p = 0.846, MSE = 0.543, η_p^2 = 0.002, but decreased significantly from a mean of 2.83 (SD = 1.11) to a mean of 2.04 (SD = 0.93) as a result of being in the geometric virtual environment, F(1,22) = 11.960, p < 0.005, MSE = 0.589, η_p^2 =

0.352. Self-reported attentiveness also decreases significantly from a mean of 2.68 (SD = 1.09) to a mean of (2.09, SD = 0.75) as a result of being in the urban virtual environment, $F(1,21) = 4.842$, $MSE = 0.793$, $\eta_p^2 = 0.187$. This data can be seen in Figure 5.

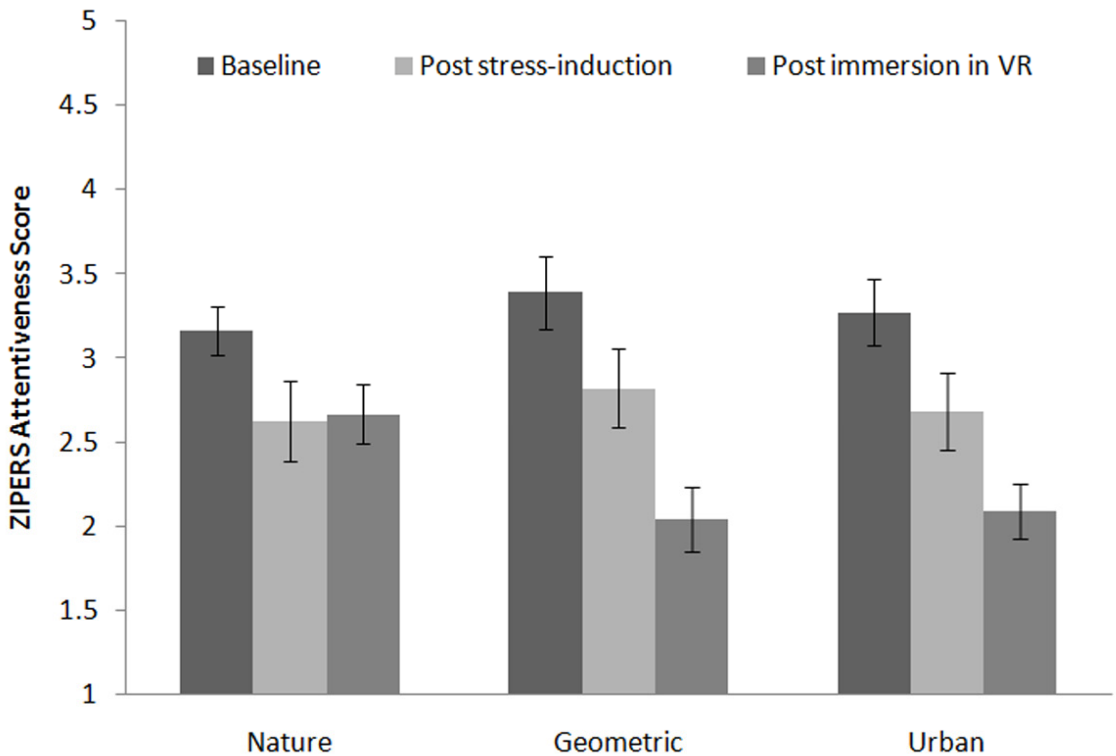

Figure 5. ZIPERS Attentiveness score (scale of 1 to 5). Error bars represent 1 S.E. Mean.

1.3.4 Statistical Analysis of the SCL and HR Measures

Both SCL and HR were recorded continuously throughout the experiment, and the data file was marked with the start and finish of each ZIPERS questionnaire that was administered (i.e., at baseline, post-stress induction, and post VR immersion). SCL and HR were averaged over the two-minute intervals during which the ZIPERS was administered so that the congruent physiological (stress) state could be captured and potential movement artifacts could be diminished. This ensured that physiological measures were temporally linked with self-report measures, measuring the physiological state of participants as they were reflecting and filling out the self-report.

For the purpose of analysis, skin-conductance measurements were converted into z-scores to standardize SCL responses between participants, so that between-subject comparisons could be made. This was required in order to prevent bias in the dataset due to 'high-responding' individuals whose changes in SCL magnitudes were up to ten times the average. Skin-conductance was measured relative to a baseline established at the start of the experiment. The equipment was zeroed at this baseline. Similarly to the analysis of the self-report data above, measurements prior to immersion in virtual reality were compared to measurements post-virtual reality immersion using a mixed-model repeated measures ANOVA. A significant time by condition interaction was found on the dependent variable of SCL was discovered, $F(2,66) = 7.166$, $p < 0.005$, $MSE = 0.424$, $\eta_p^2 = 0.178$, suggesting that the three virtual environments had different effects on participants' stress levels. Simple effects analyses were done by splitting the data by condition and performing repeated measures ANOVAs. The analyses revealed that (as seen in Table 1) SCL decreased significantly as a result of immersion in the nature environment, $F(1,23) = 11.625$, $p < 0.005$, $MSE = 0.577$, $\eta_p^2 = 0.336$, but did not change as a result of immersion in the geometric environment, $F(1,22) = 0.617$, $p = 0.441$, n.s., $MSE = 0.426$, $\eta_p^2 = 0.027$ or immersion in the urban environment, $F(1,21) = 0.557$, $p = 0.464$, n.s., $MSE = 0.254$, $\eta_p^2 = 0.026$, converging with the self-report stress measure. Means and standard deviations can be seen in Table 1.

Heart-rate was also analyzed using a mixed-model repeated measures ANOVA. The analysis revealed a trending time by condition interaction on the dependent variable of heart-rate, $F(2,66) = 2.997$, $p = 0.057$, $MSE = 20.704$, $\eta_p^2 = 0.083$. Simple effects analyses revealed that heart-rate decreased significantly as a result of immersion in the nature environment, $F(1,23) = 25.842$, $p < 0.001$, $MSE = 29.242$, $\eta_p^2 = 0.529$, the geometric environment, $F(1,22) = 34.714$, $MSE = 9.754$, $p < 0.001$, $\eta_p^2 = 0.612$, and the urban environment, $F(1,21) = 5.242$, $p < 0.05$, $MSE = 22.824$, $\eta_p^2 = 0.200$, suggesting that HR decreased significantly regardless of the virtual environment as seen in Table 1.

1.3.5 Statistical Analysis of the SART Measure

A set of mixed-model repeated measures ANOVAs were used to analyze the rate of inhibition errors and response time on the SART prior to immersion in VR (post stress-induction) and post immersion in VR. The analyses revealed no significant or trending interactions of time by condition on the dependent variable of inhibitory error rate, $F(2,66) = 1.607$, $p = 0.176$, n.s., $MSE = 3.470$, $\eta_p^2 = 0.024$, or the dependent variable of reaction time, $F(2,66) = 0.203$, $p = 0.817$, n.s., $MSE = 1182.581$, $\eta_p^2 = 0.006$, supporting the notion that participants were performing at baseline since the stress-induction failed to induce cognitive fatigue, thus no restoration could occur.

1.4 General Discussion

In the current study a variety of measures of restorative effects were used, including a standardized self-report questionnaire measuring affect, perceived attentiveness and perceived stress, physiological measures of skin-conductance level (stress) and heart-rate, and a behavioural measure of sustained attention (the Sustained Attention to Response Task) in order to thoroughly document the effects of three unique virtual reality environments on affect, stress, and attention. In doing so, I was able to produce similar restorative effects to those reported by Valtchanov et al. (2010) when immersing participants in virtual nature, while also addressing several other important questions: I was able to determine whether it was the nature within virtual reality, or virtual reality itself that was responsible for reductions in stress and improvement in affect. I was also able to determine whether the commonly used urban comparison group (Ulrich, 1981; Ulrich et al., 1991; Sheets & Manzer, 1991; Berman et al., 2008) was neutral or stressful in terms of eliciting an affective and physiological response.

Firstly, I found converging evidence from several measures that supported my hypothesis that *computer-generated* nature stimuli produce restoration when participants are immersed in virtual reality. Immersion in the virtual nature setting prompted an increase in positive affect (happiness, friendliness, affection, and playfulness), and a decrease in negative affect (fear, anger, sadness) as seen in Figures 2 and 3. Furthermore, a significant self-reported decrease in levels of perceived stress (seen in Figure 5) converged with the significant decrease in levels of physiological stress (as measured by skin-conductance level and heart-rate). These results are consistent with findings by Valtchanov et al. (2010) who have previously reported that virtual nature can have restorative properties on affect and physiological stress, as well as research by de Kort et al. (2006) and van den Berg et al. (2003) which suggests that surrogate nature (such as photographs and videos) can have similar restorative effects.

Secondly, it becomes much more apparent that it is virtual nature that is responsible for the observed restoration and not virtual reality itself when the group that was immersed in the virtual nature setting is compared to the group immersed in the geometric setting, and the group immersed in the urban setting. All participants underwent an identical protocol with the exception of the virtual environment they explored. All three virtual environments were equally large and afforded similar exploration paths, while providing appropriate cues (e.g. being able to hear the water near the ocean, or being able to hear the subway near the subway station). All three environments also had a similar level of interactivity (i.e., participants could explore freely and look at whatever they wanted). Despite the similarity of the virtual reality experiences and identical protocol, only those who were immersed in virtual nature experienced a significant and consistent improvement of affect and reductions in stress across all measures, while those immersed in the geometric and urban environments displayed either no improvement or ambiguous improvement (as shown by reductions in HR in the absence of decreases in SCL and self-reported stress). These findings support my predictions and suggest that the content of the virtual reality experience, specifically the presence of nature, and not the virtual reality experience itself is likely responsible for the observed restoration. This notion is supported by the previously documented restorative properties of exposure to nature (Berman et al., 2008; Kweon et al., 2008, Valtchanov et al., 2010).

When exploring whether urban settings were stressful (as predicted) or neutral, I was able to come to a context-specific conclusion. The results of the current study suggest that in the absence of threatening stimuli (such as moving cars, cyclists, and other pedestrians) that are normally present in an urban setting, (requiring individuals to be vigilant to avoid collisions or other threats,) virtual urban settings may reduce negative affect (anger, sadness, and fear), but do not improve positive affect or reduce stress. I believe this to be a characteristic of benign urban virtual settings since a similar effect was not present in the group that explored the geometric virtual environment. The geometric virtual environment proved consistently to have no effect on stress and affect (as predicted) and was thus used as the neutral comparison. The promotion of decreases in negative affect by urban settings in the absence of other changes may have been the result of the environment distracting individuals from their awareness of their negative emotions. In doing so, it could have influenced perceived affect (measured by the self report) without influencing physiological state. This was not seen in the geometric environment since the urban environment may have been more “attention grabbing” (given that it contained many different advertisements while the geometric environment only contained solid coloured shapes). However, this cannot be said for certain as it was not directly measured. It should be noted that the effects observed in this study were all in the context of virtual environments that lacked threatening stimuli. It is likely that the restorative effects of nature would disappear if the nature environment were filled with threatening stimuli (such as dangerous animals). Another important note is that the previous study by Valtchanov et al. (2010) and the current study both used nature settings with lush vegetation (trees, flowers, bushes). It is possible that the restorative effects of virtual nature may be restricted to natural settings containing dense vegetation. Further research is needed to clarify if other types of nature environments (e.g., rocky terrain, mountains, snow-covered landscapes, grassy fields) can also promote restoration. For example, Heerwagen and Orians (1992) suggest that our ancestors evolved to prefer habitats that offered access to food, water, and shelter from predators and the elements, which increased their chances of survival. Heerwagen and Orians further suggest that properties of good habitats became associated with positive emotional states during the evolutionary process. Thus, it is possible that various types of natural environments that have the characteristics of a ‘good habitat’ may promote positive emotional states, and even restoration.

The unpredicted decrease in negative affect due to exposure to the urban setting, and the predicted and observed neutrality of geometric environment, present a conundrum that neither Kaplan's Attention Restoration Theory (ART) (Kaplan, 1995; Kaplan, 2001), nor Ulrich et al.'s (1981;1991) theories can fully explain. In the case of the decrease of negative affect after exposure to the urban virtual setting, ART cannot provide consistent explanation: Since the environment did not contain threatening stimuli that *demanded* attention (such as moving vehicles), it could be argued that directed attention mechanisms were situated in a setting where disengagement was relatively easy. Once participants learned that there were no threats within the environment, recovery from a negative emotional state ensued. However, all participants were explicitly told that there were no threats within the virtual environment and that harm within the virtual world was impossible, so such an explanation seems inaccurate. Similarly, it could also be argued that participants habituated to the (potentially) "*attention demanding"* advertisements partway through their exploration, which then allowed directed attention mechanisms to disengage and recover. This explanation also seems inaccurate since the geometric environment, which was similar in structural features to the urban environment but did not contain any of the advertisements, did not show the effect. Ulrich et al.'s theory also fails to explain the observed pattern of results for the urban and geometric environments. In the current study, participants had an affective response to the stimulus (the urban environment) but did not exhibit a congruent physiological response as Ulrich et al.'s theory predicts. Furthermore, the observed affective and physiological responses are the reverse of the theoretical projections. Since both environments did not contain any nature stimuli, Ulrich et al.'s theory predicts that they would be perceived as threatening and would increase stress and cause a deterioration of affect. However, neither of the environments elicited a change in self-reported or measured physiological stress, and negative affect decreased due to exposure to the urban environment.

1.4.1 Implications for Current Theories on Restoration

Given the presented data, several criticisms can be made about both the Attention Restoration Theory proposed by Kaplan (1995;2001) and Ulrich et al.'s (1981;1991) 'affective response' theory. First and foremost, ART is ambiguous about what it means for a stimulus to *modestly capture* or *demand* attention, which makes it difficult to test empirically. However, despite this ambiguity, the theory still fails to encompass the results of the current study, predicting contradictory results to those observed. Similarly, Ulrich et al.'s (1981;1991) evolutionarily based 'affective response' theory also fails to predict the results observed in the current study. The presented data not only (partially) discredits both theories, but also demonstrates that a new theory is required to explain the effects on affect and stress that the three virtual environments promoted. From a technical perspective, all three virtual reality experiences were identical with the exception of the visual and auditory information presented, yet participants had significantly different responses to the three virtual environments. While the visual and aural information can be identified as the cause of the differences in affect and stress elicited between the nature and urban environments, it cannot fully explain why there were only minor or insignificant differences between participants exposed to the urban and geometric environments. The urban environment contained visual and auditory stimuli (advertisements, sound of crowds and vehicles in the distance, etc) which restoration theories predict to be stressful, yet this environment was no more stressful than the geometric environment. The similarity between the effects of the geometric and urban environments on stress and affect suggests that the stimuli responsible for nature's restorative properties may be nested in the structural properties of the visual as opposed to auditory information. In support it can be argued that the visual properties of the urban and geometric environments were similar, but quite distinct from the nature environment. For example, a cityscape is merely a composite of regular geometric shapes (cubes, spheres, cones, cylinders, etc) once colour and texture are removed from the visual information. Coincidentally, the geometric environment used in this experiment matches such a description (but includes colours seen within nature – which eliminates colour as a potential stimulus for restoration). Meanwhile, once texture and colour are removed from the nature environment, discrete geometric shapes are absent.

Thus, it is plausible that the structural information of the visual stimuli (such as the pattern of shapes, which can be further decomposed into spatial frequencies) may hold the key discovering what makes natural patterns restorative. Such a notion is supported by examining the early work by Ulrich (1981), and later work by Kweon et al. (2008) which demonstrated that viewing photographs of nature promotes improved psychophysical states when compared to viewing photographs of urban settings or abstract posters. In these scenarios, only the visual information differed, yet nature images consistently promoted more restoration despite being photographs of different nature settings, such as water, grass, trees, and mountains (thus containing different visual information). Given this pattern, or lack thereof, one can begin to see that the major difference between nature and urban stimuli is the difference in their structural and geometric properties. Urban settings can be consistently described in terms of regular geometric shapes, while nature scenes contain significantly more complex structural properties that lack a discrete geometric definition. Given this, it is certainly feasible that on a lower perceptual level different neural networks are activated by nature versus urban stimuli, resulting in an automatic psychophysiological response.

1.4.2 Conclusion

Unfortunately, I was unable to find converging evidence for the effects of virtual reality on ability to sustain attention, since the stress-induction manipulation in the current study failed to exhaust the cognitive resources of participants such that performance on the Sustained Attention to Response Task would deteriorate. Participants were performing at baseline levels on the SART before, and after stress-induction, and after immersion in virtual reality. However, it is interesting to note that while there were no changes in SART performance, participants who explored the nature environment reported no perceived deterioration of attentiveness, whereas those who explored the geometric and urban environments subjectively reported a significant decrease in perceived attentiveness. While interesting, this finding is not supported by the behavioural data from the SART (i.e., if participants were truly less attentive, they should have made more errors on the SART). It is possible that the SART was not sensitive enough to measure the deterioration, but it is also possible that participants subjectively perceived deterioration of attention. A correction for further research would be to extend the stress-induction to twenty or thirty minutes to properly induce cognitive fatigue.

The current study provides evidence that *computer-generated* nature can be used to reduce both perceived and physiological levels of stress, as well as improving positive affect (happiness, friendliness, playfulness) and reducing negative affect (fear, anger, and sadness). In demonstrating that virtual nature has the power to promote restoration (compared to other virtual urban scenes) I propose that some of the benefits of exposure to nature (specifically reductions in stress and improvement of affect), can be harnessed using technology and brought into the global urban culture that has pushed many individuals into densely populated urban centers, away from nature.

Future research aimed at stress-management and clinical uses of virtual reality to improve quality of life should focus on exploring ways to use nature stimuli to augment treatments. Since I was able to generate an effective restorative environment using a consumer-grade computer and toolkits available to the general public, I believe that researchers should begin to directly target therapeutic solutions that can be brought to the general consumer market. Raw computing power and software have become relatively inexpensive in the last decade, and with the rapid advances in technology in the field of 3-D televisions, 3-D computer monitors, 3-D projectors and screens, and consumer-grade head-mounted-displays, the general consumer market is at the brink of bringing virtual reality into their living room. Thus, I encourage further research into how these technologies can be used to bring better mental health into the homes of the general public. Lastly, research aimed at exploring 'why' nature stimuli promote the restorative effects in individuals should focus on examining the structural properties of nature versus urban and abstract stimuli as these may hold the key to discerning the qualities of nature stimuli that make them restorative.

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