



**BSc in Psychology**  
**Department of Psychology**

The Effects of Virtual Urban Neighborhoods  
on Cardiovascular Reactivity

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## **Foreword**

Submitted in partial fulfillment of the requirements of the BSc psychology degree, Reykjavík University, this thesis is presented in the style of an article for submission to a peer-reviewed journal.

This thesis was completed in the Spring of 2021 and may therefore have been significantly impacted by the COVID-19 pandemic. This thesis and its findings should therefore be viewed in light of that.

### Abstract

The study examined and compared people's cardiovascular reactivity during a virtual reality (VR) exposure to an urban neighborhood low in restoration likelihood (LRL) and another high in restoration likelihood (HRL). Heart rate (HR), heart rate variability (HRV), and blood pressure (BP) were measured continuously throughout the experiment. After fatigue was induced in 58 participants, they were assigned to a 10-minute VR exposure to either the LRL or the HRL neighborhood. Results revealed that in the VR, HR increased, and HRV and BP decreased for participants in both conditions. The only statistically significant difference between the effects of the two neighborhoods on cardiovascular reactivity was an interaction for HRV, which indicated that HRV decreased more with time in the exposure for participants in the HRL neighborhood. However, there were also trends in results indicating that participants in the HRL neighborhood experienced higher HR and lower HRV than participants in the LRL neighborhood did, and that this difference in HR increased with time in the VR. The difference in HR and HRV between conditions might reflect the greater engagement and attentional intake in the HRL neighborhood than the LRL neighborhood, which subjective measurements revealed.

*Keywords:* restoration, urban neighborhood, cardiovascular reactivity, heart rate, heart rate variability, blood pressure, virtual reality

### Útdráttur

Rannsóknin kannaði og bar saman hjarta- og æðakerfisviðbrögð fólks í sýndarveruleika í borgarnágrenni sem var ólíklegt til að stuðla að endurheimt (low restoration likelihood, LRL) og öðru sem var líklegt til að stuðla að endurheimt (high restoration likelihood, HRL). Mældur var hjartsláttur, breytileiki í hjartsláttartíðni og blóðþrýstingur, samfleytt í gegnum tilraunina. Eftir að 58 þátttakendur höfðu verið þreyttir voru þeir sendir í 10-mínútna sýndarveruleika í annað hvort LRL eða HRL nágrennið. Niðurstöður sýndu að í sýndarveruleikanum jókst hjartsláttur og blóðþrýstingur og breytileiki í hjartsláttartíðni minnkaði hjá þátttakendum í báðum nágrennum. Eini tölfræðilega marktæki munurinn milli áhrifa nágrennanna tveggja á hjarta- og æðakerfisviðbrögð var samvirkni fyrir breytileika í hjartsláttartíðni sem benti til þess að breytileiki í hjartsláttartíðni minnkaði meira með tímanum í sýndarveruleikanum hjá þátttakendum í HRL nágrenninu. Hins vegar var einnig leitni í niðurstöðunum sem benti til þess að þátttakendur í HRL nágrenninu hefðu upplifað hraðari hjartslátt og minni breytileika í hjartsláttartíðni heldur en þátttakendur í LRL nágrenninu og að þessi munur í hjartslætti hefði aukist með tímanum í sýndarveruleikanum. Munurinn á hjartslætti og breytileika í hjartsláttartíðni milli hópa gæti endurspeglað meiri tengingu (engagement) og athyglisintöku í HRL nágrenninu heldur en LRL nágrenninu, sem huglægar mælingar sýndu.

*Lykilorð:* restoration, borgarnágrenni, hjarta- og æðakerfisviðbrögð, hjartsláttur, breytileiki í hjartsláttartíðni, blóðþrýstingur, sýndarveruleiki

## **The Effects of Virtual Urban Neighborhoods on Cardiovascular Reactivity**

People face various demands in their everyday life and can, as a result of trying to meet these demands, experience diminished physical and psychological resources (Hartig, 2004). Researchers have been interested in how the environment can trigger restoration, enabling individuals to renew diminished resources (Ulrich et al., 1991). Restoration is important for general health and wellbeing (Collado et al., 2016), and restorative environments have been shown to improve the ability to direct attention (e.g., Berto, 2005) and increase positive affective states (e.g., Hartig et al., 1999; van den Berg et al., 2003). Previous studies have revealed that environments that are perceived as natural are more likely to be restorative than those perceived to be urban or artificial (e.g., Berto, 2014; Hartig et al., 2003; Herzog et al., 2003; Weber & Trojan, 2018). Studies have consistently found natural environments such as forests and watersides to have high possibilities for restoration and have suggested visiting such places as a way to elicit restoration and promote health and wellbeing (e.g., Gladwell et al., 2016; Hartig et al., 1991; Lee & Maheswaran, 2011; McMahan & Estes, 2015; Park et al., 2007; Ulrich et al., 1991). More recently, researchers have started focusing on restorative potentials in urban environments and the properties and characteristics that are likely to enhance them, such as architectural variation, building height, number of street trees, and the presence of flowers and grass (Lindal & Hartig, 2013, 2015). This new focus on restoration in urban environments is crucial, considering that most of the world's population lives in urban environments.

One approach studies have used when examining restorativeness is measuring cardiovascular reactivity, such as heart rate (HR), heart rate variability (HRV), and blood pressure (BP) (e.g., Hartig et al., 1991; Janeczko et al., 2020; Nukarinen et al., 2020; Valtchanov & Ellard, 2010; Yu et al., 2018). Studies that have reported differences in cardiovascular reactivity when comparing environments with different restorative potentials have found evidence that suggests more restorative environments stimulate the

parasympathetic nervous system, as indicated by lower HR ( Lee et al., 2009; Park et al., 2007; Ulrich et al., 1991), lower BP (Hartig et al., 2003; Janeczko et al., 2020; Lee et al., 2009; Ulrich et al., 1991) and higher HRV (Gladwell et al., 2016; Park et al., 2007; Roe et al., 2019). One of these studies was conducted by Ulrich et al. (1991), in which 120 participants watched a stressful movie and then watched one of six 10-minute videos of either natural or urban settings. During the experiment, affective states and various physiological responses were measured. Results showed that watching natural (more restorative) videos compared to urban (less restorative) videos resulted in more positive affective states and reduced physiological arousal (decreased HR, decreased muscle tension, and decreased BP). Since this study was published, similar results have been reported in studies that exposed participants to environments by using videos (Laumann et al., 2003), virtual reality (VR) (Kim & Lee, 2018), and real environments (Gladwell et al., 2016; Hartig et al., 2003; Janeczko et al., 2020; Lee et al., 2009; Park et al., 2007), showing decreased cardiovascular reactivity to environments higher compared to those lower in restorative potential.

Despite these findings, many other studies have not found evidence for these differences in cardiovascular reactivity between environments high in restorative potentials and those low in restorative potential (e.g., Anderson et al., 2017; Parsons et al., 1998; Valtchanov & Ellard, 2010; Yu et al., 2018). For example, in a study by Yu et al. (2018), no differences were found in HR, HRV, or BP when exposure to environments with different restorative potentials was compared. A recent field study by Scott et al. (2020) even found contradictory results, which demonstrated a significant increase in participants' HR and decrease in their HRV during exposure to an environment high in restorative potential (nature trip) compared to before and after the exposure. Because increased arousal has been linked to more attentional intake (Berntson & Boysen, 1987), the authors speculated that the restorative environment contained many stimuli that captured participants' involuntary attention, which thereby increased their arousal (Scott et al., 2020). The increased HR and

decreased HRV reported in the study by Scott et al. (2020) could also be a result of increased engagement in the restorative environment, as previous studies have linked increased mental engagement to increased HR and decreased HRV (e.g., Cranford et al., 2014; Mehler et al., 2012). Lessiter et al. (2001) considered engagement to reflect individuals' interest in the content of an environment and their attention to the environment. Therefore, engagement is also related to the concept of fascination, which refers to the ability of environments to capture individuals' involuntary attention through interesting stimuli (Kaplan & Kaplan, 1989). Kaplan (2001) argued that restorative environments cause a higher sense of fascination and more engagement because they are inherently more interesting and unpredictable. This interest in the content of restorative environments is likely reflected in the strong positive correlation previous studies have found between restorative environments and preference (e.g., Hartig & Staats, 2006; Staats et al., 2003; van den Berg et al., 2003). Because of the increased attentional intake and mental engagement that may be more likely to occur in restorative environments, people may be likely to experience higher HR and lower HRV during exposure to environments high in restorative potential than those low in restorative potential. However, in line with results from previous studies (Hartig et al., 2003; Janeczko et al., 2020; Lee et al., 2009; Ulrich et al., 1991), BP may be likely to be lower during exposure to environments high in restorative potential compared to those low in restorative potential, as research has found BP to be negatively associated with positive affective states (Brondolo et al., 2003), which are more common during exposure to restorative environments (e.g., Hartig et al., 1999; van den Berg et al., 2003).

The lack of consistent findings in previous research demonstrates the need to investigate cardiovascular reactivity to restorative environments further to establish definitive evidence. Another gap in the current knowledge about how environments affect cardiovascular reactivity is related to the focus restoration studies have put on exclusively comparing completely natural (e.g., forests) and urban environments (e.g., city center). This

focus often ignores the variability in urban environments and the possibility that they can also be restorative. Even though most people live in urban environments, the knowledge about how they affect us is scarce. There is a need for studies to compare cardiovascular reactivity to differently designed urban environments since subjective measures from previous studies suggest that specific urban settings can have restorative potential (Hartig et al., 1997; Hidalgo et al., 2005; Weber & Trojan, 2018), and that specific architectural characteristics in urban environments are likely to increase this potential (Lindal & Hartig, 2013, 2015). Increasing the knowledge about how urban environments affect cardiovascular reactivity is essential, considering that most individuals are exposed to urban environments daily and that this exposure could affect their health and wellbeing.

The present study's main purpose is to investigate and compare individuals' cardiovascular reactivity during a VR exposure to an urban neighborhood low in restoration likelihood (LRL) and an urban neighborhood high in restoration likelihood (HRL) by examining HR, HRV, and BP. In order to have an idea of how restorative the VR exposure is for the participants, a measure of fatigue will be employed before participants engage in a Sustained Attention to Response Task or SART (fatigue induction task), after the SART, and then finally after the VR exposure. The experiment will also include subjective measurements about participants' experience in the virtual neighborhoods in order to facilitate interpretation of the cardiovascular reactivity. These include a measure of fascination, a preference measure, and a measure of engagement. Based on previous research, it is hypothesized that compared to participants in the LRL condition, participants in the HRL condition will have a higher preference for the virtual neighborhood, experience a higher sense of fascination, and be more engaged in the environment. It is also hypothesized that after the VR, participants in the HRL condition will experience a greater decrease in fatigue than those in the LRL condition. Finally, it is hypothesized that participants in the HRL condition will demonstrate

higher HR and lower HRV and BP than those in the LRL condition and that this difference between conditions will increase with time in the VR.

## **Method**

### **Participants**

A total of 58 individuals participated in the experiment, 39 females (67.24%) and 19 males (32.76%). Participants' average age was 22.90 ( $SD = 3.57$ ), ranging from 18 to 41. Participants were recruited through introductions in psychology and computer science classes. To be eligible for the study, participants had to be 18 years old and speak Icelandic fluently, as instructions in the experiment were only available in Icelandic. Participants were randomly assigned to either the LRL condition ( $N = 30$ ) or the HRL condition ( $N = 28$ ). The LRL condition consisted of 20 females and ten males, with an average age of 23.53 years ( $SD = 4.35$ ). The HRL condition consisted of 19 females and nine males, with an average age of 22.21 years ( $SD = 2.36$ ). The questionnaires and measurements used in the study have all been used in previous studies without problems and consequences and should not involve any risk. Participants were informed that they could skip answering individual questions in the experiment and were free to stop their participation at any time. Participants were also asked to report if they were experiencing discomfort while in the VR. The data collected from the participants could not be re-identified and was stored in a secure area with limited access. Participants received credit in a café store as reimbursement, unless they were psychology students, in which case they received extra credit for a class they were taking.

### **Stimuli and Measures**

#### ***Subjective measures***

**Fatigue.** The Fatigue Check Items (FCI) have been used in previous restoration studies to measure participants' fatigue (Hartig & Staats, 2006; Staats et al., 2003; Staats & Hartig, 2004). The FCI are divided into an affective factor and a behavioral factor, each consisting of four statements/items. The affective factor measures affective states consistent



with attentional fatigue (e.g., irritation), and the behavioral factor measures behavioral indications of attentional fatigue (e.g., ability to concentrate). Responses to the items are on a seven-point Likert scale, with the scores ranging from 1 (no attentional fatigue) to 7 (extreme attentional fatigue). Hartig and Staat's (2006) study demonstrated that both factors are internally consistent (Cronbach's  $\alpha = 0.80$  for affective FCI, Cronbach's  $\alpha = 0.84$  for behavioral FCI). In the present study, internal consistency was high for both the affective FCI (Cronbach's  $\alpha = 0.78$ ) and the behavioral FCI (Cronbach's  $\alpha = 0.812$ )

**Media Experience.** ITC-Sense of Presence Inventory (ITC-SOPI) is a self-report state questionnaire that measures users' media experiences (Lessiter et al., 2001). The ITC-SOPI consists of 44 questions about how people feel during and after media immersion with responses on a five-point Likert scale (0 = strongly disagree, 4 = strongly agree). Items in the ITC-SOPI are divided into four different factors: spatial presence (19 items), engagement (13 items), ecological validity/naturalness (5 items), and negative effects (6 items). Spatial presence refers to a user's sense of being physically located in the environment presented. Engagement refers to a user's general enjoyment of the media experience and interest in the content of the displayed environment. Ecological validity refers to how believable and realistic/natural a user finds the media content. Negative effects refer to adverse physiological reactions associated with the media form (e.g., headaches or eyestrain). While the engagement factor is likely to be affected by both the media form and the content/environments displayed in the media, the other three factors are predominantly affected by the media form (Lessiter et al., 2001). Lessiter et al. (2001) demonstrated that the ITC-SOPI is a reliable and valid tool to measure media experience, with good internal consistencies on all factors (Cronbach's  $\alpha = 0.77- 0.94$ ). In the present study, internal consistency was high for all factors (Cronbach's  $\alpha = 0.82- 0.91$ ).

**Preference.** In the present study, the question "what did you think of the architecture and the design in the neighborhood you walked through" measured environmental

preference, with responses on a five-point Likert scale (1 = disliked it very much, 5 = liked it very much).

**Fascination.** Fascination refers to how effortlessly aspects of the environment capture attention (Kaplan, 1995). In the present study, five items measured participants' sense of fascination on a five-point Likert scale (1 = not at all, 5 = completely). These fascination items were taken from the Perceived Restorativeness Scale (PRS) (Hartig et al., 1997). The PRS has been found to have a high internal consistency (Cronbach's  $\alpha = 0.94$ ) (Berto, 2007). In the present study, the fascination measure had internal consistency (Cronbach's  $\alpha = 0.90$ ).

### ***Cardiovascular Reactivity***

Participants' cardiovascular reactivity was measured continuously throughout the experiment. To measure HRV, the wireless portable electrocardiograph (ECG) recorder and transmitter, eMotion Faros 360° Sensor, was used. ECG electrode leads attached to the skin acquisition data to ECG, which are then transformed to interpretable HRV results. The eMotion Faros 360° Sensor is a certified medical device that has been used in previous studies to measure HRV (e.g., Drougard et al., 2018; Moshammer et al., 2018). A Caretake device was used to measure HR and BP. The Caretaker is a wrist-worn device with a finger cuff that noninvasively and continuously measures HR, respiration rate, and beat-by-beat SYS, DIA, and mean BP (*Caretaker Medical*, 2016). These measures are derived from the pulse pressure waveform using the scientific method of pulse decomposition analysis.

### ***Fatigue Induction***

The Sustained Attention to Response Task (SART) is a computer-based task that requires participants to respond as quickly as possible by pressing a response button after digits from 0-9 are presented (in random order) on a computer screen, except when the target number "3" appears, in which case the behavioral response should be withheld (Manly & Robertson, 2005). The SART was designed to measure sustained attention but has also been used in previous studies to induce fatigue in participants (Berto, 2005; Berto, 2015; Cassarino

et al., 2019). In this study, the SART was only used to induce fatigue in participants. The 20-minute SART in the present study consisted of 1060 continuous digit presentations, of which 10% were the target digit “3” (appeared 106 times). The digits presented were black on a white background and had a 30 point font size. Each digit appeared for 250 msec, followed by an 1125 msec mask (i.e., a blank screen).

### ***Virtual Reality***

**Virtual Environments.** For this study, two interactive three-dimensional virtual urban neighborhoods were created, one with an LRL environment and the other with an HRL environment. The architectural properties of both environments were guided by the environments used in Lindal (2013). For the LRL neighborhood, streets were lined with 4-to-6 story buildings, all of which had flat roofs and no details on the façades. No street greenery was included in the LRL neighborhood. For the HRL neighborhood, the streets were lined with 1-to-3 story buildings. The buildings had four different kinds of roofs (flat, peaked, peaked with a “simple” dormer, or peaked with a “complex” dormer), which either had no façade decoration, a low level of façade decoration, or a high level of façade decoration. The façade color was either grey, red, green, or blue. Street greenery (trees and bushes) was included in the HRL neighborhood to boost restorative quality further. Open public spaces/playgrounds/gardens were scattered around both neighborhoods. Both neighborhoods also included street lamps, road signs, and a few people but no vehicles. In each neighborhood, the participants teleported on a predetermined path that consisted of 49 points. Within each point, the participants could freely look around and physically move within a square of 3x3 meters for as long as they wanted.

**VR Equipment.** The Blender™ 3D modeling software was used to create three-dimensional virtual models of the buildings. The models were then imported into version 5 of the Unity 3D® game engine to provide interactivity to the virtual environments. The virtual neighborhoods were presented in the HTC Vive® head-mounted display (960×1080 per eye

resolution and 90-degree horizontal field of view) using a desktop computer with an NVIDIA™ 980 GTX graphics card rendering on the “fantastic” settings in the Unity engine.

### **Procedure**

Data collection was carried out at Reykjavik University from September 2019 to January 2020. Before the experiment, participants were told that the interaction between people and the environment was being examined. Participants were informed that participation in the experiment would take about one hour and 15 minutes and included answering questionnaires, solving tasks, and immersing in VR. After signing a consent form, participants completed a quick tutorial in the VR for approximately two minutes. In the tutorial, participants were instructed on how to travel around in the VR environment and use the remote to “jump” to different locations within the environment. After the tutorial, an eMotion Faros and a Caretaker device were placed on participants, after which they were asked to relax for 3 minutes for a baseline measure. Participants then sat in front of a computer, where they answered background questions, the FCI, and then solved the 20-minute SART. After the SART, participants again answered the FCI. Participants were then immersed in either the LRL or the HRL virtual environment for about 10 minutes. After the VR period, participants sat again in front of the computer and answered the FCI for the third time, as well as the ITC-SOPI questionnaire, the fascination items, and the preference question.

### **Research Design and Data analysis**

All data analyses were conducted in the Statistical Package for the Social Sciences (SPSS). Cardiovascular data for the baseline period were averaged into three one-minute intervals, but only the data from the second minute were used in the analyses. Participants' cardiovascular reactivity during the SART period was averaged into ten time point values, which each represented a two-minute interval. Participants' cardiovascular reactivity during

the VR period was averaged into seven time point values, which each represented a little over a one-minute long interval.

Independent sample *t*-tests, which compared average HR, HRV, SYS BP, and DIA BP during the resting baseline period between participants in the LRL and HRL condition, were conducted to check whether participants cardiovascular reactivity differed between conditions before the experiment.

A 2 (condition) x 11 (time points) mixed-design ANCOVA was conducted for each cardiovascular variable (HR, HRV, SYS, and DIA BP) to examine participants' cardiovascular reactivity during the SART period and whether the fatigue induction worked. Each analysis included cardiovascular data from 11 time points, one for the resting baseline period to control for baseline activity and then ten to cover the duration of the SART period. Each analysis also controlled for familiarity and gender.

The data for each cardiovascular variable during the VR period were analyzed in a 2 (condition) x 8 (time points) mixed-design ANCOVA in order to examine the hypothesis that participants in the HRL condition would demonstrate higher HR and lower HRV and BP during the VR period and whether this difference between conditions would increase with time in the VR. Each analysis included cardiovascular data from eight time points, one for the last time point in the SART period to control for the activity before the VR, and the other seven to cover the duration of the VR period. Each analysis also controlled for familiarity and gender.

In order to check whether the SART successfully increased participants' fatigue and to examine the hypothesis that after the VR period, participants in the HRL condition would experience a greater fatigue reduction than participants in LRL condition, two separate 2 (condition) x 3 (time of measurement) mixed-design ANCOVA analyses (one for affective FCI and one for behavioral FCI) were conducted. Both analyses included the three different

FCI time measurements (before SART, after SART, and after VR). Both analyses controlled for familiarity and gender.

Independent samples *t*-tests comparing the means between conditions for the fascination measure, preference measure, and the engagement factor of the ITC-SOPI, were conducted in order to examine hypotheses that compared to those in the LRL condition, participants in the HRL condition would have a higher preference for the virtual neighborhood, experience a higher sense of fascination, and be more engaged in the environment.

Of the 58 participants who completed the experiment, one participant (1.72%) was excluded from the analysis because of an error in his data. There was also some data missing for the variables in the experiment ( $N = 52 - 58$ ). Greenhouse-Geisser and Huynh-Feldt corrections were used when the assumption of sphericity was not met. The *p* values related to the study's directional hypotheses were divided by two.

## Results

### Results from the Cardiovascular Measures

Table 1 shows the averaged time point values within the three different time periods (baseline, SART, and VR) for the four cardiovascular variables.

**Table 1**

*Averaged Cardiovascular Reactivity during the Experiment's Time Periods by Condition*

	LRL			HRL			Total		
	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>
<b>HR</b>									
Baseline	77.19	10.46	27	78.78	11.63	27	77.98	11.0	54
20-min SART	80.10	10.45	27	80.01	9.44	25	80.06	9.88	52
VR	86.39	8.61	27	90.06	7.94	25	88.16	8.42	52
<b>HRV</b>									
Baseline	785.81	125.15	26	733.85	176.69	26	759.83	153.85	52
20-min SART	771.97	130.26	26	773.98	90.91	26	772.97	111.22	52
VR	740.85	118.27	26	722.10	98.14	26	731.48	108.02	52
<b>SYS BP</b>									
Baseline	126.48	14.01	27	127.78	15.02	27	127.13	14.40	54

20-min SART	126.66	13.66	27	130.06	15.65	25	128.30	14.61	52
VR	121.21	15.04	27	123.06	17.27	25	122.10	16.02	52
<b>DIA BP</b>									
Baseline	77.78	10.95	27	77.63	14.00	27	77.70	12.45	54
20-min SART	77.86	10.73	27	79.15	14.17	25	78.48	12.39	52
VR	75.19	12.00	27	75.68	14.74	25	75.43	13.25	52

Note. *M* = mean; *SD* = standard deviation.

### ***Baseline***

An independent sample *t*-test revealed no significant differences between conditions for any of the cardiovascular variables during the baseline period, suggesting that participants in the HRL and LRL condition did not differ in their cardiovascular activity at baseline.

### ***Effects of the SART on Cardiovascular Reactivity***

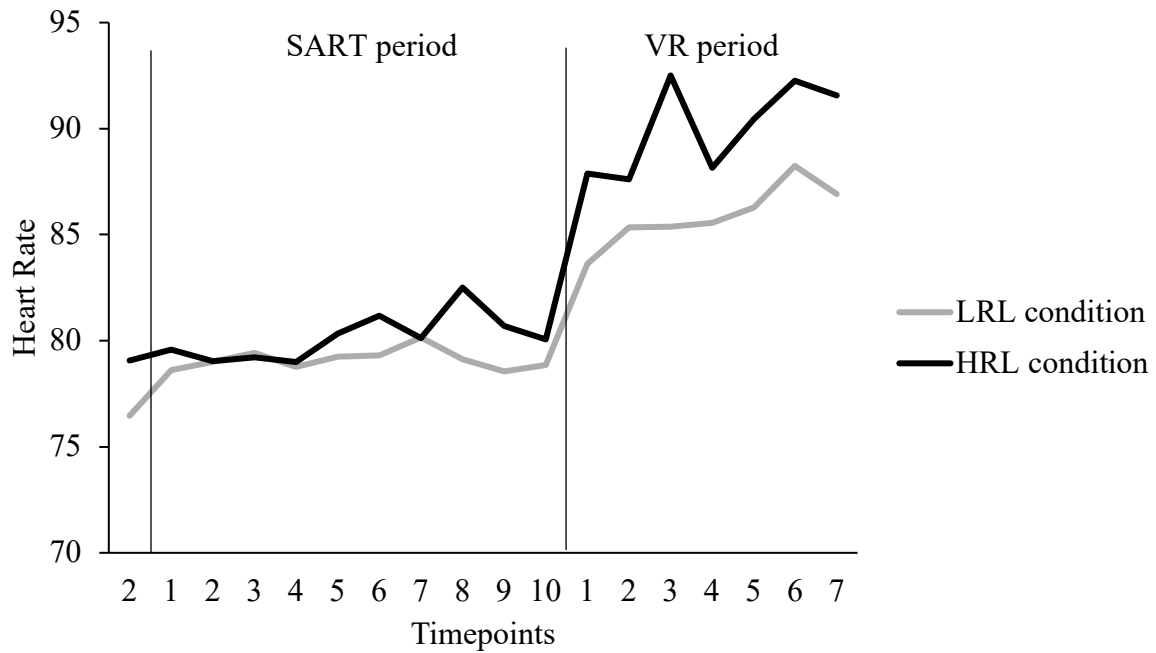
Results from the 2 x 11 mixed-design ANCOVA showed a significant main effect of time for HR  $F(4.76, 223.58) = 2.47, p = 0.036$ , partial  $\eta^2 = 0.05$ . The means presented in Table 1 show that participants' average HR was higher during the SART than it was during the baseline period, indicating that performing the SART increased participants' HR and, therefore, that the fatigue induction was successful. Results also showed that average SYS BP differed between the two conditions during the SART, as there was a significant main effect of condition for SYS BP  $F(1.00, 47.00) = 4.18, p = 0.047$ , partial  $\eta^2 = 0.08$ . As can be seen in Table 1, SYS BP was higher for participants in the HRL condition than for those in the LRL condition. No other main effects or interactions were significant.

### ***Effects of the VR Environments on Cardiovascular Reactivity***

Results from the 2 x 8 mixed-design ANCOVA revealed significant main effects of time for HR  $F(4.83, 226.87) = 4.89, p < 0.001$ , partial  $\eta^2 = 0.09$ , HRV  $F(4.20, 197.20) = 4.20, p = 0.002$ , partial  $\eta^2 = 0.08$ , SYS BP  $F(5.08, 238.71) = 2.36, p = 0.040$ , partial  $\eta^2 = 0.05$ , and DIA BP  $F(5.13, 241.19) = 2.28, p = 0.046$ , partial  $\eta^2 = 0.05$ . Bonferroni *post hoc* tests showed that participants' HR was significantly higher on all time points in the VR than it was on the last time point before the VR. Figure 1 shows that participants' average HR increased

**Figure 1**

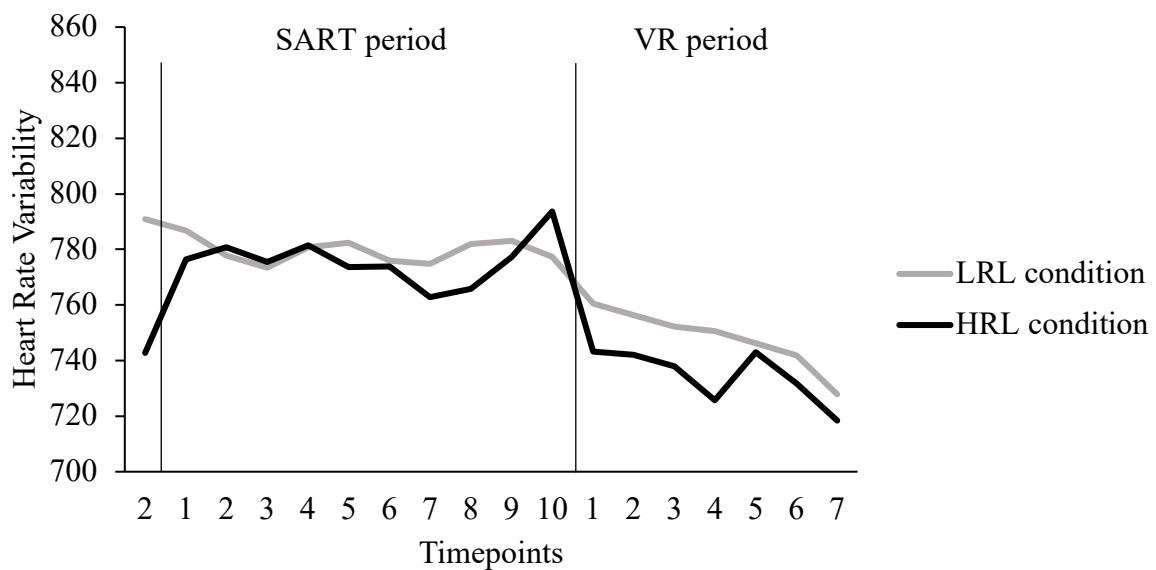
*Participants' Average HR During the Experiment by Condition*



throughout the time points in the VR period. Bonferroni *post hoc* tests also showed that participants' HRV was significantly lower on all time points in the VR than it was on the last time point before the VR. Figure 2 shows that participants average HRV decreased slightly throughout the timepoints in the VR period. Finally, Bonferroni *post hoc* tests showed that

**Figure 2**

*Participants' Average HRV During the Experiment by Condition*

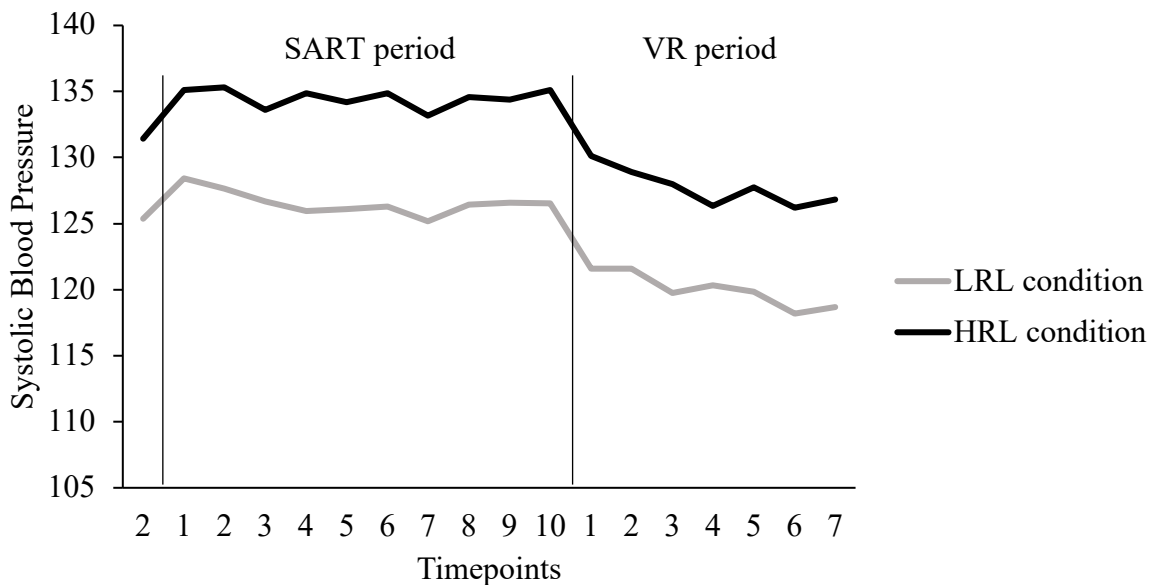




participants' SYS and DIA BP was significantly lower on all time points in the VR period than it was on the last time point before the VR. Figure 3 and Figure 4 show that participants' BP decreased slightly throughout the time points in the VR period.

**Figure 3**

*Participants' Average SYS BP During the Experiment by Condition*



**Figure 4**

*Participants' Average DIA BP During the Experiment by Condition*

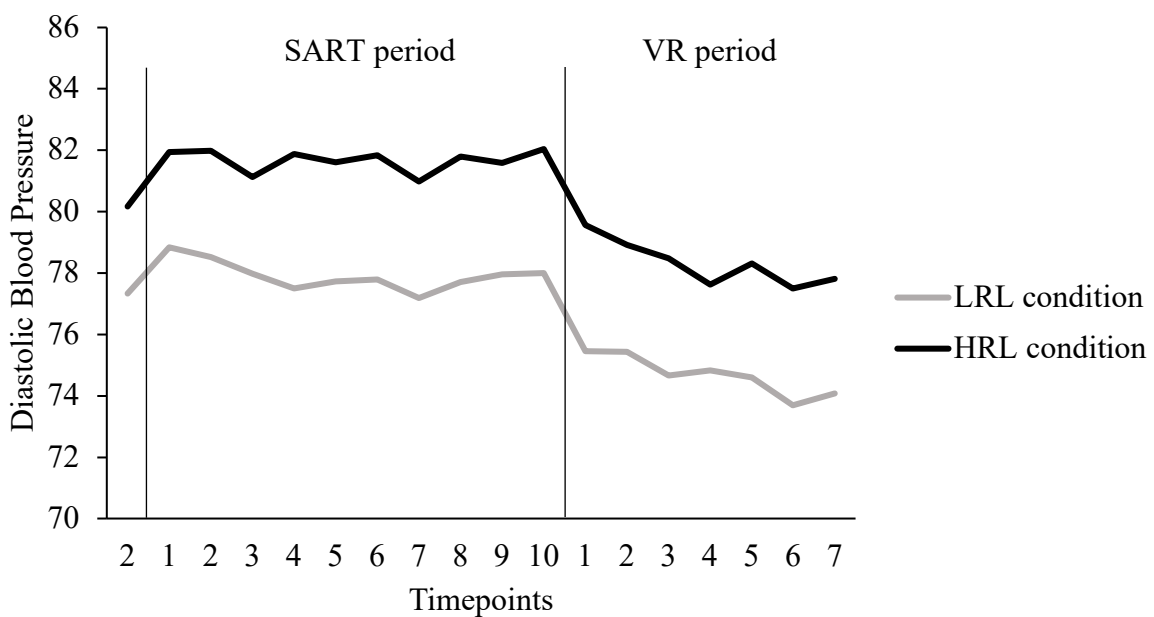


Figure 1 and Figure 2 show differences between conditions in participants' HR and HRV during the VR period, that were not present before the VR exposure. Although these

figures show that participants in the HRL condition had higher HR and lower HRV than those in the LRL condition during the VR period, the results did not reveal a significant main effect of condition for HR  $F(1.00, 47.00) = 2.16, p = 0.074, \text{partial } \eta^2 = 0.04$ , nor HRV  $F(1.00, 47.00) = 0.08, p = 0.388, \text{partial } \eta^2 < 0.01$ . Results showed a significant interaction between time and condition for HRV  $F(4.20, 197.20) = 1.98, p = 0.048, \text{partial } \eta^2 = 0.04$ , but not for HR  $F(4.83, 266.87) = 0.87, p = 0.251, \text{partial } \eta^2 = 0.02$ . Figure 2 shows that HRV seems to decrease more with time in the VR period for those in the HRL condition than for those in the LRL condition. Although the interaction between time and condition for HR was not significant, Figure 1 shows a trend which suggests HR increased more with time in the VR period for those in the HRL condition than those in the LRL condition. Results did not reveal significant interactions between time and condition for SYS BP  $F(5.08, 238.71) = 0.253, p = 0.470, \text{partial } \eta^2 = 0.01$ , nor DIA BP  $F(5.13, 241,19) = 0.25, p = 0.472, \text{partial } \eta^2 = 0.01$ . Results showed there was significant main effect of condition for SYS BP  $F(1.00, 47.00) = 0.034, p = 0.034, \text{partial } \eta^2 = 0.07$  but not DIA BP  $F(1.00, 47.00) = 0.91, p = 0.172, \text{partial } \eta^2 = 0.02$ . However, this difference between conditions in SYS BP was also present before the VR period. These results suggest the VR exposure had similar effects on BP, regardless of condition.

## **Results from the Subjective Measures**

### ***Fatigue measure***

Results from the 2 x 3 mixed-design ANCOVA showed there was a significant main effect of the time of measurement for participants' affective FCI scores  $F(1.85, 96.38) = 5.81, p = 0.005, \text{partial } \eta^2 = 0.10$ , and behavioral FCI scores  $F(1.72, 89.51) = 12.29, p < 0.001, \text{partial } \eta^2 = 0.19$ . Participant's average scores on both FCI factors were lowest before the SART. Bonferroni *post hoc* tests showed that after the SART, participants' affective and behavioral FCI scores both increased significantly ( $p < 0.001$ ). Bonferroni *post hoc* tests also showed that after the VR exposure, there was a significant decrease in participants' affective

FCI scores ( $p = 0.007$ ) but not behavioral FCI scores ( $p = 0.727$ ). There was not a significant interaction between time of measurement and condition for affective FCI scores  $F(1.85, 96.38) = 0.691$ ,  $p = 0.493$ , partial  $\eta^2 = 0.01$ , nor behavioral FCI scores  $F(1.72, 89.51) = 1.67$ ,  $p = 0.198$ , partial  $\eta^2 = 0.03$ , indicating that participants experienced similar fatigue reduction after the VR exposure, regardless of condition. Table 2 shows how participants' average scores on the FCI changed throughout the experiment.

**Table 2**

*Average Scores on the Affective and Behavioral FCI Between Conditions*

FCI	Condition	Before SART			After SART			After VR		
		<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>
Affective	LRL	2.37	1.13	29	3.48	1.48	29	3.12	1.50	29
	HRL	2.63	1.26	28	3.46	1.52	28	3.04	1.55	28
	Total	2.50	1.19	57	3.47	1.49	57	3.08	1.51	57
Behavioral	LRL	4.96	1.15	29	3.94	1.33	29	4.18	1.43	29
	HRL	4.83	1.11	28	3.40	1.24	28	3.45	1.28	28
	Total	4.89	1.12	57	3.68	1.31	57	3.82	1.40	57

*Note.* *M* = mean; *SD* = standard deviation.

### **Media experience**

Results from the independent samples *t*-tests showed that participants' average scores on the spatial presence, ecological validity and negative effects factors of the ITC-SOPI, were not significantly different between conditions. Results indicate that participants' spatial presence in the VR environments ( $M = 2.16$ ,  $SD = 0.68$ ), and the ecological validity of the VR environments ( $M = 2.30$ ,  $SD = 0.72$ ), were medium, but negative effects experienced in the VR were low ( $M = 1.05$ ,  $SD = 0.78$ ) (potential scores from 0 to 4). Results also revealed that engagement in the VR environments was significantly higher for participants in the HRL condition ( $M = 2.50$ ,  $SD = 0.69$ ) than those in LRL condition ( $M = 2.10$ ,  $SD = 0.71$ )  $t(55) = -2.14$ ,  $p = 0.018$ ,  $d = 0.06$ .

### **Preference**

Results from the independent samples *t*-test showed that the average preference score was significantly higher for participants in the HRL condition ( $M = 3.71, SD = 0.85$ ) than for those in the LRL condition ( $M = 2.76, SD = 0.99$ )  $t(55) = -2.07, p < 0.001, d = 0.10$ .

### ***Fascination***

Results from independent samples *t*-tests showed that on average, sense of fascination in the virtual neighborhoods was significantly higher for participants in the HRL condition ( $M = 2.84, SD = 0.86$ ) than for those in the LRL condition ( $M = 2.41, SD = 0.85$ )  $t(55) = -1.93, p = 0.030, d = 0.05$ .

## **Discussion**

The SART successfully induced participants' fatigue, as revealed by a significant increase in their average affective and behavioral FCI scores after the SART and an increased HR during the SART. Participants' fatigue reduction after the VR period was considered to reflect the restoration experienced due to the exposure of the virtual neighborhoods. As the two types of virtual neighborhoods were of different restorative likelihoods, it was hypothesized that participants in the HRL condition would experience a greater fatigue reduction after the VR period than those in the LRL condition. The study's results showed that participants' scores on the affective, but not behavioral FCI reduced significantly after the VR period. These results suggest that at least some restoration took place, although the restoration may also have been caused exclusively by the time passed from the fatigue induction. Contrary to the study's hypothesis, participants' fatigue reduction did not differ between conditions, suggesting that the restorative effects of the two neighborhoods (if any) were similar.

Previous studies have reported a reduction in BP due to exposure to restorative environments (e.g., Hartig et al., 2003; Janeczko et al., 2020) and found BP to be associated with positive affective states (Brondolo et al., 2003), which research has shown to be more common in more restorative environments (e.g., Hartig et al., 1999; van den Berg et al.,

2003). Therefore, it was hypothesized that during the VR exposure, participants in the HRL condition would have lower BP than those in the LRL condition and that this difference would increase with time spent in the VR. The study's BP results suggest, just like the fatigue results, that at least some restoration took place during the VR exposure for participants in both conditions, as there was a significant reduction in participants' SYS and DIA BP. Contrary to the study's hypothesis, the results did not find evidence indicating that exposure to the HRL neighborhood and LRL neighborhood had different effects on BP. If a reduction in BP is indeed an indication of restoration, these results suggest, just like the results from the fatigue reduction, that both types of neighborhoods were restorative and to a similar degree (if the fatigue reduction was not simply caused by the time passed). The lack of significant differences in BP between participants in the LRL and HRL conditions may be due to insufficient differences between the two urban neighborhoods. Indeed, previously mentioned studies that reported significantly lower BP in more restorative environments compared environments that differed more from each other (e.g., forest vs. city) than the environments used in this study did.

The present study's hypotheses for HR and HRV were based on results from a study by Scott's et al. (2020), which showed that a restorative environment significantly increased participants' HR and decreased HRV, and studies that have associated mental engagement with increased HR and decreased HRV (Cranford et al., 2014; Mehler et al., 2012). In the present study, it was hypothesized that participants in the HRL condition would experience higher HR and lower HRV during the VR exposure than participants in the LRL condition and that this difference would increase with time spent in the VR. The study's findings partially supported this hypothesis. Results showed that, on average, participants in the HRL condition had higher HR and lower HRV than participants in the LRL condition, but contrary to the study's hypothesis, this difference was not significant. In accordance with the study's hypothesis, there was a significant interaction for HRV, which indicated that participants'

HRV decreased more with time spent in the VR for participants in the HRL condition than for those in the LRL condition. Findings also revealed a trend for HR in line with the study's hypothesis, suggesting HR increased more with time spent in the VR for those in the HRL condition than those in the LRL condition, however, this interaction was not significant. Taken together, these results provide at least some support for the notion that exposure to HRL neighborhoods causes higher HR and lower HRV than exposure to LRL neighborhoods and that these differences increase with time in the exposure. These differences in the effects of the two virtual neighborhoods on HR and HRV can be interpreted with results from the study's subjective measures. In line with the study's hypothesis, participants in the HRL condition were more engaged in the environment and had a higher sense of fascination and higher preference for the virtual neighborhood than participants in the LRL condition. The higher engagement experienced in the HRL environment might explain the reported differences in HR and HRV between conditions, as previous studies have linked increased mental engagement with increased HR and decreased HRV (Cranford et al., 2014; Mehler et al., 2012). Higher scores for participants in the HRL condition on the measures of engagement and fascination also suggest that participants in the HRL environment experienced higher involuntary attentional intake. Differences in attentional intake in the two neighborhoods could also be used to explain this study's reported differences in HR and HRV as increased arousal has been linked to attentional intake (Berntson & Boysen, 1987). The HRL neighborhood might have caused greater cardiovascular arousal than the LRL neighborhood (i.e., higher HR and lower HRV) because it included more interesting stimuli that captured participants' involuntary attention, such as trees and building variations.

This study set out to examine the effects of exposure to urban neighborhoods on cardiovascular reactivity and whether these effects differed between an HRL neighborhood and an LRL neighborhood. The main findings were that BP decreased during exposure to both neighborhoods and that this decrease was the same for both neighborhoods. HR

increased, and HRV decreased during exposure to both neighborhoods. Trends in results suggest that exposure to the HRL neighborhood may have caused higher HR and lower HRV than exposure to the LRL neighborhood did and that these differences increased with time in the exposure. However, the only statistically significant difference between the effects of the two neighborhoods on cardiovascular reactivity was an interaction for HRV, which indicated that HRV decreased more with time in the exposure for those in the HRL neighborhood than for those in the LRL neighborhood. It is possible that the other trends of differences between the effects of HRL and LRL neighborhoods on HR and HRV would become statistically significant with an increased number of participants, as the present study only included cardiovascular data from about 25 participants in each condition. Other limitations of the study that could have affected the results are participants' perceived spatial presence and the ecological validity of the environmental exposure. Results showed that ecological validity and spatial presence were only medium, suggesting that the effects of the neighborhood exposure on cardiovascular reactivity may have been greater if participants were exposed to these neighborhoods in the real world. In addition, many people have not experienced VR before, and the VR immersion could therefore have affected the cardiovascular reactivity through excitement or interest for the VR itself. Another limitation of the current study is that it did not explore potential long-term effects but instead only focused on cardiovascular reactivity during the 10-minute environmental exposure. Despite its limitations, the present study offers some insight into how exposures to urban neighborhoods affect people's cardiovascular reactivity, which could be useful for further research in this area. Future studies should be conducted on this topic, ideally with bigger samples and environmental exposures with better ecological validity.

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