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To cite this article: Jill McSweeney, Shannon Johnson, Simon Sherry, Jerome Singleton & Daniel Rainham (2019): Indoor nature exposure and influence on physiological stress markers, International Journal of Environmental Health Research, DOI: [10.1080/09603123.2019.1679357](https://doi.org/10.1080/09603123.2019.1679357)

To link to this article: <https://doi.org/10.1080/09603123.2019.1679357>



Published online: 18 Oct 2019.



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ARTICLE



Indoor nature exposure and influence on physiological stress markers

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ABSTRACT

Spending time in nature is beneficial for stress reduction and recovery. Using the properties of biophilic design, this study examined the influence of a nature-based indoor environment on physiological stress systems. An experimental study was designed to assess the influence of indoor natural elements on autonomic activity (heart rate variability or HRV), self-reported environmental assessments. No differences in heart rate variability were found between participants assigned to either condition. The room with natural elements was rated more positively than the room without natural elements. Participant preference had more impact on changes in HRV for participants without exposure to natural elements. The results suggest that natural elements in indoor environments may influence the regulation of stress response via environmental preference.

Abbreviations: ANCOVA: Analysis of Covariance; ANS: Autonomic Nervous System; AVNN: Average of NN; DST: Digit Span Test; EAS: Environmental Assessment Scale; ECG: Electrocardiograph; fMRI: Functional magnetic resonance imaging; HF: High Frequency; HRV: Heart Rate Variability; INE: Indoor Nature Exposure; NR: Nature-Relatedness Scale; PANAS: Positive and Negative Affect Schedule; SAM: Search and Memory Test; SLSI: Student Life Stress Inventory; SMT: Sentence Making Test

ARTICLE HISTORY



Received 21 June 2019
Accepted 8 October 2019

KEYWORDS

Indoor nature exposure; heart rate variability; environmental preference; stress response; biophilic design

Introduction

A growing body of research is focused on the health impacts associated with the dramatic transition of human settlement and habitat, from a largely agrarian existence to one that is dominated by urban living. For example, in Canada, the proportion of rural to urban settlement has reversed from 16% urban to more than 82% urban according to semi-decadal census data (Statistics Canada 2014). Trends in urbanization have led to several empirical investigations of how urban living environments may contribute to rising incidence of stress and stress-related illness (Evans 2003; Galea and Vlahov 2005; Velarde et al. 2007), and which suggest that urban, or built environments, may contribute to increasing levels of stress and associated resultant health impacts. As a respite from the stressors of urban environments, research on the activity of ‘Shinrinryoku’, also known as forest bathing, shows that immersion in natural environments is associated with a reduction in stress as indicated by a reduction in blood pressure, stress-related levels of cortisol, and stabilization of

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Trial registration: ISRCTN17359995.

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respiratory activity (Lee et al. 2009; Park et al. 2010). Although it would be challenging to dispute benefits associated with trends in urbanization, it is also crucial to distinguish the characteristics of urban environments that negatively impact health, particularly those that may be easily remedied through a form of urbanization that maintains a higher proportion of natural landscapes and ecological integrity.

The biophilia hypothesis (Wilson 1984) suggests that humans have an innate affiliation towards nature and natural stimuli. Much of human development, particularly the evolution of human physiology and intellectual capacity, occurred in more natural settings and had significant consequences on lifestyle and procreation behaviours (Park et al. 2008). Aspects of the natural environment increased our ancestors' chance of survival by fostering a sense of safety and rejuvenation; for these reasons, contact and interaction with nature are closely associated with restoration and relaxation (Wilson 1984; Lohr and Pearson-Mims 2000). More recently it has been suggested that a strong connection to, and relatedness with, nature is health-promoting, such that modern living which is largely time spent in urban and indoor environments results in a disconnection from nature, increased levels of stress and risk to maintenance of positive mental health outcomes (Kellert 2012). Our relatedness with nature and natural environments, typically expressed as the degree to which a person sees themselves and the natural world as connected (Mayer and Frantz 2004), has been shown to be associated with several physiological benefits (Ottoosson and Grahn 2005; Kjellgren and Buhrkall 2010). However, much less is known about how individual preference for nature and relatedness to nature are connected to health benefits, particularly exposure to nature in indoor environments. Recent evidence suggests that preference and relatedness to natural environments correspond to the potential to benefit from contact with nature and, ultimately, affect the influence these factors have on health in urban contexts (Bratman et al. 2012). However, much less is known about how exposure to nature in indoor environments is associated with physiological response and health outcomes.

Building on the biophilia hypothesis, Stress Recovery Theory proposes that physiological stress is associated with psycho-evolutionary emotional processes (Ulrich 1983; Ulrich et al. 1991). With a specific focus on attentional mechanisms, several studies have demonstrated relationships between nature exposure and restoration of attention (particularly directed attention) and reductions in stress response (Kaplan and Kaplan 1989; Ulrich et al. 1991; Hartig et al. 2013). For example, when the surrounding environment is perceived as pleasing, the body responds with a restorative response, such as feelings of wellbeing, calmness and a relief from stress. Stress recovery can be facilitated through an increase in positive affect associated with environments we prefer, typically those with more natural features (Ulrich 1983), and is reflected in physiological changes and responses to these preferences (Thayer et al. 2010). Several studies have shown that exposure to natural settings are associated with a reduction in self-rated levels of stress, and a positive change in biomarker activity associated with reductions in physiological stress (De Vries et al. 2003; Evans 2003; Berto 2005; Park et al. 2010; Cole and Hall 2010; Hartig et al. 2013).

Since the quality of environmental surroundings can have a significant impact on the body's stress-related physiology (Laumann et al. 2003), it is important to explore how stress is physiologically manifested. Stress can be simply defined as an individual responding to mental, social, environmental and/or physical demands (Schnell et al. 2013). Although a stress response may result in a variety of physiological and, subsequently, behavioural reactions, it most notably affects the performance of the autonomic nervous system (ANS) consisting of the sympathetic and parasympathetic nervous systems which regulate biological response (Vente et al. 2003; Jönsson 2007; Viamontes and Nemeroff 2009). Depending on the change in the ANS system, a person may feel relaxed, aroused, stressed, or rejuvenated. For example, there is evidence showing that exposure to nature can immediately stabilize respiration and blood pressure in stressed individuals (Ulrich 1983; Chang and Chen 2005; Annerstedt and Währborg 2011). Pulmonary and circulatory responses reveal an

internal environment adapting to external cues, stimuli and responses, and represent instantaneous sympathetic reactions of the ANS. A more well-known example is the increase in respiration and heart rate associated with the adaptive ‘flight-or-flight’ response to external stress cues (Fich et al. 2014). Alternatively, parasympathetic responses of the ANS control relaxation and recovery; when the sympathetic nervous system is suppressed, parasympathetic responses facilitate feelings of calmness and induce a relaxed or less-stressed state. Exposure to natural environments and stimuli activates the parasympathetic system and suppresses the sympathetic system leading to physiological stress reduction and recovery (Gathright et al. 2006; Park et al. 2008, 2010, 2011; Brown et al. 2013).

The restorative influence of contact with natural environments appears, in part, to be associated with stress reduction mechanisms and is gaining increased interest from environment and health researchers (Frumkin 2001), particularly in the context of increasing prevalence of stress and stress-related co-morbidities in urban populations (Maller and Townsend 2006; Dustin et al. 2009; Fich et al. 2014). However, the majority of urban dwellers spend more than 90% of their time indoors (Evans and McCoy 1998; Klepeis et al. 2001; Schweizer et al. 2007), and suggests the importance of attention to how outdoor, nature-based experiences can be recreated in indoor built environments to reduce stress and support restoration of cognitive function (Parsons et al. 1998; Mcsweeney et al. 2015). Biophilic design as applied to indoor environments includes natural elements such as sunlight, plants, landscape photos and paintings, scents and other natural materials (Kellert 2012). Using biophilic design, indoor nature exposure (INE) is a pathway for adapting the built environment to reflect the restorative properties of nature and may be an important tool for health promotion.

Despite a growing body of evidence in support of the benefits of nature contact on human health, scant attention has been paid to the role of indoor nature exposure in reducing stress, improving cognitive performance, or providing benefit to overall health and well-being. The current study addresses this gap, by investigating how a multi-sensory and immersive nature-based indoor environment influences human health via response of physiological stress systems. Using an experimental design this study investigates changes in time and frequency domain indices of heart rate variability (HRV), as a measure of stress response (Hainsworth 1995; Jönsson 2007; Schnell et al. 2013), and measures changes in HRV associated with indoor environments with and without natural elements.

Methods

One hundred and forty-seven participants were recruited, and represent a convenience sample of undergraduate psychology students. Students were ineligible to participate if they had a known cardiovascular illness, an allergic reaction to organic-based scents, consumed caffeine and/or alcohol on the day prior to testing, or engaged in moderate to heavy physical activity (e.g., running, strenuous weight lifting) at least 12 h prior to participation. This study received ethical approval from the Social Sciences and Humanities Research Board at Dalhousie University (2014–3274).

Procedure and measures

Participants were randomly assigned to either an experimental or control condition on recruitment. The experimental condition provided indoor nature exposure guided by the principles of biophilic design (Kellert 2012). This condition included a desk and chair facing a window providing natural light and a view of a mixed urban landscape (e.g., campus buildings, trees, and partial view of the ocean), green-leafed plants, several pictures/paintings of a local, familiar landscapes, nature sounds, and an oil diffuser containing organic pine oil in a room approximately 125 square feet in area (11.6 m²) in a typical office environment (Figure 1). The control condition included the same desk and chair, but the window was covered, and all other natural elements were removed.



Figure 1. Experimental condition elements including window of ocean cityscape with natural lighting and mixed urban landscape, plants, paintings and natural pine scent oil diffuser (not shown).

Exposure to either condition commenced on entering the room. Participants were seated at a desk and connected via three electrocardiograph leads to a PowerLab 16/30 recording unit (AD Instruments 2009) to capture cardiac electrical activity sampled at 100 kHz. Immediate ANS reactions (e.g., physiological stress responses) can be observed through HRV (Hainsworth 1995; Jönsson 2007), as a non-invasive measure of parasympathetic and sympathetic nervous system function, and is a common approach employed to investigate changes to physiological stress (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996; Dekker et al. 2000). PowerLab software was employed to correct data artifacts and ectopic beats, as well as average R-R interval data (milliseconds, msec) were calculated for task intervals. R-R is the time interval measured from the peak of the QRS complex (the section of the ECG that corresponds with the depolarization of the heart), to the peak of the next complex, and represents the ventricular HR (Berntson et al. 1997). Intervals between sinus beats (NN) were calculated as a representation of HR, where msec has an inverse relationship to beats per minute (bpm). Using the maximum entropy method (Ohtomo et al. 1994; Kobayashi et al. 1999), two components of the frequency domain of HRV were calculated: the low-frequency (LF, 0.15–0.4 Hz) and high-frequency (HF, 0.04–0.15 Hz; ESC/NASPE, 1996). HF power of HRV reflects parasympathetic nervous activity, a physiological response associated with calmness and

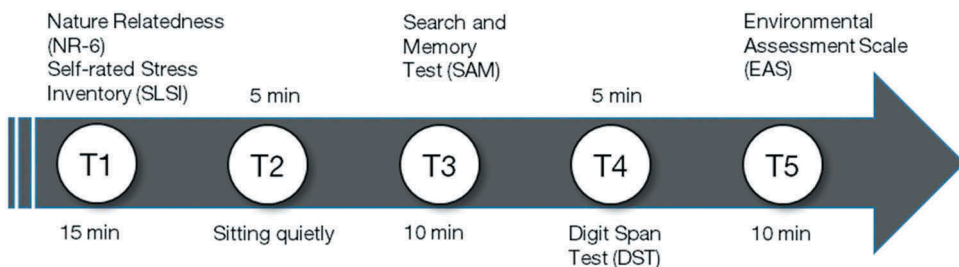


Figure 2. Data collection time periods. Heart rate variability calculated as the average ECG signals collected during each period.

restoration (Cacioppo et al. 1994). Sympathetic dominance can be calculated as the ratio of LF/HF, with higher values associated with the fight or flight response.

As shown in [Figure 2](#), changes in heart rate variability were calculated for five time periods (T1-T5) over 50 min. In the first time period which was 15 min in duration, participants completed several questionnaires, including the connected to nature scale (NR-6), the self-rated stress inventory (SLSI), and a questionnaire to collect demographic data. The Nature Relatedness Scale (NR-6) is a six-item likert-scale that measures how an individual views their relationship with the natural world (Nisbet and Zelenski 2013). The scales ranges from 1 (*disagree strongly*) to 5 (*agree strongly*). Sample items include 'My ideal vacation spot would be a remote, wilderness area', and 'My relationship to nature is an important part of who I am'. The NR-6 was examined as a potential covariate influence on the relationship between environment and HRV. The Student-Life Stress Inventory (SLSI) measures academic stressors and reactions to stress (Gadzella et al. 1991; Gadzella 2004). The SLSI is comprised of 51-items that are rated on a 5-point likert scale ranging from 1 (*never*) to 5 (*most of the time*). The scale is broken down into two sections and nine sub-scales including pressures, self-imposed stress, and physiological and emotional reactions to stressors. Studies on the reliability and validity of the instrument (Gadzella 2004) have found it to be an acceptable measure of stress in both university/college-aged males and females. The SLSI was used as a potential covariate to account for the influence of a participant's school-related stress on HRV.

In the second time period (T2) participants sat quietly for a duration of 5 min. No tasks were allocated for this period of time and, as such, participants were able to acclimatize and observe or 'take in' the condition. During the third and fourth time periods (T3 and T4) participants completed a series of filler tasks. During the third time period (T3, 10 min) participants completed the Search and Memory test (SAM) (Smith and Miles 1987). The SAM is a measure of attention performance (e.g., speed and accuracy of completion), and constitutes a collection of puzzles that asks participants to memorize target letters, and search for them within rows of randomized letters. In the fourth time period (T4, 5 min) participants completed the Digit Span Test, a standardized measure of attention. A member of the research team read off a sequence of random digits at a pace of one number per second, and participants were required to recall the numbers back in order. The test began at two numbers and finished at nine. Completion of the test was either at the end of the sequence of nine numbers, or when participants incorrectly recalled a set of two sequences consecutively. The final score represents the mean proportion of correct numbers. In the final time period (T5, 10 min) participants completed the Environment Assessment Scale (EAS) (Rohles and Milliken, 1981), a scale to assess participant's perception of their environment. The EAS is a 9-point scale (1 = *most desirable*, 9 = *least desirable*) that consists of 13 adjective pairs to describe feelings about an individual's surroundings. The scale has been used and validated to evaluate the affective characteristics of the environment and the attributes and characteristics within it (Laviana et al. 1983; Laviana 1986). The EAS was employed to understand participant's perception of the study condition (natural vs. non-natural elements) in relation to changes in HRV.

Analysis

After assessing for normality, averages of HRV measures across each time period were compared using paired student's *t*-tests. Repeated measures analyses of covariance (ANCOVA) were used for analyses of physiological measures (e.g., average NN intervals (further referred to as AVNN), HF and LF/HF), with time as the within-subject repeated factor, experimental condition as the between-subject factor and demographic covariates (investigated through bivariate correlations, $p < 0.05$). Significant effects were reported with Huynh-Feldt adjustments (ϵ) to correct for violation of the assumption of sphericity, together with unadjusted degrees of freedom, adjusted *p*-values, and Eta^2 . Spearman's rank correlations

between the change in HRV between periods T1 to T5 and environmental preference were examined if perceptions of the environment influenced physiological stress.

Results

Demographics

One hundred and forty-seven individuals (118 females, 29 males) aging from 18 to 50 years ($M = 21.4$, $SD = 4.2$) participated in the study. Participants were in their first to sixth program year ($M = 2.1$, $SD = 1.2$); and 53.1% ($n = 78$) reported not being employed, while 35.4% ($n = 52$) reported working part-time. The average nature relatedness (NR) scores were 3.2 ($SD = 0.8$, $\alpha = 0.82$), with no difference in NR between experimental ($M = 3.2$, $SD = 0.9$) and control ($M = 3.3$, $SD = 0.9$) condition groups ($F_{(1,145)} = 0.45$, $p = 0.50$, $\eta^2_p = 0.003$). Overall, participants had an SLSI score of 140.5 ($SD = 22.97$, $\alpha = 0.77$). SLSI scores did not differ between the experimental ($M = 140.74$, $SD = 23.74$) and control ($M = 140.26$, $SD = 22.33$) group ($F_{(1,140)} = .02$, $p = .90$, $\eta^2_p = .00$), indicating that participants in both groups were experiencing similar levels of academic stress at the time of the study. Bivariate correlations between individual demographics, NR, and HR, HF and LF/HF for each time point indicated significant relationships between SLSI scores at $p < 0.05$ for HR, and sex and age at $p < 0.01$ for HF, and were therefore included in all subsequent analyses as potential covariates. NR was not significantly correlated with any HRV markers at any time points, and was not included in additional analyses.

Physiological stress

The groups did not significantly differ ($p > 0.05$) at T1 (baseline) on any of the HRV indices, suggesting that any subsequent changes were likely due to experimental conditions. Repeated measures ANCOVA (Table 1) revealed a main effect of condition for AVNN, indicating differences over time irrespective of condition ($F_{(4,296)} = 3.2$, $p < 0.05$). No other main effects or interactions were present between groups.

Further inspection of AVNN differences within conditions (Table 2) revealed significant differences over time for the experimental condition, but not the control. Figure 3 shows significant differences between time periods T1 – T3 ($p < 0.01$), T1 – T5 ($p < 0.001$), T2 – T5 ($p < 0.05$), and differences approaching significance for T1 – T2 ($p = 0.086$) and T4 – T5 ($p = 0.056$). While both groups follow a similar reduction in HR between T1 – T3 (i.e., an increase during the filler task (T4) and then a decrease after the filler tasks), these changes are significantly greater for the experimental group, suggesting that INE provided some recovery immediately after a stress-inducing cognitive task (i.e., T4 increase in AVNN), as well as over time (i.e., significant increase between T1 and T5).

Figure 4 shows that HF power in the control was higher than that of the INE group, and suggests that, while not significantly different, participants in the control condition experienced a change in parasympathetic nervous system dominance, possibly associated with stress-inducing tasks, unlike the experimental condition.

Table 1. Results of the two-way repeated measures ANCOVA of heart rate variability (HRV).

	Main Effect				Interaction	
	Condition		Time		Condition x Time	
	<i>F</i>	<i>Eta</i> ²	<i>F</i>	<i>Eta</i> ²	<i>F</i>	<i>Eta</i> ²
HRV						
AVNN	0.113	0.001	3.18*	0.03	1.76	0.02
HF	0.52	0.01	0.26	0.003	0.42	0.01
LF/HF	0.72	0.01	0.12	0.001	1.62	0.02

AVNN: Average intervals between sinus beats (NN), a representation of HR.

HF: High-frequency (range of 0.04–0.15 Hz) reflects parasympathetic nervous activity.

LF/HF: Ratio of low frequency to high frequencies, a measure of sympathetic dominance.

* $p < 0.05$.

Table 2. Physiological measures within conditions.

HRV		Experimental			Control		
		Mean (SD)	F	Eta ²	Mean (SD)	F	Eta ²
AVNN	T1	529.54 (105.27)	4.84**	0.08	540.75 (131.87)	0.83	0.01
	T2	540.76 (115.53)			542.74 (139.65)		
	T3	548.58 (116.50)			547.13 (134.86)		
	T4	538.87 (107.95)			532.25 (126.04)		
	T5	556.86 (115.92)			543.05 (144.22)		
HF	T1	342.14 (480.95)	0.12	0.00	287.29 (332.53)	1.04	0.03
	T2	349.75 (477.82)			425.68 (636.41)		
	T3	309.20 (424.09)			422.12 (518.08)		
	T4	352.70 (465.47)			495.23 (575.0)		
	T5	356.54 (535.0)			403.89 (732.03)		
LF/HF	T1	3.21 (2.48)	0.50	0.01	2.82 (1.71)	0.83	0.02
	T2	2.75 (1.59)			3.17 (1.94)		
	T3	2.73 (1.34)			2.66 (1.36)		
	T4	2.61 (1.82)			3.17 (3.28)		
	T5	2.59 (1.49)			2.69 (1.54)		

AVNN: Average intervals between sinus beats (NN), a representation of HR.

HF: High-frequency (range of 0.04–0.15 Hz) reflects parasympathetic nervous activity.

LF/HF: Ratio of low frequency to high frequencies, a measure of sympathetic dominance.

** $p < 0.01$.

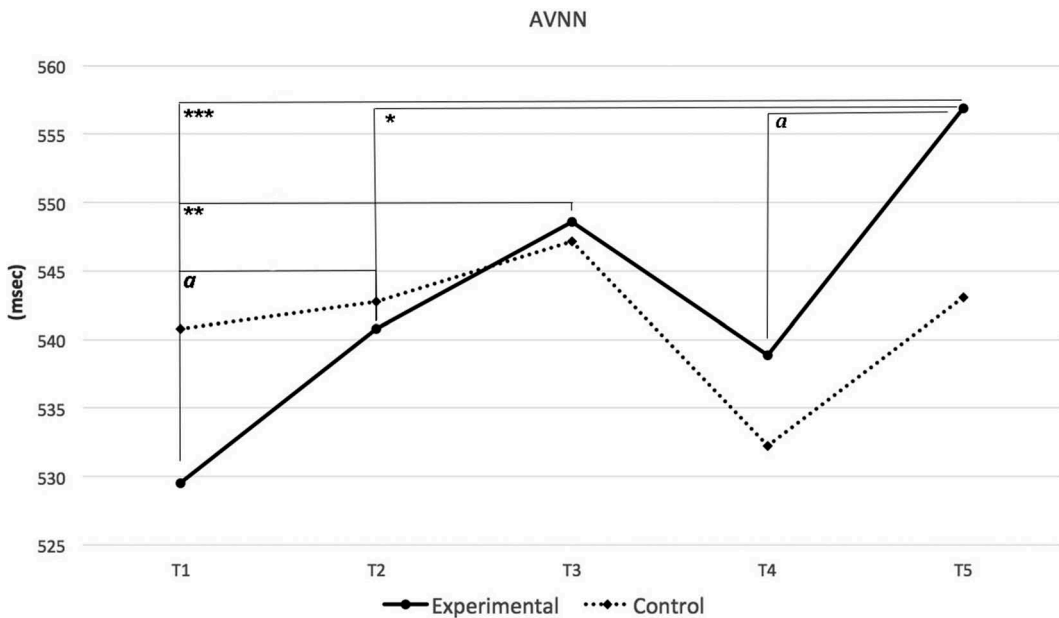


Figure 3. Average change in N-N intervals for all time points between groups.

Figure 5 shows LF/HF ratio values of HRV, which mediate the activity of the sympathetic nervous system. While no significant differences were found between the two experimental groups, LF/HF consistently reduced over time in the experimental condition, and was significantly lower over time period T5 than at baseline (T1), suggesting that over time, INE may be involved in suppressing the sympathetic nervous system, and reduction in physiological stress response.

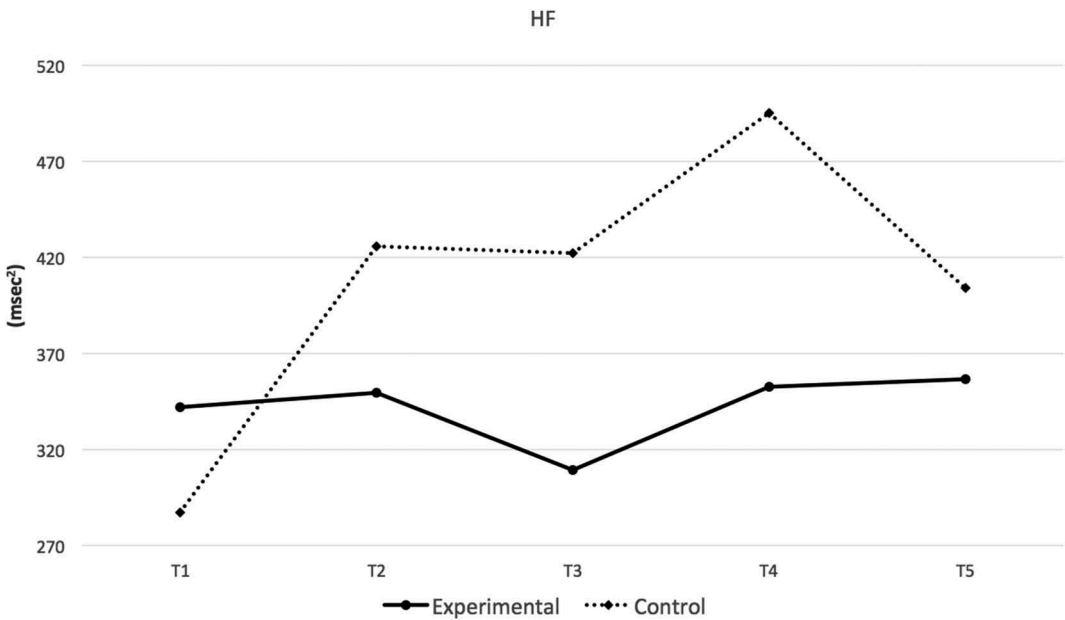


Figure 4. Average change in HF power for all time points between groups.

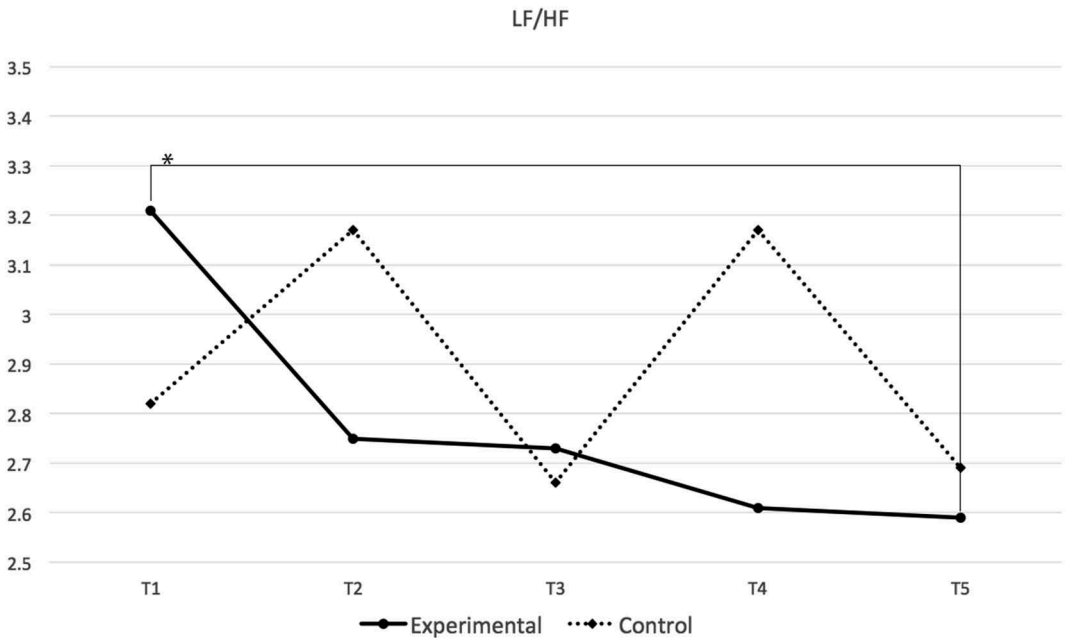


Figure 5. Average change in LF/HF ratio for all time points between groups.

Environmental preference

Excluding ‘quiet – noisy’, participants in the experimental condition rated their surroundings as significantly more desirable on all EAS items (Table 3). Items that had the greatest differences between conditions were ‘colorful – drab’ and ‘attractive – unattractive’. Participants in the experimental group rated their environment as more colorful ($M = 3.87$) compared to control,

Table 3. Means (standard deviations) of EAS items between conditions.

EAS Items	(1–9 scale) [‡]		F	Eta ²
	Experimental	Control		
<i>Satisfying – annoying</i>	2.38 (1.29)	3.65 (1.75)	22.89***	0.15
<i>Clean – dirty</i>	1.34 (0.53)	1.94 (1.11)	15.92***	0.11
<i>Relaxing – stressing</i>	1.97 (1.07)	3.64 (1.89)	39.93***	0.23
<i>Comfortable – uncomfortable</i>	2.01 (1.11)	3.68 (1.92)	37.98***	0.22
<i>Colorful – drab</i>	3.87 (1.43)	6.36 (1.82)	78.68***	0.37
<i>Happy – sad</i>	2.97 (1.41)	4.86 (1.63)	51.80***	0.28
<i>Pleasant smell – unpleasant smell</i>	3.32 (1.61)	4.33 (1.28)	16.05***	0.11
<i>Bright – dull</i>	2.58 (1.64)	3.74 (2.00)	13.51***	0.09
<i>Spacious – crowded</i>	3.34 (4.49)	4.49 (1.72)	15.03***	0.10
<i>Calming – irritating</i>	2.44 (1.32)	4.22 (1.65)	12.78***	0.26
<i>Warm – cool</i>	2.96 (1.59)	4.01 (1.69)	13.58***	0.09
<i>Attractive – unattractive</i>	3.30 (1.52)	5.32 (1.65)	54.65***	0.29
<i>Quiet – noisy</i>	2.21 (1.72)	2.46 (1.82)	0.46	0.00

‡ 1 – Most desirable, 9 – Least desirable.

*** $p < 0.001$.

Table 4. Correlations between T1 and T5 HRV differences by EAS items.

EAS Items	Experimental			Control		
	AVNN	HF	LF/HF	AVNN	HF	LF/HF
<i>Satisfying – annoying</i>	0.09	-0.03	-0.17	0.14	0.07	-0.07
<i>Clean – dirty</i>	0.22	-0.03	-0.17	0.09	0.05	-0.12
<i>Relaxing – stressing</i>	0.16	0.09	-0.14	0.18	-0.03	-0.07
<i>Comfortable – uncomfortable</i>	0.23	0.03	-0.17	0.05	-0.02	-0.06
<i>Colorful – drab</i>	0.08	-0.14	-0.15	-0.02	-0.04	0.15
<i>Happy – sad</i>	0.18	-0.00	-0.09	0.26*	-0.09	-0.08
<i>Pleasant smell – unpleasant smell</i>	0.08	-0.10	-0.13	0.25*	0.05	-0.02
<i>Bright – dull</i>	-0.03	-0.03	0.02	0.48**	-0.21	-0.02
<i>Spacious – crowded</i>	0.11	0.22	-0.15	0.23	0.04	-0.20
<i>Calming – irritating</i>	0.05	-0.04	-0.09	0.30*	-0.05	-0.09
<i>Warm – cool</i>	0.01	-0.08	-0.14	0.13	-0.20	0.12
<i>Attractive – unattractive</i>	0.08	-0.19	-0.09	0.01	-0.24	0.21
<i>Quiet – noisy</i>	0.05	0.05	-0.27*	0.12	*0.03	0.01

AVNN: Average intervals between sinus beats (NN), a representation of HR.

HF: High-frequency (range of 0.04–0.15 Hz) reflects parasympathetic nervous activity.

LF/HF: Ratio of low frequency to high frequencies, a measure of sympathetic dominance.

* $p < 0.05$. ** $p < 0.01$.

which rated their condition as more drab ($M = 6.36$). Similarly, experimental participants rated their condition more attractive ($M = 3.30$) compared to the control ($M = 5.32$).

Overall differences in HRV measures between groups show several significant correlations between environmental preference and physiological stress reduction (Table 4). Within the control group, greater changes in AVNN and HF occurred in individuals who rated the environment as sad, unpleasant smelling, dull, irritating and noisy. While the experimental group had greater suppression of the sympathetic nervous system (i.e., reduction in stress) when they rated the condition as quiet. Overall, participants' environmental assessment of the control condition (which was rated more negatively than the experimental condition) appeared to have more impact on HRV changes than that of the experimental condition.

Discussion

More work on the physiological effects of nature exposure is needed to inform clinical investigations into the benefits of nature for human health (Park et al. 2010, 2011). This study is one of the first to investigate how indoor nature exposure (INE) is associated with physiological

measurements and contributes to the growing body of literature calling for greater evidence to support the preventative and potentially therapeutic benefits of INE. Using the properties of biophilic design, this study sought to understand how a multi-sensory and immersive nature-based indoor environment influenced physiological stress.

Overall, the results reveal no significant differences between control and exposure groups and heart rate variability (HRV). However, within-group analyses suggest that INE suppressed the sympathetic nervous system over time, and provided stress recovery immediately after attention-demanding tasks, as indicated by increases in N-N intervals and a significant reduction in LF/HF ratios. Previous work on nature exposure has found similar suppression of the sympathetic nervous system during exposure to forest environments (Yamaguchi et al. 2006; Lee et al. 2011; Park et al. 2011) and viewing images of forest landscapes (Ulrich 1981; Ulrich et al. 1991; Hartig et al. 2003; Laumann et al. 2003; Park et al. 2008; Brown et al. 2013), and suggests a dominance of parasympathetic activity which is typically observed in conditions that promote relaxation (Lee et al. 2011). This is further supported by significant increases in N-N intervals, which is a major component of physiological stress response and is usually elevated in reaction to stress (Laumann et al. 2003). Therefore, results suggest that INE allowed participants to feel relaxed and less stressed.

According to the Attention Restoration Theory (Kaplan 1995), natural settings may allow for restoration after the depletion of attentional resources, and the results from this study suggest that INE may be a source of stress recovery after attention-demanding tasks. INE was rated as more relaxing, calming, comfortable and happy compared to the control condition, which indicates that INE may have provided a restorative environment that facilitated recovery from mental fatigue and stress. This environmental perception corresponds with other studies that show individuals find natural settings to be more relaxing, calming and comfortable (Shin 2007; Park et al. 2008). Unlike previous studies that have found improved cognitive performance after INE (Cackowski and Nasar 2003; Berman et al. 2008; Raanaas et al. 2011), filler tasks assessing attention and cognitive performance showed no differences between the two exposure groups. The absence of a mentally fatiguing task prior to exposure may have caused INE to act as a buffer during stress recovery (Brown et al. 2013). Future work should consider the timing of tasks in relation to exposure, and whether or not cognitive performance is altered.

Environmental preference evaluations show that those in the INE condition rated their environment more positively than those in the control and that individual preferences of the control environment influenced physiological changes more than the experimental condition. Work on environmental perception has shown that a sense of sight, hearing and smell are important in field experiments examining the nature–health relationship (Ulrich 1981). Natural environments are multi-sensory, and consist of many kinds of stimuli and environmental characteristics are an important factor to consider in the design of INE. The flight-or-fight stress systems theory, in which an organism determines its behavior based on an appraisal of immediate threat suggests that characteristics associated with sound (Dijkstra et al. 2008; Schnell et al. 2013), spatial openness (Fich et al. 2014), colours (Kaufman and Lohr 2004), and scent (Edris 2007; Jin et al. 2009) may trigger stress responses unknowingly. For example, characteristics of surrounding environments might be mediated through spatial features (e.g., size of room, open layout), and those characteristics, such as whether escape is possible, might influence the magnitude of stress reaction (Fich et al. 2014). Future work should examine the cumulative effects of a variety of sensory interactions and how spatial characteristics of INE may mitigate the impacts of nature exposure on stress reduction and recovery.

The results of the study confirm related research that suggests environmental stimuli regulate ANS functions. Research suggests that this may be a ‘top-down mechanism’ beginning within the brain (Lederbogen et al. 2011; Gladwell et al. 2012; Brown et al. 2013). When viewing urban scenes, fMRI images show increased activity in the amygdala (which is associated with emotional control), compared to when viewing nature scenes (Kim et al. 2010). This activity is likely to engage the ANS (Thayer et al. 2010) and may be responsible for the parasympathetic and sympathetic nervous

system changes seen in this study. The suppression of the parasympathetic nervous system occurs within the prefrontal cortex which sends signals through the amygdala and engages the body's flight-or-fight response. INE results from the current study suggest that the parasympathetic nervous system was dominant, indicating an absence of threat within the INE condition. This pattern raises the possibility that participant responses to nature (experimental condition) had a salient parasympathetic nervous system component; that is, there is no evidence of unusual parasympathetic involvement in the control condition (in response to a room without any natural features) but that the effect of the experimental condition is restorative leading to a more positively toned emotional state and corresponding positive changes in physiological activity.

The current study examined a moderate duration of exposure (50 min), which is known to increase HRV (Gladwell et al. 2012; Brown et al. 2013). A longer exposure time may augment changes seen in the current study; however, recent work within laboratory settings (Brown et al. 2013) suggests that even an additional 5 or 10 min of INE exposure would not be as effective as the primary dosage. Additional research is needed to understand the impact of INE duration on stress reduction and recovery and future work should consider optimal lengths (Mcsweeney et al. 2015).

Although the primary objective of this study was to assess the impact of INE on physiological stress, the results also indicate absence of a relationship between HRV and nature relatedness (NR). NR is believed to be the degree to which an individual sees themselves and the natural world as connected (Kals et al. 1999; Mayer and Frantz 2004) and views themselves as a part of nature (Schultz 2002). Research on nature exposure suggests that previous experiences and connections with nature will influence and possibly enhance benefits associated from future exposures (Ottosson and Grahn 2005; Kjellgren and Buhrkall 2010) and has been linked with varying levels of mood (Nisbet et al. 2011), and higher positive appraisal of natural environments (Mcsweeney et al. 2015). Recent research has suggested that work needs to be done to understand if this relationship mediates stress recovery and restoration (Brown et al. 2013; Mcsweeney et al. 2015), and, as far as we are aware, this study is the first to investigate individual beliefs and relatedness with nature on HRV outcomes. The results showed that NR was not related to differences in physiological stress; however, it seems important to note that subjective and psychological factors of the human-nature relationship are mediated by NR (Nisbet et al. 2011), but that nature is physiologically beneficial regardless of an individual's NR score.

There are a number of limitations associated with the results. As the study sample was composed of healthy undergraduate students, the results are not necessarily generalizable to the broader population. Although exposure to nature in an indoor environment may result in temporary reductions in stress, the impact or effect on chronic or prolonged stress conditions is unknown. Work has shown the restorative benefits of viewing nature, and has also demonstrated the stress-inducing influence of viewing urban images (Herzog et al. 2003; Berman et al. 2008). The view from the INE condition contained mixed urban landscape and may have unknowingly influenced HRV. In addition, it is known that respiration and control of respiration directly influence sympathetic and parasympathetic activity (Thayer et al. 2010; Billman 2013). In our study participants remained in a seated position throughout the duration of exposure; however, respiration was neither measured nor controlled.

Conclusion

Given the rising rates of stress and stress-related illnesses (Kim et al. 2010; Lederbogen et al. 2011), exposure to indoor nature environments may provide opportunities to reduce or recover from negative stressful influences. The current study provides preliminary evidence that indoor nature exposure can provide some relief from stress arising from the domination of parasympathetic activity. Moreover, INE appears to increase autonomic recovery to stress and offers a rationale for incorporating biophilic design into indoor environments. The design of indoor built environment settings such as schools, workplaces, hospitals and homes should include natural elements as one approach to stress reduction and recovery among occupants.

Authors Contributions

All authors made substantial contributions to the study concept and design. JM was responsible for study management, acquisition of the data and data analysis. JM, SJ and DR interpreted the data analysis. JM developed the initial manuscript and all authors were responsible for revision and the provision of intellectual content.

Acknowledgments

The authors wish to thank the students who participated in the study and sincerely appreciate the support of Rachel Shin who assisted with data collection.

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Availability of Data and Materials

Physiological and non-demographic data are available on request to the corresponding author.

Ethical Approval

This study was approved by the Social Sciences and Humanities Research Ethics Board at Dalhousie University as Project 2014-3274.

Consent for Publication

Not applicable.

Competing Interests

None declared.

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