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Research Paper

A dose of nature: Tree cover, stress reduction, and gender differences

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HIGHLIGHTS

- We describe the dose–response curve for the impact of tree cover density on stress reduction.
- We employed 6-min, 3-D videos of community street scenes as the nature treatment.
- We measured skin conductance and salivary cortisol levels as measures of participants' stress.
- For men, the dose–response curve was an inverted-U shape.
- For women, we found no relationship between tree cover density and stress reduction.

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ABSTRACT

Although it is well established that exposure to nearby nature can help reduce stress in individuals, the shape of the dose–response curve is entirely unclear. To establish this dose–response curve, we recruited 160 individuals for a laboratory experiment. Participants engaged in the Trier Social Stress Test (TSST) to induce psychological stress, and were then randomly assigned to view one of ten, 6-min, 3-D videos of neighborhood streets. The density of tree cover in the videos varied from 1.7% to 62.0%. We measured their stress reactions by assessing salivary cortisol and skin conductance levels. Results show a clear disparity between women and men. For women, we found no relationship between varying densities of tree cover and stress recovery. For men, the dose–response curve was an inverted-U shape: as tree cover density increased from 1.7% to 24%, stress recovery increased. Tree density between 24% to 34% resulted in no change in stress recovery. Tree densities above 34% were associated with slower recovery times. A quadratic regression using tree cover density as the independent variable and a summary stress index as the dependent variable substantiated these results [$R^2 = .22$, $F(2, 68) = 9.70$, $p < .001$]. The implications for our understanding of the impacts of nearby nature, and for the practice of planning and landscape architecture are discussed.

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1.. Introduction

1.1 Background

The demands and pressures of modern life are precursors to some of the most threatening medical problems we face today. Chronic stress can suppress the immune system (Cohen, Miller, & Rabin, 2001) and trigger cardiovascular disease, stroke, depression, asthma, and other critical health problems (e.g., Childs & Wit, 2009; Dimsdale, 2008; Gump et al., 2011; Russ et al., 2012; Steptoe & Brydon, 2009). There is mounting evidence, however, that exposure to nature enhances the resources necessary to manage the demands and pressures of modern life. Settings that include tress, grass, and open spaces have been shown to aid physiological stress reduction (e.g., Chang & Chen, 2005; Hartig, Mang, & Evans, 1991; Ulrich et al., 1991; van den Berg, Hartig, & Staats, 2007).

Although it is well established that exposure to nature enhances stress reduction, the shape of the dose–response curve is entirely unclear. We do not know if exposure to a small amount of green space is enough to induce calming effects, whether increase in the density of vegetation produce additional calming effects, or even if the relationship between exposure to nature and stress reduction is linear. Lack of this knowledge prevents landscape architects

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and urban planners from making science-based design and management decisions that might improve the health and longevity of people in the communities they serve.

In this paper, we seek to describe the shape of the dose–response curve for how exposure to nearby nature impacts stress reduction. We begin by reviewing theory and evidence regarding stress and human health. Next we review recent evidence connecting exposure to nearby nature to lower levels of stress. Finally, reporting the results of an experiment involving 160 individuals, we describe a dose–response curve for each gender and discuss the implications of the findings for design and planning.

1.2 Stress and health

When we feel stress, our bodies respond via two physiological pathways: the sympathetic–adrenomedullary system (SA) and the hypothalamic–pituitary–adrenocortical axis (HPA) (Smith & Vale, 2006; Taylor, 1999). The SA activates what is often termed the fight or flight response. It causes the adrenal medulla glands to produce epinephrine and norepinephrine, which result in increased blood pressure, heart rate, sweating, and constricts peripheral blood vessels. The SA enhances our ability to physically engage with the stress or threat. The HPA axis, on the other hand, prepares our bodies for possible injury and helps bring our bodies back to normal after the threat is no longer present. In the HPA axis, the cerebral cortex sends a message to the hypothalamus, which activates the corticotrophin-releasing factor (CRF), and results in cortisol being released into the blood stream. Cortisol plays an important role in helping the body return to its normal state after the stress (Young, Abelson, & Lightman, 2004).

Cortisol responses differ within and among individuals. Cortisol levels change within healthy individuals each day, generally peaking shortly after waking in the morning and reaching a low shortly after falling asleep at night (Edwards, Clow, Evans, & Hucklebridge, 2001; Kudielka, Buske-Kirschbaum, Hellhammer, & Kirschbaum, 2004; Kudielka, Schommer, Hellhammer, & Kirschbaum, 2004). Men typically have stronger physiological responses to stress than do women, as indicated by greater increases in cortisol levels to stressful events (Bratman, Hamilton, & Daily, 2012; Dedovic, Wadiwalla, Engert, & Pruessner, 2009; Jackson, 2003). An individual's health status also can impact the levels of cortisol in their blood (De Rooij & Roseboom, 2010). Given this amount of variation within and among individuals, research that examines levels of cortisol must take gender and other confounding factors, such as measurement time, physical and mental health status, and intake of drugs, tobacco, or acohol, into consideration.

Together, these physiological responses to stress can be lifesaving. But if they are activated too often, if we spend significant parts of our daily lives feeling stress, these same physiological systems can be life threatening. People who experience chronic stress are at risk for immune dysfunction, cardiovascular disease including ventricular arrhythmias and stroke, depression, obesity, memory and concentration problems, and early death (Curtis & O'Keeffe, 2002; Lee, Park, Tsunetsugu, Kagawa, & Miyazaki, 2009; Taylor, 1999).

1.3 Contact with nature and stress recovery

For centuries, philosophers, poets, and artists have suggested that people can reduce the stress they feel by escaping to nature. Emerson, Whitman, and Thoreau all wrote about the sense of peace and tranquility that comes with being in a wood, meadow, or other natural place. During the past two decades, scientists have shown that exposure to urban nature is related to a greater capacity to deal with difficult life problems (Kuo, 2001); increasing "peacefulness," "tranquility," and "relaxation" (Ulrich, 1993); and decreasing physiological indicators of stress (Chang & Chen, 2005; Parsons, Tassinary, Ulrich, Hebl, & Grossman-Alexander, 1998).

Ulrich's Stress Reduction Theory (SRT) is an important framework explaining why contact with nature might foster stress reduction (Bratman et al., 2012; Ulrich et al., 1991). Ulrich et al. (1991) postulated that landscapes containing water, vegetation, richness (or complexity), some visual depth, and a degree of curvilinearity would have aided human survival for hundreds of thousands of human generations. The idea is that in such settings, our ancestors could have spotted food or other resources, predators, and other humans that would have aided their survival. Ulrich argued that, given the impact such settings had on shaping our survival as a species, such settings should help moderate and reduce the physiological signs of stress in modern day humans.

SRT proposes that contact with such natural places will produce a relatively fast (within minutes) affective reaction at a subconscious level that can be measured through physiological pathways. In the last decade, scholars have measured physiological responses associated with various kinds of landscapes and have generally found that, in urban areas, the higher the level of vegetation, the greater the stress reduction (e.g., Alvarsson, Wiens, & Nilsson, 2010; Beil & Hanes, 2013; Lee et al., 2009; Roe et al., 2013; Ward Thompson et al., 2012).

None of these previous studies have reported gender differences in physiological responses after individuals have been exposed to various forms of nature. But a host of other studies that examine physiological responses to stressful conditions do report varying rates of recovery between males and females (e.g., Kudielka, Buske-Kirschbaum, et al., 2004; Kudielka, Schommer, et al., 2004; Wang et al., 2007; Weekes et al., 2008). Both biological and social difference between men and women might explain gender difference in stress responses (e.g., Carrillo et al., 2001; Dedovic et al., 2009; Wang et al., 2007). Thus, in this study, we examine the extent to which gender differences exist in response to varying densities of nature.

Although previous studies demonstrate that exposure to nature, even urban nature, has calming effects, they do not help us understand the shape of the dose–response curve for the impact of nature on stress reduction. That is because none of the previous studies was able to examine the impacts of small, incremental increase in the density of nature have on stress outcomes. Previous findings show that exposure to natural environments is generally more beneficial to human well-being than exposure to predominantly built environments (Hartig, Evans, Jamner, Davis, & Garling, 2003; Laumann, Garling, & Stormark, 2003; Lee et al., 2009; Ulrich et al., 1991), but they do not help us understand the dose–response relationship between exposure to nature and stress reduction.

Thus, there is a critical gap in our knowledge regarding the shape of the dose–response curve for the effect of nearby nature on stress reduction. Is a little exposure to nearby trees and other forms of vegetation enough to produce calming effects from a stressful event? Do higher densities of vegetation produce more calming? Is the relationship linear, or does the effect lessen with greater and greater amounts of vegetation? Are there gender differences in these responses? This study begins to address these questions for one particular setting: the residential street in a single-family neighborhood.

2.. Methods

2.1 Overview

To establish this dose–response curve, we recruited 160 individuals for a laboratory experiment. Participants engaged in the Trier Social Stress Test (TSST), which was designed to induce mental

Fig. 1. Streetscapes presented in 3-D videos with low (top, average tree cover density is 1.7%), moderate (middle), and high (bottom) tree cover density within single-house communities.

stress, and were then randomly assigned to view one of ten, 6-min, 3-D videos of neighborhood streets as the nature treatment. The density of tree cover in the videos varied from 1.7% to 62.0%. We measured stress reactions by assessing salivary cortisol and skin conductance levels.

2.2 Nature treatments

To simulate exposure to nature in this laboratory experiment, we created three-dimensional (3-D) videos of neighborhood streets that varied in the density of tree canopy. The 6-min videos were shown on a high resolution Sony, 3-D personal viewer (Sony HMZ-T1). The device has a head mounted display that allows a viewer to have an experience similar to that of watching a 3-D movie in a theater.

To make the videos, we first identified hundreds of residential streets in four mid-western metropolitan areas: Champaign-Urbana and Springfield, Illinois; Indianapolis, Indiana; and St. Louis, Missouri, in which the tree density varied. We employed several steps to limit the physical characteristics among sites, besides the density of the trees. First, we selected residential streets that had a medium annual income per household between $50,000 and $75,000 at the block group level (data from Google Earth Pro, 2011). This step was helpful to reducing the variability of neighborhood characteristics other than tree cover density. Neighborhoods in the cities we examined that had similar values or household income tended to have similar levels of building density, building quality, and maintenance. Through this process, we identified 255 candidate streets and visited each of them.

At each candidate street, we completed a short inventory of the nearby visual characteristics. We looked for streets with similar physical characteristics including quality of the housing stock, quality of road surface, quality of sidewalks, upkeep, and general maintenance of the neighborhood. Sites without sidewalks or street curbs were rejected.

If the street scene looked promising, we mounted a 3-D camera (Sony HDR-TD10) on a tripod and positioned it at the edge of the street next to a driveway. Filming locations did not have a tree or similar structure within 10 m of the front of the camera.

We then shot video by smoothly panning through approximately 150°, always in a clockwise motion, over a period of 25 to 30 s. Each shot was repeated five times, and the smoothest shot with the least variation in sunlight was selected for use in the study. All videos were taken on sunny days without strong winds in middle to late summer (July 1 to September 10, 2011). Videos were shot between 10 a.m. and 3:30 p.m. to mitigate inconsistencies of shadows and sun angles (Ulrich et al., 1991). In an effort to keep distractions to a minimum and limit confounding physical characteristics, the videos did not contain people or moving cars. Each video was soundless to mitigate influence of different environmental noises.

Finally, we generated panoramic photographs of each of the resulting 255 street scenes that represent the viewshed of each video. Three experts in Landscape Architecture evaluated the photos in order to remove any scene that contained unusual elements such as a unique looking building, unusual or outstanding plants, animals of any kind, unusual architectural decorations, vehicle traffic, the absence of a sidewalk, or distinct weather conditions. Each expert identified a list of scenes that were regarded unsuitable. The scenes rated as unsuitable by at least two researchers were removed from the sample pool. Then all three experts discussed the suitability of the photos that had one vote. Based on this procedure, we removed from consideration streets with

Table 1
Range and mean of tree cover density (%) of ten street scene videos.

Video	1st	2nd	3rd	4th	5th
Range	0–2.5	2.6–5.0	5.1–7.5	7.6–10.0	10.1–20.0
M	1.7	3.8	6.1	8.9	14.9
SD	1.2	.1	.9	.9	3.7
Video	6th	7th	8th	9th	10th
Range	20.1–30.0	30.1–40.0	40.1–50.0	50.1–60.0	60.1–70.0
M	24.0	35.7	44.4	54.1	62.0
SD	3.6	1.9	3.6	2.4	.7

unusual physical characteristics from the pool of 255 candidate sites. This process left us with 50 street scenes for this study.

2.3 Measuring street tree density

In order to measure the density of tree cover along the streets in each video, three landscape architecture research assistants used Photoshop CS5 to measure the number of pixels in each of the panoramic photos and identified the pixels that were associated with trees and those that were not (Fig. 1). The research assistants followed a standard measurement setting in Photoshop to mitigate bias. Then an author reviewed results to further prevent bias. We then divided the number of pixels occupied by trees by the number of pixels in the entire photograph and multiplied this number by 100 for our measure of tree density in each street scene.

We used 3-D video-editing software to combine clips from five different sites with similar levels of tree cover into ten different videos. The density of tree cover for the ten videos is listed in Table 1.

2.4 Using tree cover density as the indicator of greenness

The amount of nature other than tree cover (lawns, shrubs, and flowers) may be significantly different among the street scenes. If that were the case, these other green elements might impact people's stress response and alter the relationship we seek to measure between tree density and stress recovery. To examine this possibility, we counted the pixels in each panoramic photograph associated with vegetation other than trees and then ran a one-way analysis of variance (ANOVA) to see if there were any differences in these other forms of vegetation for the ten categories of street scenes. We found no significant differences in the percent of other nature features among the 50 video clips, $F(9, 40) = 1.54$, $p = .17$. In addition, Levene's test confirmed a significant homogeneity of the amount of non-tree vegetation among the ten videos, LS = 1.71, df 1 = 9, df 2 = 40, $p = .12$. These findings demonstrate that the amount of vegetation visible from the street other than trees did not vary significantly among the videos. Therefore, we examined tree cover density as the sole indicator of greenness in this study.

2.5 Participants

We recruited 160 healthy adults to participate in this study. Cortisol information of two participants was missing, and therefore 158 participants were included in the statistical analysis: 80 men, 78 women. Their age range was limited from 18 to 32 years to reduce difference in cortisol levels caused by age difference ($M = 21.2$, SD = 2.7). Participants identified themselves primarily as Caucasians (75 individuals), Asian Americans or Pacific Islanders (61), African Americans (8), Hispanics (7), 4 Middle Eastern or Persians (4), and 3 Native American or Alaska Natives (3).

For each participant, we gathered demographic data, a brief health background, and a record of what they had eaten and drank during the last 24 h. Individuals were excluded who had a history of cardiovascular diseases, depression, or post-traumatic stress disorder. We excluded individuals who had used tobacco, alcohol, or prescription or non-prescription drugs within 24 h prior to the experiment. We also excluded individuals who had participated in vigorous exercise within 6 h prior to the experiment, who had consumed caffeine within 6 h prior to the experiment, who had consumed a dairy product within 20 min prior to the experiment, or who had any food within two hours prior to the experiment.

2.6 Procedure

The procedure and timing used to measure stress responses are summarized in Fig. 2. After entering the building, a participant was greeted and asked to sit quietly for 3 min. The participant was then given an introduction to the experiment, filled out a short health background questionnaire and signed the experimental consent

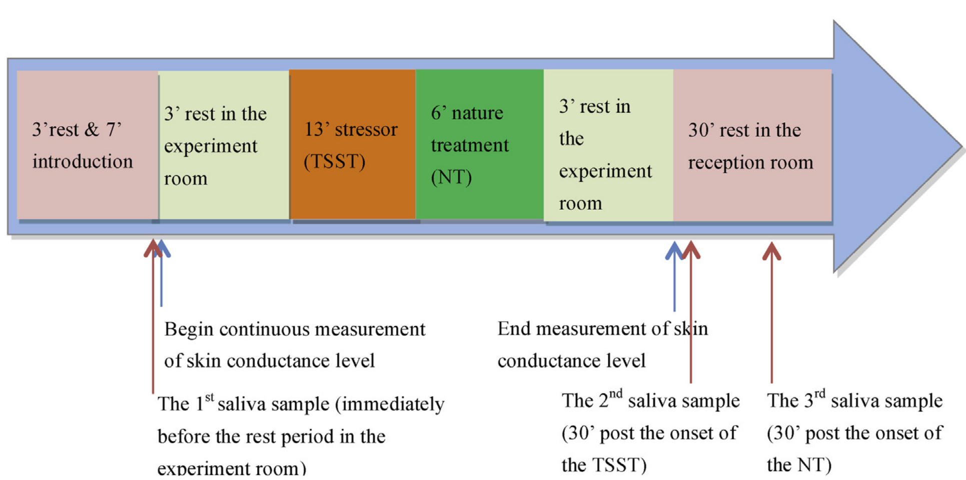

Fig. 2. Sequence of the experiment and timing for measurement of salivary cortisol and skin conductance responses.

form. Next, we collected the first salivary cortisol sample from the participant and then escorted that person into a room where she or he was fitted with the skin conductance sensors.

At the beginning of the experimental phase, two fingers on the participant's left hand were connected to a skin conductance sensor–skin conductance levels were continuously measured throughout the experiment. Then a receptionist asked the participant to rest for 3 min. Following the rest, the participant then took a Trier Social Stress Test (TSST) to induce a moderate level of stress. After the TSST, the participant was randomly assigned to watch one of the ten, 3-D nature treatment videos through a Sony, personal 3-D movie viewer. The videos lasted 6-min. The participant and two interviewers who administered the TSST did not know which video the participant was watching. The double-blind experiment eliminated threats to internal validity that might have arisen from the unconscious behavior of the investigators or the desire to please the investigators on the part of the participants. Following the nature treatment, the participants rested for 3 min before we removed the sensors and escorted them to a waiting room where, over the next 30 min, we collected two more salivary cortisol samples from them.

2.7 Inducing stress

We used the Trier Social Stress Test (TSST) to induce moderate, acute stress in a laboratory setting (Kirschbaum, Pirke, & Hellhammer, 1993). The TSST has been used widely to induce mental stress under controlled conditions (e.g., Kudielka & Wust, 2010; von Dawans, Kirschbaum, & Heinrichs, 2011). The TSST included two tasks. First, participants made a 5-min, impromptu speech as part of a mock job interview in front of two interviewers and a video camera. Second, participants solved a series of subtraction problems without the aid of paper and pencil or any type of computing device. Both tasks were performed with time constraints under social pressure caused by face-to-face interviewers and the video camera. A meta-analysis of 208 studies demonstrates that the TSST produced more reliable levels of stress (as indicated by changes in salivary cortisol levels) than other types of stressors, such as noise exposure, emotion induction, cognitive tasks only, or public speaking only (Dickerson & Kemeny, 2004).

2.8 Measuring mental stress

We measured mental stress by assessing changes of cortisol and skin conductance levels. We also created a summary measure of stress from the average change of cortisol and skin conductance levels. We obtained participants' cortisol from three samples of saliva taken at specific moments during the experiment. Each participant chewed on a small synthetic Oral Swab (a product from Salimetric) for approximately 90 s until the swab was saturated with saliva. The mean effect size for salivary cortisol responses to stress is greatest 21 to 30 min after the onset of the stressor (Dickerson & Kemeny, 2004). Therefore, we collected three salivary cortisol samples immediately before the first rest period, 30 min after the onset of the stressor, and 30 min after the onset of nature treatment (Fig. 2). Salivatte Laboratory in the U.S. used the Enzyme Linked Immuno-Sorbent Assay to analyze the cortisol samples.

Following the procedures of many previous studies, we measured skin conductance to assess stress and stress reduction (e.g., Alvarsson et al., 2010; Carrillo et al., 2001; De Kort, Meijnders, Sponselee, & Ijsselsteijn, 2006; Hsiao-Pei, Hung-Yu, Wei-Lun, & Chih-Wei, 2011; Ulrich et al., 1991). Skin conductance activity is directly related to the amount of active sweat glands in an individual's fingers and is controlled by the sympathetic branch autonomic nervous system (Jacobs et al., 1994; Ulrich et al., 1991).

We used a ProComp5 Infiniti biofeedback system from Thought Technology Ltd to continuously measure skin conductance throughout the experiment (Chang & Chen, 2005). The ProComp5 Infiniti is a 5-channel diagnostic tool that sends information gathered from sensors attached to the participant via fiber-optic cable directly to a computer. Skin conductance sensors (Thought Technology: SA9309M) were connected to two of the participants' fingers.

All experiments were conducted between 2:30 p.m. and 5:30 p.m. to control for diurnal variations of cortisol secretion (Dickerson & Kemeny, 2004; von Dawans et al., 2011). Individuals were paid $20 for the approximately 70 min it took to participate in the experiment.

2.9 Calculating change in stress level

The standardized mean-change statistic, d, was used to estimate the effect size of the change in stress status. The d value has been widely used as an index for repeated measures effect size estimates: An effect size of .20 is considered small; .50 is moderate; and .80 or greater is large (Dickerson & Kemeny, 2004). We measured the d value for skin conductance levels (amplitude), salivary cortisol levels, and the summary measure of stress. We calculated d as follows:

$$d = (M_{\text{post\_stressor}} - M_{\text{pre\_stressor}})/\text{SD}_{\text{pre\_stressor}}$$

$$d = -(M_{\text{post\_treatment}} - M_{\text{pre\_treatment}})/\text{SD}_{\text{pre\_treatment}}$$

3.. Results

3.1 Overview of the results

Results are presented in three parts. We begin by examining the extent to which the Trier Social Stress Test (TSST) induced acute stress. Next, we present analyses indicating that the relationship between tree cover and stress reduction should be investigated separately by gender. Finally, we examine the relationship between tree cover and stress reduction for men and women and present the resulting dose–response curves that best fit the data.

3.2 Did the stressor create stress?

To what extent did the TSST produce a stress response in our participants? To address this question, we conducted paired t-tests on cortisol levels sampled before and after the TSST, and mean values of skin conductance levels during the rest time before the TSST and immediately following the TSST time.

As the results in Table 2 demonstrate, mean salivary cortisol levels increased more than 35% from the base line to immediately after the TSST. The effect size for this change in cortisol level is significant: $d = .54$, $t\,(142) = 4.27$, $p < .0001$. Mean skin conductance levels changed more dramatically. There was a 122% increase in skin conductance levels from the base line to the time immediately following the TSST: $d = 1.4$, $t\,(142) = 15.44$, $p < .0001$. Clearly, the TSST produced a stressful experience for the average participant.

We also examined TSST's effect by gender (Table 2). The effect sizes for salivary cortisol level and skin conductance level remain significant. These results demonstrate that TSST is an effective stressor for both genders.

3.3 Should women and men be analyzed separately?

Previous studies have reported gender differences in the effects of nearby green outdoor environment on perceived stress (Lottrup, Grahn, & Stigsdotter, 2013) and cognitive functioning (Taylor, Kuo, & Sullivan, 2002). To check whether the effects of viewing street

Table 2
Comparison of means in salivary cortisol level (μg/dL) and skin conductance level (amplitude, percent of value) before and after participants were exposed to the same laboratory stressful event (TSST).

		All participants (n = 142)		Women (n = 71)		Men (n = 71)	
		Salivary cortisol level	Skin conductance level	Salivary cortisol level	Skin conductance level	Salivary cortisol level	Skin conductance level
Change of stress level after the stressful event (T2−T1)	t	4.27	15.44	.20	12.07	3.80	1 .26
	p	<.0001	<.0001	<.05	<.0001	<.001	<.0001
	d	.54	1.38	.41	2.14	.64	1.20

Table 3
Gender difference in salivary cortisol level (μg/dL) and skin conductance level (amplitude, percent of value) reduction after participants were exposed to the same set of nature treatment (10 videos of community street scenes).

Reduction	M		SD		t	p
	Women	Men	Women	Men		
Salivary cortisol level	.03	.06	.06	.06	−2.91	<.01
Skin conductance level	17.01	9.78	23.18	24.00	1.83	.07

scenes with varying levels of tree canopy coverage would best be examined separately for women and men, we conducted independent t-tests to examine gender difference in stress reduction indicated by change of cortisol and skin conductance levels. As the first row in Table 3 shows, there is a significant gender difference in salivary cortisol level reduction between women and men ($t = -2.91$, $p < .01$). As the second row shows, there is also a marginally significant gender difference in skin conductance level reduction ($t = 1.83$, $p = .07$). Taken together these results suggest that it would be reasonable to analyze the dose response for each gender.

To get a visual sense of the dose–response curve, we employed a scatterplot with a Locally Estimated Scatterplot Smoothing (LOESS) curve to the data for women and men. LOESS is a simple but powerful method for fitting smooth curves to quantitative data (Jacoby, 2000). The LOESS curves (Fig. 3) show distinctively different trends for men and women. For men, the scatterplots for the three indices of stress reduction show similar inverse-U shape LOESS curves, which might be best explained by polynomial curves rather than a straight line. In contrast, the scatterplots for women show irregularly shaped LOESS curves.

3.4 Shape of the dose–response curve for men

In assessing the dose–response curve for men, perhaps the most straightforward association between percent tree cover and stress is a linear relationship in which more tree cover indicates greater stress reduction. To test this possibility, we conducted a simple linear regression with density tree cover as the independent variable and the three measures of stress as the dependent variables (Table 4). Results from this ordinary least squares regression indicate that any relationship that might exist between the density of the tree canopy and stress reduction stress reduction is not linear. This result corresponds to our observation of the scatterplots and LOESS curves presented above.

The inverse-U shape of LOESS curves suggests that a curvilinear line can explain the relationship. The most straightforward test of this possibility is to conduct a quadratic regression with the same variables as before (Table 4). Results from this regression indicate that a relatively flattened, inverse-U describes the dose–response curve. As the percent tree cover increases from barren to greener scenes, there is a rapid increase in stress reduction until the density of the tree cover reaches about 35%. After this point, increases in the density of tree cover predict a decrease in stress reduction. In the quadratic equation, tree cover density explains between 9 and 22% of the variance in stress reduction.

Might a more complex curve, one that is more similar to an "S" than a "U," describe the dose–response curve better than the inverted-U? To test this possibility, we conducted a cubic regression with the same variables as before (Table 4). Results from these regressions indicate that an S-shaped curve does fit the data. In the cubic equation, density of tree cover explains between 13% and 23% of the variance in stress reduction.

These results raise the question, which curve fits the data best? To identify whether the quadratic or cubic models are more appropriate, we calculated Bayesian Information Criterion (BIC) for each model. BIC is a widely used tool for selecting the best fitting model among a set of plausible models (Schwarz, 1978). The more parameters one adds to a regression model the more one risks over-fitting the model to the data. BIC addresses this problem by invoking a penalty for the number of parameters adopted by the model. For data with small or moderate sample sizes, BIC is superior to other popular model selection criteria (Neath & Cavanaugh, 2012). The simplest model is favored when the difference between BICs is less than 2 (Neath & Cavanaugh, 2012). In SPSS 17.0, we calculated BIC through the equation: $\mathrm{BIC} = n\mathrm{Ln}$ (residual sum of squares) $+ (p+1)\mathrm{Ln}(n) - n\mathrm{Ln}(n)$. Ln is natural logarithm, n is sample size of cases, and p is the number of parameters in the regression equation.

As Table 4 shows, each quadratic model has a smaller BIC than its counterpart cubic model. In addition, each quadratic model contains one less parameter than a cubic model. Thus, we conclude that the inverted U-shaped quadratic models are most appropriate for describing the dose–response relationship of the impact of tree cover density on stress reduction for men.

3.5 Controlling of individual characteristics

Although we randomly assigned each participant to one of ten nature treatments, it is possible that participants' individual characteristics, including age, baseline salivary cortisol levels, and baseline skin conductance levels, could influence the results (Cramer, 2003). To examine whether the quadratic relationship between tree cover density and stress reduction still held when age, baseline salivary cortisol levels, and baseline skin conductance levels were controlled, we examined correlations among these three individual characteristics with stress reduction indicated by the three indices. We found no significant correlations which indicate individual characteristics did not impact the association between

Table 4
Linear, quadratic, and cubic model analysis using percent tree cover as the independent variable to predict salivary cortisol level reduction, skin conductance level reduction, and combined stress reduction for men ($n = 71$).

	Salivary cortisol level reduction			Skin conductance level reduction			Combined stress reduction		
	Linear	Quadratic	Cubic	Linear	Quadratic	Cubic	Linear	Quadratic	Cubic
Adjusted R^2	−.01	.06	.09	.03	.11	.12	−.01	.20	.19
F	.41	3.34*	3.23*	2.95	5.28**	4.09**	.41	9.70***	6.53***
BIC		−128.51	−127.09		−160.46	−158.33		−217.26	−213.00

* $p < .05$.
** $p < .01$.
*** $p < .001$.

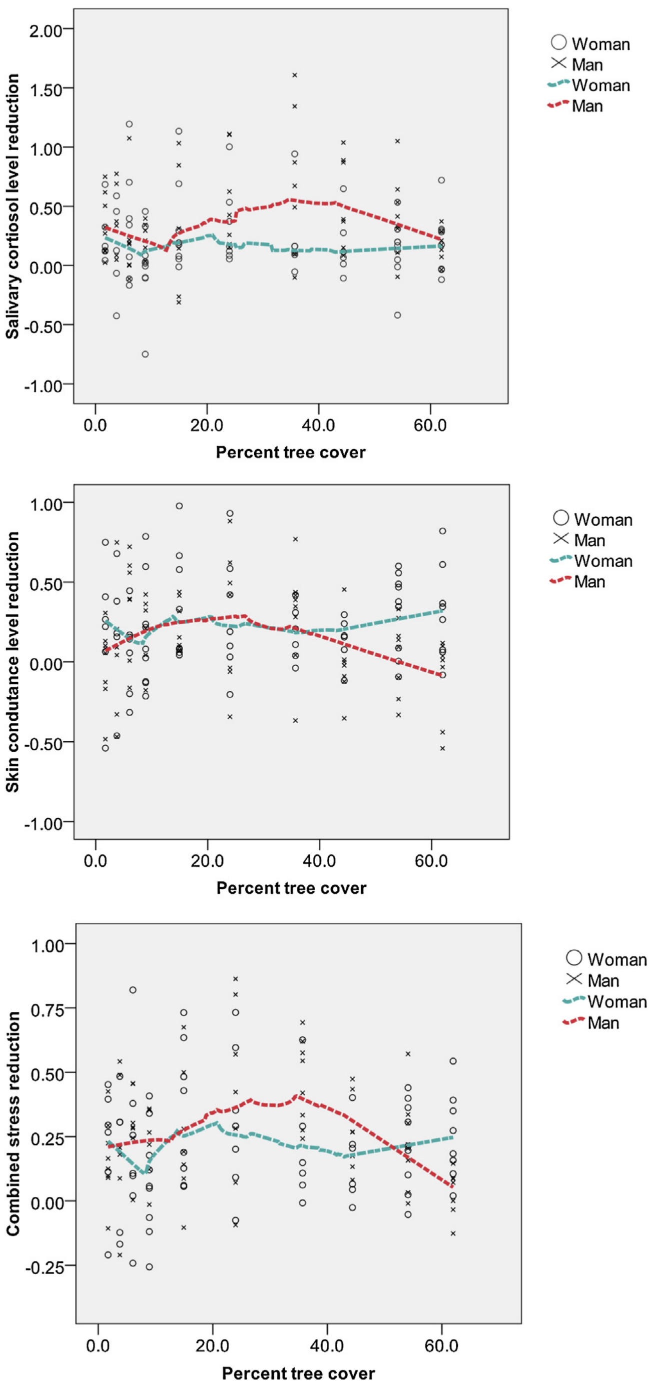

Fig. 3. Scatterplots and LOESS curves (Kernel: Epanechnikov, 50% of points to fit) provide a visual description of the relationship between density of tree cover and three index of stress reduction (d): Salivary cortisol level reduction (top), skin conductance level reduction (middle), and combined stress reduction (bottom).

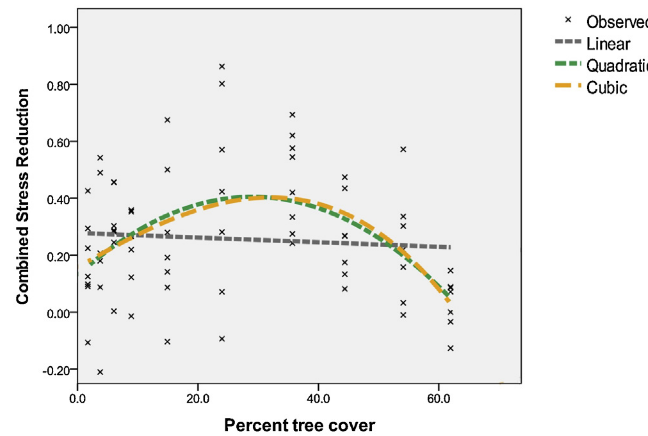

Fig. 4. Linear, quadratic, and cubic dose–response curves explaining effect of varying densities of tree cover on combined stress levels (effect size d) for men. The quadratic curve has the lowest BIC value, which suggests it might be the most appropriate model.

tree cover density and stress reduction. Thus, the quadratic models identified above best explain the relationship between percent tree cover and men's physiological stress reduction. In the following paragraphs, we present dose–response curves and equations for men for two indices of stress reduction and their summary index.

First, for salivary cortisol level reduction, the dose–response relationship can be best explained by a quadratic equation: $Y = -.00035X^2 + .023X + .187$ ($R^2 = .09$, $p < .05$), where Y is the effect size of salivary cortisol levels reduction and X is the percent tree cover. The maximum Y value ($Y = .56$) occurs as X is 32.9. Note that the maximum Y value occurs as X is 32.9, which is 3 times the Y value ($Y = .19$) as X is 1.7.

For skin conductance level reduction, the dose–response relationship can be best explained by a quadratic equation: $Y = -.00030X^2 + .015X + .071$ ($R^2 = .13$, $p < .01$), where Y is the effect size of skin conductance reduction levels and X is the percent tree cover. The maximum Y value (.26) occurs as X is 25.0, which is 3.7 times the Y value (.07) as X is 1.7.

For combined stress level reduction, the dose–response relationship can be best explained by a quadratic equation: $Y = -.00033X^2 + .019X + .129$ ($R^2 = .22$, $p < .001$), where Y is the effect size of combined stress levels reduction and X is the percent tree cover (Fig. 4). The maximum Y value (.40) occurs as X is 28.8, which is 3.1 times the Y value (.13) as X is 1.7.

3.6 Shape of the dose–response curve for women

Following the same analyses conducted for men, we examined linear, quadratic, and cubic models to fit a dose–reponse curve for women. None of the three models, however, were statistically significant. That is, varying levels of tree cover density do not

Table 5
Linear, quadratic, and cubic model analysis using percent tree cover as the independent variable to predict salivary cortisol level reduction, skin conductance level reduction, and combined stress reduction for women ($n = 71$).

	Salivary cortisol level reduction			Skin conductance level reduction			Combined stress reduction		
	Linear	Quadratic	Cubic	Linear	Quadratic	Cubic	Linear	Quadratic	Cubic
Adjusted R^2	−.01	−.02	−.03	.00	−.01	−.01	−.01	−.02	−.02
F	.12	.25	.25	1.26	.62	.79	.23	.24	.53

Note: All three models for each measure yielded insignificant results ($p > .1$).

influence women's salivary cortisol or skin conductance responses after experiencing a stressful event (Table 5).

4.. Discussion

This study identified the shape of the dose–response curve for the impact of tree cover density along residential streets on stress reduction measured by salivary cortisol and skin conductance levels. There are two central findings. First, there was a significant gender difference in physiological stress responses measured by salivary cortisol and skin conductance levels: men had changes in physiological stress that were significantly associated with varying densities of tree cover but women did not. Second, for men, the shape of the dose–response curve was best described as an inverse U-shaped quadratic curve in which moderate tree cover density elicited greater stress reduction than either low or high levels of tree cover density. For males, a 6-min exposure to a video with moderate tree cover density evoked about 3 times the stress reduction than a 6-min exposure to a video with no trees.

These findings contribute to our understanding of the relationship between exposure to nearby nature and human health, suggest opportunities for future research, and offer opportunities for interventions.

4.1 Contributions, limitations, and future research

4.1.1 Gender difference

We found the density of tree cover predicted how much men recovered from a stressful event but not women. What might account for this gender difference?

One possibility may seem plausible at first, but becomes less feasible on further inspection—that exposure to varying levels of tree cover reduces stress for men but not for women. There are two reasons to discount this possibility. First, there is no *a priori* theoretical reason to expect these effects are limited to men. Major theories regarding the impacts of exposure to nature on humans suggest that contact with nearby nature should impact healthy functioning individuals (Kaplan & Kaplan, 1989; Ulrich et al., 1991); these theories make no distinction between men and women. Second, the empirical work on the benefits of exposure to varying levels of nearby nature with girls or women has demonstrated impacts on mental health in the past. For instance, in one study, girls' views of near-home trees were systematically and positively related to a variety of forms of self-discipline (Taylor et al., 2002). In another study, women who had greater exposure to trees and grass near their homes were significantly less likely to have engaged in aggressive and violent behavior during the past year than their counterparts who lived in more barren conditions (Kuo & Sullivan, 2001). In a recent study, researchers found that greater density of tree cover around homes (within 50 m buffer) was associated with lower rate of small for gestational age birth weight of babies (Donovan, Michael, Butry, Sullivan, & Chase, 2011). In a pilot study, participants visited landscape settings with varying levels of greenness and found generally that environmental differences had a stronger impact on women than men (Beil & Hanes, 2013). Thus, in a variety of previous empirical studies, girls and women have been shown to respond to variations in the density of tree cover.

Another explanation seems more promising: Women's physiological reactions to stress are measurably different than men's reactions. Theoretical and empirical evidence show that men and women have different cortisol responses to stress due to both biological and social differences. These differences may influence responses to varying densities of tree cover. For instance, compared to men, women's cortisol responses can be more buffered by higher levels of oxytocin and lower levels of vasopressin (Aguilera, 1998; Neumann, 2007) and sexual steroids (Dedovic et al., 2009). Women also have a milder cortisol response to stress while they are in the follicular phase of their menstrual cycle or when they are taking oral contraceptives (Foley & Kirschbaum, 2010). In another study, researchers employed functional magnetic resonance imaging (fMRI) to measure stressed participants' cerebral blood flow to the brain. Gender difference were significant: the active brain areas were different between men and woman, and intensity of activity for men had a significantly higher correlation with salivary cortisol levels than for woman (Wang et al., 2007).

Social difference between men and women may also partly explain the gender difference in cortisol response to stress. Previous studies have found that men tend to have a stronger HPA response and subsequently greater changes in salivary cortisol level in response to achievement or performance-oriented stressors than do women. In contrast, women tend to have a stronger response to social rejection-oriented, or interpersonal stressors than do men (Dedovic et al., 2009; Lottrup et al., 2013). That may be because men's self-esteem is more likely to be established through achievement of gender-ascribed goals and a degree of independence while women's self-esteem is more likely to be established through social connections with others (Dedovic et al., 2009; Wang et al., 2007). In general, the TSST used in this study is more relevant to the performance-oriented stressor because we told participants that we would assess their performance of their job interview speech and the subtraction task. This may explain why men had greater cortisol responses than women—a result that is in keeping with another recent study (Foley & Kirschbaum, 2010).

Compared to the consistent findings of gender difference in cortisol responses to stress, only a limited number of empirical studies have produced evidence of gender differences in skin conductance responses to stress. For instance, women had greater skin conductance response than men after public speaking tasks (Carrillo et al., 2001). Men, however, had a greater skin conductance response than women after mental arithmetic tasks (Back, Brady, Jackson, Salstrom, & Zinzow, 2005). Regarding responses to a nature treatment, only a handful of studies have employed skin conductance to measure recovery from stress and none of these studies have reported difference between genders (Alvarsson et al., 2010; De Kort et al., 2006; Ulrich et al., 1991). Clearly, future research on gender difference on skin conductance responses is necessary.

In sum, although we found gender difference in salivary cortisol and skin conductance responses to the TSST and the nature treatment, the reason for these differences is not totally clear. Although we did not find a significant association between density of tree cover and stress reduction for women, we cannot conclude they are not related. It may be that, compared to men, women need a longer exposure to nature to gain a measurable stress reduction in physiological responses. It is also possible that, compared to men, women ruminated longer on the stress they experienced from the TSST as they were watching the videos, which thus led to a weaker impact of the nature treatment on stress reduction (Simonson, Mezulis, & Davis, 2011). In order to examine these issues, future research should present nature videos that are longer than 6 min. Future research should also use stressors that balance achievement-oriented tasks and social-rejection tasks.

4.1.2 Identification of a dose–response curve

A second contribution of this work is to describe a dose–response curve for the impact of a wide range of densities in tree cover—from 1.7% to 62.0%—along single-family residential streets on physiological measures of stress for men. This curve was an inverse-U shape with the maximum impact on stress reduction coming between 24% and 34%. We were surprised to find the inverse-U shape best described the data in this experiment, though it is not hard to imagine situations in which dense vegetation could make individuals feel uncomfortable. When vegetation becomes dense enough to obstruct a person's view, the result is often a sense of discomfort or even fear (Jansson, Fors, Lindgren, & Wiström, 2013). But it is typically forested settings or prairie preserves in which this density of vegetation occurs, not urban streets.

In all the scenes presented in this study, views of the street were preserved. As the density of tree cover increased, views to the sky became blocked. Perhaps the overall reduction in openness associated with the higher densities of trees explains the slower stress reduction stress reduction stress reduction found at higher densities. A recent study suggests that humans may prefer openness as well as greenness: places with moderate tree cover might be more preferred for recreational activity than landscapes with dense tree cover (Brown & Corry, 2011). It is possible that, for different types of urban places, the mechanisms through which green landscape mitigate stress might differ (Fan, Das, & Chen, 2011). Therefore, future research should focus on replicating this study in a variety of settings in which people typically spend time such as schools, campuses, work places, and urban streets to see if there are different results among various settings and tree cover densities. In addition to examining various places, future research should examine different populations of people. The majority of participants in this study were healthy, young adults. But we know that age and health status are important factors influencing physiological responses to stress (Dickerson & Kemeny, 2004; Ward Thompson et al., 2012). Therefore, future research should recruit participants from a variety of age groups and with different health statuses.

4.1.3 Three-dimensional video as a surrogate for real landscapes

The third contribution of this study concerns the use of immersive three-dimensional video as a surrogate for real landscapes. Like 2-D video and photography, 3-D video can control the conditions under which participants are exposed to some design feature. In real settings, variations in the presence of people, pets, traffic, noise, temperature, and humidity can all impact the outcomes that scholars might want to measure. In addition, 3-D videos can create an immersive experience. But it is also likely that we lose something in the richness of human reactions to videos compared to having research participants explore the landscape with all their senses. Research in this area would benefit from multiple methods that expose people to varying doses of nature through various methods (e.g., simulations, being in various landscapes).

To our knowledge, the validity of 3-D video technology as a surrogate for real landscapes has been assessed in one study: Valtchanov, Barton, and Ellard (2010) found that 3-D virtual nature evoked significantly healthier physiological and psychological responses than a slideshow of abstract paintings. It seems reasonable that 3-D videos would be reliable surrogates for real landscapes because numerous studies have successfully used 2-D videos (e.g., Parsons et al., 1998; Ulrich et al., 1991) or photography (e.g., Chang & Chen, 2005; Kuo, Bacaicoa, & Sullivan, 1998). 3-D videos played in the head-mounted device create a more immersive experience than 2-D video or 2-D photography. The image resolution and perceived screen size of 3-D video in this study are close to those of a standard 3-D commercial film. Several of the participants commented that they felt they were watching the 3-D video of community streets in a movie theater, which makes the visual experience more immersive than watching the video on a regular TV screen or projector screen (De Kort et al., 2006). However, more direct evidence of the validity of 3-D video as a surrogate for real landscapes is needed. In a study comparing views of a landscape out a window to a view of the same landscape through a high definition monitor, individuals who had the view out the window tended had more rapid decreases in their heart rate than individuals randomly assigned to view the landscape through the monitor (Kahn et al., 2008). Future research might examine differences in responses as participants are exposed to a real landscape, a 2-D video, and a 3-D video of the same scene.

5.. Conclusions

This study is an initial attempt to describe the dose response curve for the impact of increasing densities of tree cover on stress reduction. Although we found no relationship between tree cover density presented through a 6-min, 3-D video and stress reduction in women, the findings do not necessarily mean that exposure to nearby nature does not impact women. To further investigate the dose–response curve of the density of tree cover and female's stress recovery, future research should use nature treatments with a longer duration or include a social rejection task as part of the stressor. Clearly, more work in this area is necessary if we are to develop evidence-based guidelines for designers (Brown & Corry, 2011).

Stress is a major threat to human health. Creating greener living environments appears to be an effective way to aid stress reduction for men, which in turn might help reduce chronic stress and the many diseases that accompany it, such as cardiovascular disease, stroke, cancer, depression, and asthma. Now that we have some evidence of the dose–response curve for the impact of tree cover density of residential street on stress reduction, landscape planners and city managers can help create settings that provide a density of tree cover that has been shown to help men recover from stressful experiences. Taken together, these findings reinforce the idea that planting trees along community streets and in other urban environments could help reduce disease caused by stress, thus promote the wellbeing of urban residents.

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References

Aguilera, G. (1998). Corticotropin releasing hormone, receptor regulation and the stress response. *Trends in Endocrinology and Metabolism*, *9*(8), 329–336.

Alvarsson, J. J., Wiens, S., & Nilsson, M. E. (2010). Stress recovery during exposure to nature sound and environmental noise. *International Journal of Environmental Research and Public Health*, *7*(3), 1036–1046.

Back, S. E., Brady, K. T., Jackson, J. L., Salstrom, S., & Zinzow, H. (2005). Gender differences in stress reactivity among cocaine-dependent individuals. *Psychopharmacology*, *180*(1), 169–176.

Beil, K., & Hanes, D. (2013). The influence of urban natural and built environments on physiological and psychological measures of stress-a pilot study. *International Journal of Environmental Research and Public Health*, *10*(4), 1250–1267.

Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health. *Year in Ecology and Conservation Biology*, *1249*, 118–136.

Brown, R. D., & Corry, R. C. (2011). Evidence-based landscape architecture: The maturing of a profession. *Landscape and Urban Planning*, *100*(4), 327–329.

Carrillo, E., Moya-Albiol, L., Gonzalez-Bono, E., Salvador, A., Ricarte, J., & Gomez-Amor, J. (2001). Gender differences in cardiovascular and electrodermal responses to public speaking task: The role of anxiety and mood states. *International Journal of Psychophysiology*, *42*(3), 253–264.

Chang, C. Y., & Chen, P. K. (2005). Human response to window views and indoor plants in the workplace. *Hortscience*, *40*(5), 1354–1359.

Childs, E., & Wit, H. (2009). Hormonal, cardiovascular, and subjective responses to acute stress in smokers. *Psychopharmacology*, *203*(1), 1–12.

Cohen, S., Miller, G. E., & Rabin, B. S. (2001). Psychological stress and antibody response to immunization: A critical review of the human literature. *Psychosomatic Medicine*, *63*(1), 7–18.

Cramer, P. (2003). Defense mechanisms and physiological reactivity to stress. *Journal of Personality*, *71*(2), 221–244.

Curtis, B. M., & O'Keeffe, J. H. (2002). Autonomic tone as a cardiovascular risk factor: The dangers of chronic fight or flight. *Mayo Clinic Proceedings*, *77*(1), 45–54.

De Kort, Y. A. W., Meijnders, A. L., Sponselee, A. A. G., & Ijsselsteijn, W. A. (2006). What's wrong with virtual trees? Restoring from stress in a mediated environment. *Journal of Environmental Psychology*, *26*(4), 309(312).

De Rooij, S. R., & Roseboom, T. J. (2010). Brief reports: Further evidence for an association between self-reported health and cardiovascular as well as cortisol reactions to acute psychological stress. *Psychophysiology*, *47*(6), 1172–1175.

Dedovic, K., Wadiwalla, M., Engert, V., & Pruessner, J. C. (2009). The role of sex and gender socialization in stress reactivity. *Developmental Psychology*, *45*(1), 45–55.

Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychological Bulletin*, *130*(3), 355–391.

Dimsdale, J. E. (2008). Psychological stress and cardiovascular disease. *Journal of the American College of Cardiology*, *51*(13), 1237–1246.

Donovan, G. H., Michael, Y. L., Butry, D. T., Sullivan, A. D., & Chase, J. M. (2011). Urban trees and the risk of poor birth outcomes. *Health and Place*. *17*(1), 390–393.

Edwards, S., Clow, A., Evans, P., & Hucklebridge, F. (2001). Exploration of the awakening cortisol response in relation to diurnal cortisol secretory activity. *Life Sciences*, *68*(18), 2093–2103.

Fan, Y., Das, K. V., & Chen, Q. (2011). Neighborhood green, social support, physical activity, and stress: Assessing the cumulative impact. *Health & Place*, *17*(6), 1202–1211.

Foley, P., & Kirschbaum, C. (2010). Human hypothalamus–pituitary–adrenal axis responses to acute psychosocial stress in laboratory settings. *Neuroscience and Biobehavioral Reviews*, *35*(1), 91–96.

Gump, B. B., MacKenzie, J. A., Bendinskas, K., Morgan, R., Dumas, A. K., Palmer, C. D., et al. (2011). Low-level pb and cardiovascular responses to acute stress in children: The role of cardiac autonomic regulation. *Neurotoxicology & Teratology*, *33*(2), 212–219.

Hartig, T., Mang, M., & Evans, G. W. (1991). Restorative effects of natural-environment experiences. *Environment and Behavior*, *23*(1), 3–26.

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S., & Garling, T. (2003). Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology*, *23*(2), 109–123.

Hsiao-Pei, Lin, Hung-Yu, Lin, Wei-Lun, LinHuang, & Chih-Wei, A. (2011). Effects of stress, depression, and their interaction on heart rate, skin conductance, finger temperature, and respiratory rate: Sympathetic-parasympathetic hypothesis of stress and depression. *Journal of Clinical Psychology*, *67*(10), 1080–1091.

Jackson, L. E. (2003). The relationship of urban design to human health and condition. *Landscape and Urban Planning*, *64*(4), 191–200.

Jacobs, S. C., Friedman, R., Parker, J. D., Tofler, G. H., Jimenez, A. H., Muller, J. E., et al. (1994). Use of skin-conductance changes during mental stress-testing as an index of autonomic arousal in cardiovascular research. *American Heart Journal*, *128*(6), 1170–1177.

Jacoby, W. G. (2000). Loess: A nonparametric, graphical tool for depicting relationships between variables. *Electoral Studies*, *19*(4), 577–613.

Jansson, M., Fors, H., Lindgren, T., & Wiström, B. (2013). Perceived personal safety in relation to urban woodland vegetation—A review. *Urban Forestry and Urban Greening*, *12*(2), 127–133.

Kahn, P. H., Jr., Friedman, B., Gill, B., Hagman, J., Severson, R. L., Freier, N. G., et al. (2008). A plasma display window? The shifting baseline problem in a technologically mediated natural world. *Journal of Environmental Psychology*, *28*(2), 192–199.

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. New York: Cambridge University Press.

Kirschbaum, C., Pirke, K. M., & Hellhammer, D. H. (1993). The Trier Social Stress Test—A tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology*, *28*(1–2), 76–81.

Kudielka, B. M., Buske-Kirschbaum, A., Hellhammer, D. H., & Kirschbaum, C. (2004). Differential heart rate reactivity and recovery after psychosocial stress (TSST) in healthy children, younger adults, and elderly adults: The impact of age and gender. *International Journal of Behavioral Medicine*, *11*(2), 116–121.

Kudielka, B. M., Schommer, N. C., Hellhammer, D. H., & Kirschbaum, C. (2004). Acute HPA axis responses, heart rate, and mood changes to psychosocial stress (TSST) in humans at different times of day. *Psychoneuroendocrinology*, *29*(8), 983–992.

Kudielka, B. M., & Wust, S. (2010). Human models in acute and chronic stress: Assessing determinants of individual hypothalamus-pituitary-adrenal axis activity and reactivity. *Stress—The International Journal on the Biology of Stress*, *13*(1), 1–14.

Kuo, F. E., Bacaicoa, M., & Sullivan, W. C. (1998). Transforming inner-city landscapes—Trees, sense of safety, and preference. *Environment and Behavior*, *30*(1), 28–59.

Kuo, F. E. (2001). Coping with poverty—Impacts of environment and attention in the inner city. *Environment and Behavior*, *33*(1), 5–34.

Kuo, F. E., & Sullivan, W. C. (2001). Aggression and violence in the inner city—Effects of environment via mental fatigue. *Environment and Behavior*, *33*(4), 543–571.

Laumann, K., Garling, T., & Stormark, K. M. (2003). Selective attention and heart rate responses to natural and urban environments. *Journal of Environmental Psychology*, *23*(2), 125–134.

Lee, J., Park, B. J., Tsunetsugu, Y., Kagawa, T., & Miyazaki, Y. (2009). Restorative effects of viewing real forest landscapes, based on a comparison with urban landscapes. *Scandinavian Journal of Forest Research*, *24*(3), 227–234.

Lottrup, L., Grahn, P., & Stigsdotter, U. K. (2013). Workplace greenery and perceived level of stress: Benefits of access to a green outdoor environment at the workplace. *Landscape and Urban Planning*, *110*(1), 5–11.

Neath, A. A., & Cavanaugh, J. E. (2012). The Bayesian Information Criterion: Background, derivation, and applications. *Wiley Interdisciplinary Reviews: Computational Statistics*, *4*(2), 199–203.

Neumann, I. D. (2007). Stimuli and consequences of dendritic release of oxytocin within the brain. *Biochemical Society Transactions*, *35*(5), 1252–1257.

Parsons, R., Tassinary, L. G., Ulrich, R. S., Hebl, M. R., & Grossman-Alexander, M. (1998). The view from the road: Implications for stress recovery and immunization. *Journal of Environmental Psychology*, *18*(2), 113–140.

Roe, J. J., Ward Thompson, C., Aspinall, P. A., Brewer, M. J., Duff, E. I., Miller, D., et al. (2013). Green space and stress: Evidence from cortisol measures in deprived urban communities. *International Journal of Environmental Research and Public Health*, *10*(9), 4086–4103.

Russ, T. C., Stamatakis, E., Hamer, M., Starr, J. M., Kivimäki, M., & Batty, G. D. (2012). Association between psychological distress and mortality: Individual participant pooled analysis of 10 prospective cohort studies. *British Medical Journal (Online)*, *345*(7871).

Schwarz, G. (1978). Estimating dimension of a model. *Annals of Statistics*, *6*(2), 461–464.

Simonson, J., Mezulis, A., & Davis, K. (2011). Socialized to ruminate? Gender role mediates the sex difference in rumination for interpersonal events,. *Journal of Social and Clinical Psychology*, *30*(9), 937–959.

Smith, S. M., & Vale, W. W. (2006). The role of the hypothalamic–pituitary–adrenal axis in neuroendocrine responses to stress. *Dialogues in Clinical Neuroscience*, *8*(4), 383–395.

Steptoe, A., & Brydon, L. (2009). Emotional triggering of cardiac events. *Neuroscience and Biobehavioral Reviews*, *33*(2), 63–70.

Taylor, A. F., Kuo, F. E., & Sullivan, W. C. (2002). Views of nature and self-discipline: Evidence from inner city children. *Journal of Environmental Psychology*, *22*(1–2), 49–63.

Taylor, S. E. (1999). *Health psychology* (4th Edition ed.). Boston: McCraw-Hill.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, *11*(3), 201–230.

Valtchanov, D., Barton, K. R., & Ellard, C. (2010). Restorative effects of virtual nature settings. *Cyberpsychology Behavior and Social Networking*, *13*(5), 503–512.

van den Berg, A. E., Hartig, T., & Staats, H. (2007). Preference for nature in urbanized societies: Stress, restoration, and the pursuit of sustainability. *Journal of Social Issues*, *63*(1), 79–96.

von Dawans, B., Kirschbaum, C., & Heinrichs, M. (2011). The Trier Social Stress Test for Groups (TSST-G): A new research tool for controlled simultaneous social stress exposure in a group format. *Psychoneuroendocrinology*, *36*(4), 514–522.

Wang, J. J., Korczykowski, M., Rao, H. Y., Fan, Y., Pluta, J., Gur, R. C., et al. (2007). Gender difference in neural response to psychological stress. *Social Cognitive and Affective Neuroscience*, *2*(3), 227–239.

Ward Thompson, C., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. *Landscape and Urban Planning*, *105*(3), 221–229.

Weekes, N. Y., Lewis, R. S., Goto, S. G., Garrison-Jakel, J., Patel, F., & Lupien, S. (2008). The effect of an environmental stressor on gender differences on the awakening cortisol response. *Psychoneuroendocrinology*, *33*(6), 766–772.

Young, E. A., Abelson, J., & Lightman, S. L. (2004). Cortisol pulsatility and its role in stress regulation and health. *Frontiers in Neuroendocrinology*, *25*, 69–76.

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