Building Research & Information

ISSN: 0961-3218 (Print) 1466-4321 (Online) Journal homepage: https://www.tandfonline.com/loi/rbri20

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To cite this article: Michael David Burnard & Andreja Kutnar (2019): Human stress responses in office-like environments with wood furniture, Building Research & Information, DOI: 10.1080/09613218.2019.1660609

To link to this article: https://doi.org/10.1080/09613218.2019.1660609

Published online: 04 Sep 2019.

BUILDING RESEARCH & INFORMATION
2019
https://doi.org/10.1080/09613218.2019.1660609

Human stress responses in office-like environments with wood furniture

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ABSTRACT

Stress is a major public health concern and work stress is a contributor to both acute and chronic stress. Moreover, most people spend the majority of their time indoors. It follows that the design of office spaces and other interior environments should consider the health impacts of individuals in terms of psychophysiological responses to stress. In this way, buildings can act as an environmental intervention to compliment social and therapeutic interventions to stress. In this study, human stress responses were compared in experimental office settings with and without wood. The hypothesis was that the office setting with wood furniture would reduce stress responses and improve stress recovery as indicated by salivary cortisol concentration. The within-subjects experiment revealed that overall stress levels were lower in the office-like environment with oak wood than the control room, but there was no detectable difference in stress levels between the office-like environment with walnut wood and the control room. Stress recovery was not found to differ between either environment, possibly because duration of the experiment was too short or that not enough samples were taken during the recovery period.

ARTICLE HISTORY
Received 5 June 2019
Accepted 22 August 2019

KEYWORDS
Healthy offices; occupant stress; timber; materials; indoor environment; well-being

Introduction

Building occupants are impacted by their environment physically and psychosocially (Dolan, Foy, & Smith, 2016). Building design, material selection, indoor environmental quality (IEQ), and other aspects of the built environment may cause a variety of impacts to user health and well-being. The negative human health and well-being effects associated with spending time indoors may manifest in several ways, including: increased frequency and symptoms of illness, often associated with Sick Building Syndrome (Finnegan, Pickering, & Burge, 1984); psychophysiological well-being, often related to physical or social stress (Burnard & Kutnar, 2015; Fell, 2010; Nyrud & Bringslimark, 2010; Rice, Kozak, Meitner, & Cohen, 2006); directed attention deficits, or the reduced capability to focus ones attention on a task (Hartig, Korpela, Evans, & Gärling, 1997; Kaplan, 1995); and issues related to the ergonomic design of space that may cause musculoskeletal complications (Attaianese & Duca, 2012).

Research examining the connection between building design and experiences of stress, including how stress is perceived, psychophysiological responses to stress, and recovery from stress, is not well established. As stress is a major public health concern (McEwen, 1998), further studies that address the relationship between building design decisions, such as material selection, and stress may lead to evidence-based interventions in the built environment that help occupants cope with stress and improve their overall health and well-being.

Human stress and recovery from stress

Human stress is often considered in two broad categories: acute and chronic (McEwen, 1998). Acute stress may be thought of as the 'fight or flight response' and chronic stress is the minor, day-to-day stress humans experience that has a cumulative load on the individual (McEwen, 1998). The human response to a stressor is the activation of adaptive systems in the body, most commonly the sympathetic nervous system and the hypothalamus–pituitary–adrenal (HPA) axis. The effects of activating these systems may include increased heart rate, changes in heart rate variability, increased blood pressure, and the release of hormones such as glucocorticoids (e.g. cortisol). Repeated activations of these systems can have negative pathophysiological consequences, including inhibited immune responses, depression, anxiety disorders, and can result in

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conditions like Cushing's disease (McEwen, 1998, 2008, 2009). The human response to stress is moderated by individual health and perceptions of stressors. Individual physical condition (including diet, exercise regime, tobacco and alcohol use, or the presence of certain diseases/conditions) and perceptions of stress events or environmental situations cause individuals to experience stress and respond to stressors differently (Cohen, Kessler, & Underwood-Gordon, 1995; McEwen, 1998, 2009). Reducing stress is an important public health concern. Individually, people may address chronic stress by improving sleep quality, through healthy eating, getting more exercise, avoiding smoking, maintaining strong social support, and with professional therapeutic support (Bernadet, 1995; McEwen, 2008; Rovio et al., 2005). Societal concerns also contribute to stress and changing them can have long-term effects on public health as well. Policy-makers, businesses, and other institutions that affect society can help remediate stressors by supporting healthy working and living environments, addressing poverty and other social disparities, providing security, etc. (McEwen, 2008). Another potential intervention to address stress, particularly chronic work stress, is to adapt the built environment directly to support reduced stress responses and improved recovery from stress (Burnard & Kutnar, 2015; Fell, 2010). However, practical evidence-based guidance is currently lacking on how to achieve this.

Restoration and recovery in buildings

In addition to the immediate response to stress, which poses health concerns, improved recovery from stress may bring health benefits and lead to improved human performance. In addition to stress, improving recovery from other draining experiences may help improve worker well-being and performance. Theories of restoration may also provide insight into how to adapt the built environment to support worker well-being.

Psychophysiological restoration theory, attention restoration theory, and the biophilia hypothesis posit that aspects of the natural environment and human connection to life and life-like processes help humans recover depleted resources and recovery from psychophysiological stress more readily in natural environments (Kaplan & Kaplan, 1989; Ulrich, 1991; Wilson, 1984). Natural settings, including parks, have been shown to improve stress responses, including recovery, compared to urban environments (Park et al., 2007; Tyrväinen et al., 2014). However, people spend most of their time indoors, and bringing nature indoors may, therefore, prove to be a useful intervention to help people cope with stress, especially in urban environments where access to nature is limited.

Supporting recovery from stress in the built environment

To effectively connect people with nature in the built environment and potentially improve stress responses, including recovery, it is important that users perceive their indoor environment as natural. User perceptions of their environment and the materials in them are based on visual recognition, haptic response, scents, and other sensory inputs (Bhatta, Tiippana, Vahtikari, Hughes, & Kyttä, 2017; Burnard, 2017; Burnard et al., 2017). Nature may be included in buildings in many ways (views, water features, plants, natural materials, variations in shape, lighting, etc.), but material selection remains a simple and widely applicable method to bring nature indoors (Burnard & Kutnar, 2015; Kellert, 2008). Using wood more abundantly may be a sustainable and cost-effective way of connecting users to the natural environment since it has been shown to be perceived as more natural than many other building materials (Burnard et al., 2017).

Previous studies examining stress-related psychophysiological responses to wood in the built environment

Many studies have examined the psychophysiological effects of exposing building occupants to wood, as detailed in recent reviews (Burnard & Kutnar, 2015; Ikei, Song, & Miyazaki, 2017; Nyrud & Bringslimark, 2010). Previous studies demonstrated individuals had varied psychophysiological responses to visual exposure to interiors with wood (sometimes compared to other materials) using a variety of indicators. Heart rate and blood pressure (Tsunetsugu, Miyazaki, & Sato, 2002, 2007) or blood pressure alone (Sakuragawa, Miyazaki, Kaneko, & Makita, 2005) have been used as measures of arousal and stress response. Fell (2010) used heart rate variability and galvanic skin response (Fell, 2010) to assess stress response and stress recovery. One study examined many indicators in the same study, in part to isolate the most efficient experimental setup. In that study, Zhang, Lian, and Wu (2017) employed electrocardiogram (returning heart rate variability, heart rate), galvanic skin response, skin temperature, oxyhaemoglobin saturation, and near distance vision. One study relied on salivary α-amylase (an enzyme related to digestion but influenced by the nervous system) activity, in addition to blood pressure and heart rate, but focused primarily on the olfactory influence of Japanese cedar on human subjects (Bamba & Azuma, 2016). In

all but one case (Fell, 2010), these studies included few participants (20 or fewer). In only two cases (Fell, 2010; Zhang et al., 2017), exposure to the test environment(s) was potentially long enough to illicit a non-reactionary response to the environment and gain knowledge about stress responses and recovery or work performance.

None of the previous studies used salivary cortisol as an indicator of stress, despite it being a robust and common indicator in other fields of study (Burnard & Kutnar, 2015; Kirschbaum & Hellhammer, 1994).

Objectives

The objectives of this study were to design and test an experimental procedure to gauge the effectiveness of building interventions on stress responses and recovery and better understand the stress response and recovery effects using wood in office environments.

The specific objectives were to:

(1) Design an experiment to test stress and stress recovery using salivary cortisol as an unobtrusive measure of stress in office-like environments; and
(2) Determine if using wood furniture in offices could improve stress responses and recovery compared to control environments (offices without wood), by assessing stress indicators in different scenarios to understand the response more fully.

Materials and methods

This experiment included testing human subjects and collecting biological samples, in addition to personal information. Accordingly, all subjects were volunteers able to give consent and sign an informed consent document.

Test environments

The test environments were two adjacent offices (A and B) in the same building located in Izola, Slovenia. The offices were divided into two equal-sized portions, approximately 2.5 m × 2.5 m, resulting in a total of four test settings. The test environments in each divided office were isolated with natural tone curtains that blocked exterior windows in the office to reduce the impact of differences in daylighting, weather, and the time of day testing took place. The two test settings in each office were a control environment with white furniture and no visible wood surface and a wood environment with wood furniture. The test environments were:

(1) Divided office A: Oak furniture (Office A:Oak).
(2) Divided office A: Control furniture (Office A: Control).
(3) Divided office B: Walnut furniture (Office B: Walnut).
(4) Divided office B: Control furniture (Office B: Control).

The furniture used in each portion of the divided offices was identical except for the surface material and included a desk, a bookshelf above the desk, a desk-height filing cabinet immediately next to the desk, and a set of drawers that fit under the desk (Figure 1).

One wood environment used oak veneered furniture (Office A:Oak, Figure 1(b)), and the other used American walnut veneered furniture (Office B:Walnut, Figure 1(c)).

Each divided office contained a control room to allow testing subjects in each half of the same divided office to minimize any variation related to potential uncontrollable differences present in each room.

Experimental design and procedure

In this within-subjects experiment, each subject was tested twice; once in the control environment and once in the wood environment of the same divided office (e.g. both A:Oak and A:Control). The order of tests was randomized (i.e. assignment to wood-first or control-first). Tests for the same subject were conducted at the same time of day, between 5 and 10 days apart, to avoid any differences that may have occurred due to the circadian rhythm of cortisol release. During each test, the procedure had two phases: pre-testing and testing.

In the pre-testing phase, the following steps were taken:

(1) Subjects were directed to their assigned test environment (control or wood) and asked to make themselves comfortable in the desk chair. Subjects were allowed to adjust the chair height and other settings to their preference.
(2) Subjects were presented with the informed consent document. They were asked to read it, ask any questions, and voice any concerns. If satisfied with the test procedure and still willing to participate, they were asked to sign the informed consent document. It was then countersigned by the researcher and archived.
(3) Subjects were asked to complete the WHO-5 well-being index questionnaire.

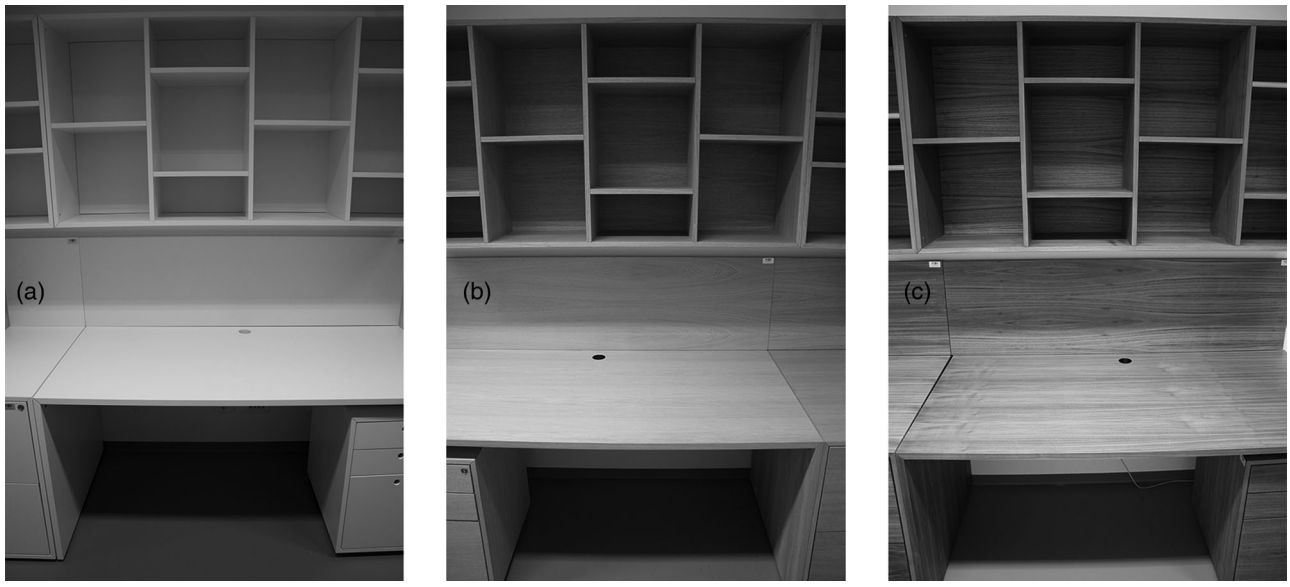

Figure 1. Furniture used in office-like experimental environments. (a) Control furniture, (b) oak furniture, (c) walnut furniture.

(4) Subjects wore the chest band used to monitor heart rate. Verification that readings were being made took place. This completed the pre-testing phase of the test.

During the testing phase, the following steps were taken (Figure 2):

(1) Subjects were given a Salivette® saliva collection device, instructed on its use, and asked to begin gently chewing the swab.
(2) A timer was started when the subjects placed the swab in their mouth.
(3) Following the first saliva collection, subjects were allowed to acclimate to the test environment for 15 min.
(4) At minute 15, subjects provided the second saliva sample.
(5) Directly after collecting the second saliva sample, the researcher began the 6-min video that served as a stressor.
(6) At minute 25, the third saliva sample was collected, and the video device was removed from the room.
(7) At minute 35, the fourth saliva sample was collected.
(8) At minute 45, the fifth saliva sample was collected, and subjects were given the proofreading text and a writing instrument. Instructions for this process were reiterated.
(9) At minute 60, the sixth saliva sample was collected.
(10) At minute 75, the seventh, and final, saliva sample was collected. The timer and heart rate recording were stopped. The proofreading text was collected and stored for later analysis.

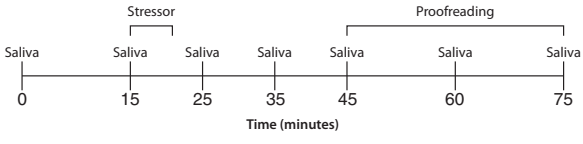

Figure 2. Experiment timeline during the testing phase.

Sampling and demographics

Subjects were recruited through e-mail distributed to regional organizations and mailing lists, advertisements on local media, and social networks. Additional recruiting took place in classrooms on campus at the University of Primorska.

Restrictions on the sample included:

- Minimum age of 18;
- Non-smokers only; and
- Healthy subjects not taking prednisolone (a corticosteroid treatment that interferes with salivary cortisol analysis), without heart conditions exacerbated by stress, and without other stress-related conditions.

In addition to the sample restrictions, subjects were also asked about any hormone therapy they were undergoing (including contraceptives) and hormone-related conditions.

The resulting sample was 61 healthy adults, aged 18 and older, from Slovenia and Italy, including long-term visitors to Slovenia (e.g. foreign students, visiting professors). Subjects were between 18 and 52 (mean: 27.7 ± 9.3 years); 47 were female, 14 were male. Fifty

participants selected the Slovenian language text, while 11 selected the English language text. Of those 11, 3 spoke English as a second language.

Six subjects used chemical contraceptives and one had a hormone condition that required treatment with hormone supplements. None of these cases produced unexpected or peculiar results.

Saliva collection and immunoassay kits

Saliva was collected at 7 points during each test (14 total for each subject). Saliva samples were collected using Salivette® Cortisol code blue collection devices (Sarstedt, Germany). Subjects were instructed to chew the swab for 45 s and were timed to make sure enough saliva was collected for processing. These devices consist of a two-chambered device with a cap and a chewable, biocompatible synthetic swab. Prior to testing, each Salivette® was labelled with a subject identifier, test identifier, and sample identifier. Following collection, saliva samples were immediately frozen for later processing.

Saliva samples were processed using enzyme-linked immunosorbent assay (ELISA) kits designed specifically for salivary cortisol assessment (Diametra, Italy). All kits were from the same lot. Each kit contained the requisite materials for processing, apart from disposable pipette tips. The materials included in the kit were:

- One 96-well microtitre plate, coated: antibody anti-Cortisol adsorbed on the plate;
- Calibrators, seven vials (with different known cortisol concentrations);
- Incubation buffer (phosphate buffer 50 mmol, Bovine Serum Albumin (BSA) 1 g/L);
- Conjugate (horseradish peroxidase, HRP);
- TMB substrate (H_2O_2-3,3′,5,5′-tetramethylbenzidine, 0.26 g/L);
- Stop solution (sulphuric acid, H_2SO_4, 0.15 mol/L);
- Concentrated wash solution (10x concentration, phosphate buffer 0.2 M); and
- Within-kit controls at two cortisol concentrations.

External cortisol controls at three concentrations were also obtained (Diametra, Italy). These controls and the kit-specific controls were used to assess the fit of the dose–response curve fit to the calibrators.

WHO-5 well-being index

The WHO-5 well-being index is a short questionnaire to assess respondent well-being. The questionnaire is self-reported and provides subjective values (Topp, Østergaard, Søndergaard, & Bech, 2015; World Health Organization, 1998). It consists of five non-invasive questions with responses provided on a five-point scale. The purpose of using this questionnaire in this study was to determine if there were any major changes in subjective well-being that may influence test results. The questionnaire was available to subjects in either English or Slovenian (Psykiatric Center North Zealand, Denmark). Responses to the WHO-5 well-being index were manually transcribed from the paper questionnaire to a digital format for analysis. Scores for this test are the sum of the number value for each response, multiplied by 4, to place the index on a scale of 0–100.

Heart rate monitoring

Heart rate was monitored using a Garmin F920 sports watch connected to a chest band worn on the skin. Heart rates were recorded on the watch, then transferred to a computer and analysed later. The recorded data were converted from the propriety XML format (TCX) to comma-separated values using R (R Core Team, 2017) and a modified version of an open-source R-script (White & Kleinböhl, 2013). In many instances, gaps in the heart rate record were found. This was most likely caused by the band contacts not maintaining connection with the skin, and, in some cases, batteries running out of power. In a few instances, readings could not be acquired at all due to chest bands not fitting or otherwise failing to supply readings.

Inducing stress

Stress was induced using an emotion induction procedure by presenting film segments to elicit a negative affective state (Dickerson & Kemeny, 2004). Two segments of feature films were selected and used to induce stress with the presumption of fair use of copyrighted materials (Greengrass, 2016; Soderbergh, 2012). Each video was approximately 6 min long and contained similar, but not identical, content. Both were excerpts from separate action films featuring intense scenes of physical violence. Videos were shown on a tablet or laptop computer with the volume on. The device was left in the test environment until the following saliva sample collection. Video selection was randomized between tests, and subjects did not see the same video twice.

Cortisol concentration determination

Saliva samples were processed according to kit manufacturer suggestions. Saliva samples and washing liquid

were transferred by hand, while other components were transferred by a pipetting robot.

Each test produced 7 saliva samples (854 total saliva samples). Each saliva sample was tested in duplicate. Each 96-well microtitre plate had space for 5 tests to be assayed fully on the plate (7 samples per test, in duplicate, required 14 wells) after wells for calibrators, blanks, negatives, and controls were filled.

In one case, the pipetting robot failed to securely attach a pipette tip to one pipette channel, leaving the second row on the plate without TMB substrate, producing negative readings for the entire row. In this case, the dose–response curve was fit with six calibrators instead of seven, and all controls were within the specified range. The second saliva sample for the effected samples was not read, and the reported results exclude this reading for those samples.

In another case, a power outage in the building occurred while the pipetting robot was transferring the diluted conjugate to the plate. This event required that the diluted conjugate was manually transferred to columns 6 through 12.

Cortisol analysis

Optical densities from microtitre plate readings taken at 450 nm were converted to cortisol concentrations by first fitting a curve to the mean value of each calibrator. The curve was fit using a four-parameter log-logistic regression as suggested by the kit manufacturer (Equation (1)). Following curve fitting, cortisol concentrations were calculated for controls and saliva samples.

$$f(x, (b, c, d, e)) = c + \frac{d - c}{(1 + \exp^{(b(\log(x) - \log(e))})} \quad (1)$$

where x is the optical density reading, b is the steepness of the curve, c is the lower asymptote, d is the upper asymptote, e is the midpoint between asymptotes, exp is the exponent and log is the natural logarithm.

Cortisol concentrations were compared within-subjects, meaning that the compared value was the difference between an individual's cortisol concentration in the wood environment and control environment.

Data analysis

Analysis was conducted in R 3.4.2 (R Core Team, 2017) using RStudio 1.0.153 (RStudio Inc., 2017). Charts were made using the R packages ggplot2 (Wickham, 2009) and ggforce (Pedersen, 2016). Dose–response curves were fit using the R package drc (Ritz, Baty, Streibig, & Gerhard, 2015). Documentation of the analysis in R is available online (Burnard, 2019).

Hypotheses were tested using the Wilcoxon signed-rank test to look for statistically significant differences between values of interest. The Wilcoxon signed-rank test was used because the data did not meet the assumptions of a *t*-test based on the normal distribution and equal variance. *P*-values less than .05 indicate a statistically significant difference. All hypothesis tests were constructed as one-sided, paired tests. Therefore, reported confidence intervals are one-sided and range from a single value to infinity. Since these significance tests were paired, the reported medians are not the difference between the medians of each sample but are the median of the difference between a sample from each test environment (control and wood) and all samples from the other test environment.

Within-subjects comparison of the WHO-5 well-being index differences between tests was made using the two-sided, paired Student's t-test.

The raw data for this study were the transmittance readings for each well on the microtitre plates, subject heart rate during each test, and demographic data. Demographic data consisted of age in years, sex, and occupation category (student or professional). Heart rate was recorded as beats per minute at 1-s intervals throughout the test duration. Microtitre plate readings were optical densities taken at 450 nm then converted to cortisol concentrations in nmol/L. WHO-5 responses were numerical values between 0 and 100.

Ethics approval for testing human subjects and anonymity

Medical ethics approval for this experiment was required because it dealt with human subjects, biological samples, and stress interventions. An application was prepared and submitted to the Komisija Republike Slovenije za medicinsko etiko (Commission of the Republic of Slovenia for Medical Ethics) on 6 November 2014. Approval was granted 16 December 2014; the reference number is 78/12/14.

All respondents reviewed and signed an informed consent document based on the World Health Organization informed consent template for clinical studies but modified for this experiment. It was available in Slovenian and English.

Participant identities are masked with pseudonyms to ensure their anonymity in this report.

Results

The results indicated that, under certain conditions, using wood in the built indoor environment may lead to improved stress responses. For example, stress

responses indicated by salivary cortisol levels were lower in the test environment with oak furniture (Office A: Oak) than in the corresponding control environment (Office A:Control). The reduced reaction to stress has a small effect for any single stressful situation, but, over time, even small reductions to stress responses can contribute to improved mental and physical health outcomes, which in turn lead to improved social outcomes (McEwen, 1998).

Experiment efficacy

The goals of this experiment were to create a stress response that could be detected by monitoring heart rate and salivary free cortisol concentration and then observe the magnitude of the response to the stressor and recovery from it for comparison between test conditions. The stressor produced visible stress responses of similar magnitudes. There was no detectable difference between cortisol responses to the different videos (two-sided p-value: .819).

Cortisol response

Cortisol responses in the body are nearly immediate, but there is a delay of 25–45 min after the stress event before it reaches saliva. The response to the stressor was visible in cortisol concentration changes, typically as an increase in cortisol concentration from minute 45 to minute 60. In ideal situations, the pattern was similar between the two tests for each subject but with a detectable difference between the two tests. Recovery was expected to be visible as a decrease in cortisol concentration that appeared between the minutes 45 and 75 (Figure 3).

However, this pattern was not always observed. Variations of the expected pattern were observed in several cases. These variations included:

- Minor variations in one segment of the test (e.g. the moderate rise in cortisol concentration at the beginning of the test discovered in the control environment, Figure 3);
- A near-continuous decrease in cortisol concentration in one test with no evidence of an acclimation period;
- No noticeable reaction to the stressor, as in the wood environment; or
- Sharp rises at the beginning of the test, which may have indicated feeling stress when coming to take the test (i.e. the test itself may have caused a stress reaction before it even began).

In addition to variations on the expected response pattern, several cases produced more ambiguous results. In ambiguous cases, it was difficult to determine if there

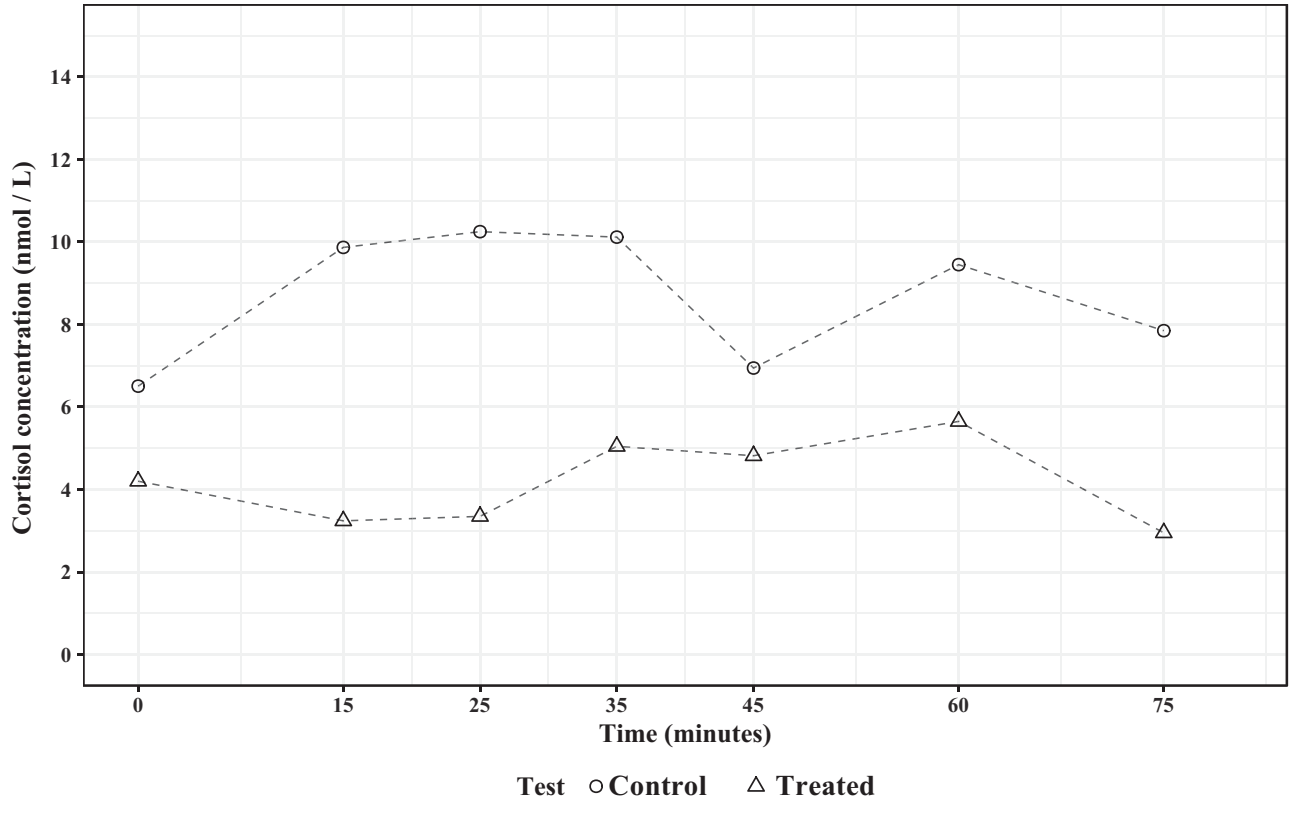

Figure 3. Observed cortisol response pattern for one subject, representing a typical pattern.

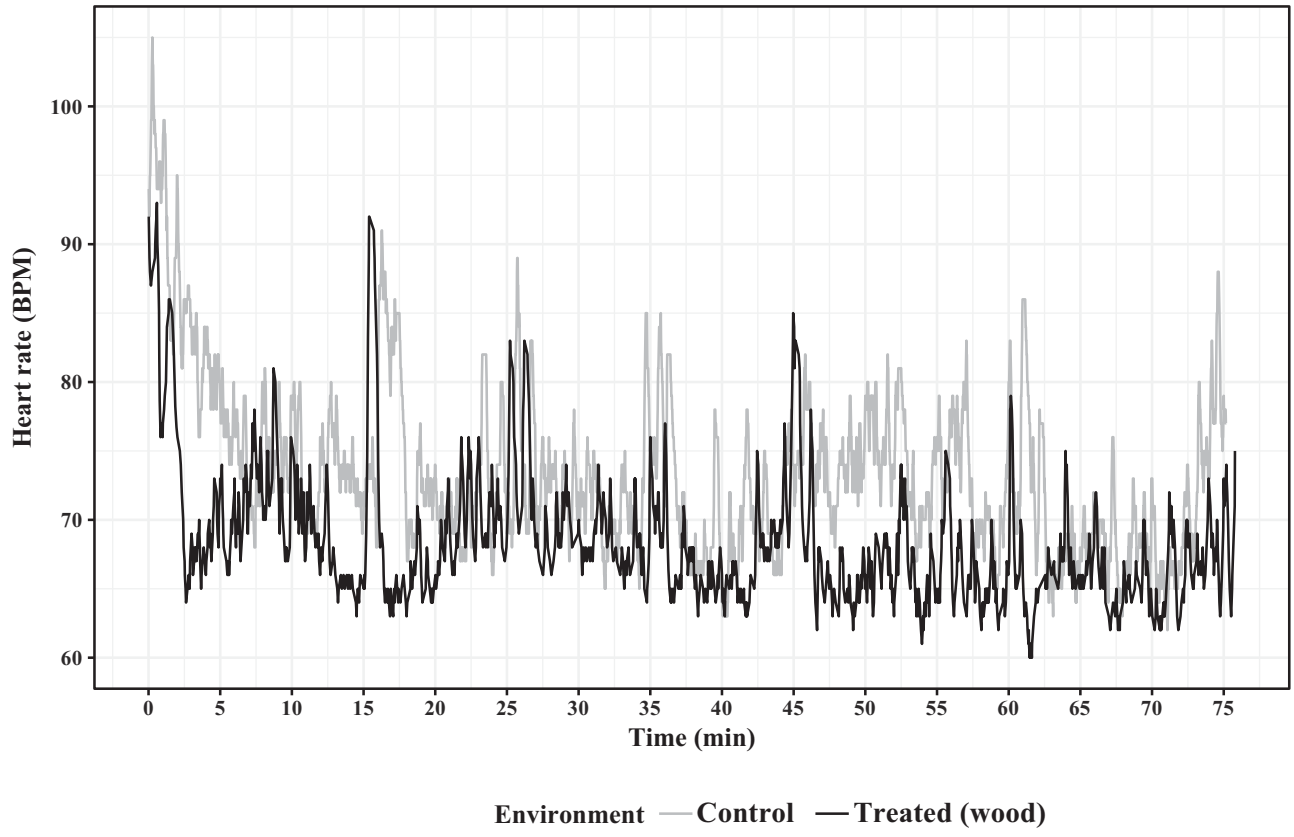

Figure 4. Example heart rate of a participant through both the control and treated tests.

was a stress response that changed salivary cortisol concentration.

Although it is tempting to associate some ambiguous cases with positive outcomes (i.e. a lack of a stress response in the treated environment mitigated the effect of the stressor), the presence of the expected response pattern in the majority of cases makes this difficult to support without further evidence.

Despite any variations or ambiguities present in the cortisol response patterns, this method for monitoring stress proved effective in this experiment.

Heart rate

Heart rate was used to verify that the stress response occurred. In heart rate responses, the stressor produced a clear pattern with sharp and large increase when exposed to the stressor and smaller increases when saliva samples were collected (e.g. sharp heart rate increases at minutes 25, 35, 45, 60, and 75 in Figure 4). The cause of these spikes remains uncertain but are likely related to either the sudden appearance of the researcher collecting the saliva sample or the response to the actual process of providing the sample (gently chewing on a small swab for 45 s).

Analysis of ELISA processing

Differences in plate to plate processing is a source of uncertainty in ELISA analysis. The outcome of this analysis is reasonably positive (Table 1). The most

Table 1. Known and calculated calibrator cortisol concentrations.

Known concentration (nmol/L)	Mean concentration (nmol/L)	Concentration difference (nmol/L)	Concentration difference (%)	Standard deviation	Coefficient of variation
0	0.38	0.38	∞	0.60	1.57
1.38	2.52	1.14	83	0.70	0.28
2.76	4.21	1.45	53	0.78	0.18
13.80	13.97	0.17	1	1.04	0.07
27.60	27.40	−0.20	−1	1.28	0.05
55.20	58.27	3.07	6	1.84	0.03
276.00	285.28	9.28	3	8.43	0.03

concerning deviations are those between the expected value of 2.76 nmol/L and the calculated mean value of 4.21 nmol/L (153% difference in concentrations). Not only is this a large deviation relative to the known value, it also lies in the same range as many calculated concentrations for saliva samples.

While this may not provide strong confidence that the calculated cortisol concentrations from saliva samples are true concentration values, the consistency between plates is strong enough to provide confidence that a sample calculated to have a cortisol concentration in this range would have approximately the same calculated concentration on another plate. This ensures within-subjects comparison, and test-to-test quantities should be reliable. The fit of individual models is reported in the supplemental material.

The controls used on each plate provide another means of assessing the reliability of the output. Unlike the calibrators with precisely known quantities, the cortisol concentration of the controls had an expected range. The three external controls used on all plates and the two internal controls for each kit were within the expected range.

To further validate plate-to-plate consistency, three full saliva sets (i.e. all seven samples from a single test), were assayed a second time on another plate. Only one of three saliva sets revealed a concerning difference between measurements, while the other two sets were near the expected amount of variation in this type of biochemical assay (10%, Kirschbaum et al., 1995). The mean cortisol concentration calculated in the duplicated assessment for subject XMI10 was 24% lower in the verification assay than in the original assay (Table 2). However, replacing the original results with the verification results does not alter the outcome of the significance tests. The original results for all duplicated sets were used for significance testing and visualizations.

WHO-5 well-being index

Reponses to the well-being index were within the expected range in all but three cases, where the total score was low enough to raise concern about the subject's overall well-being (scores totalling 32 or lower). In these cases, subjects were notified that their scores were low enough to raise concern, and the option was given to provide contact information for counselling. The test outcomes for these individuals were in line with expectations and left in the final analysis.

There was no evidence of a within-subjects difference in WHO-5 well-being index scores between tests (paired, two-sided p-value: .30).

Table 2. Mean absolute and per cent difference in cortisol concentrations between assays duplicated on separate trays.

Duplicate	Mean absolute difference (nmol/L)	Mean per cent difference (%)
FSE92	0.41	7.91
WTL11	0.62	12.4
XMI10	3.83	24.0

Stress responses and cortisol concentration comparisons

For the purpose of these cortisol concentration descriptions and comparisons, outcomes are considered positive if the cortisol concentration is lower for the period of interest (i.e. the entire duration or a subset of the duration) in the associated wood environment than in the control environment. When this is not true, the outcome is considered negative.

However, in the case of recovery, the value compared is the within-subjects difference between the control and wood environment (control value minus value in the wood room). This parameterization tests the hypothesis that the value in the control environment is greater than in the associated wood environment, or that the degree of recovery was lower in the control environment.

In both Office A and Office B, there were more positive outcomes than negative in all tested conditions except for recovery, where there were 16 negative and 15 positive outcomes. This indicates wood furniture may produce positive health impacts for the majority of office workers in offices without wood furniture by reducing the cortisol response to stressors in the workplace.

Full test duration cortisol concentration

In Office A:Oak, the mean observed difference in cortisol concentration was 13.6% (std. dev.: 44%) greater in the control environment than in the test environment. In Office B:Walnut, the mean observed difference in cortisol concentration was 1% (std. dev.: 45%); however, there were many more negative outcomes in Office B than in Office A (Figure 5).

In Office A, there were 22 tests with positive outcomes (mean cortisol concentration was lower in the wood environment) and 7 negative outcomes. In Office B, there were 18 positive and 13 negative outcomes.

Due to the wide range of cortisol concentrations exhibited by individuals, the differences in cortisol concentrations between control and treated environments as a per cent of the control environment cortisol concentration are presented in Table 3. These values indicate

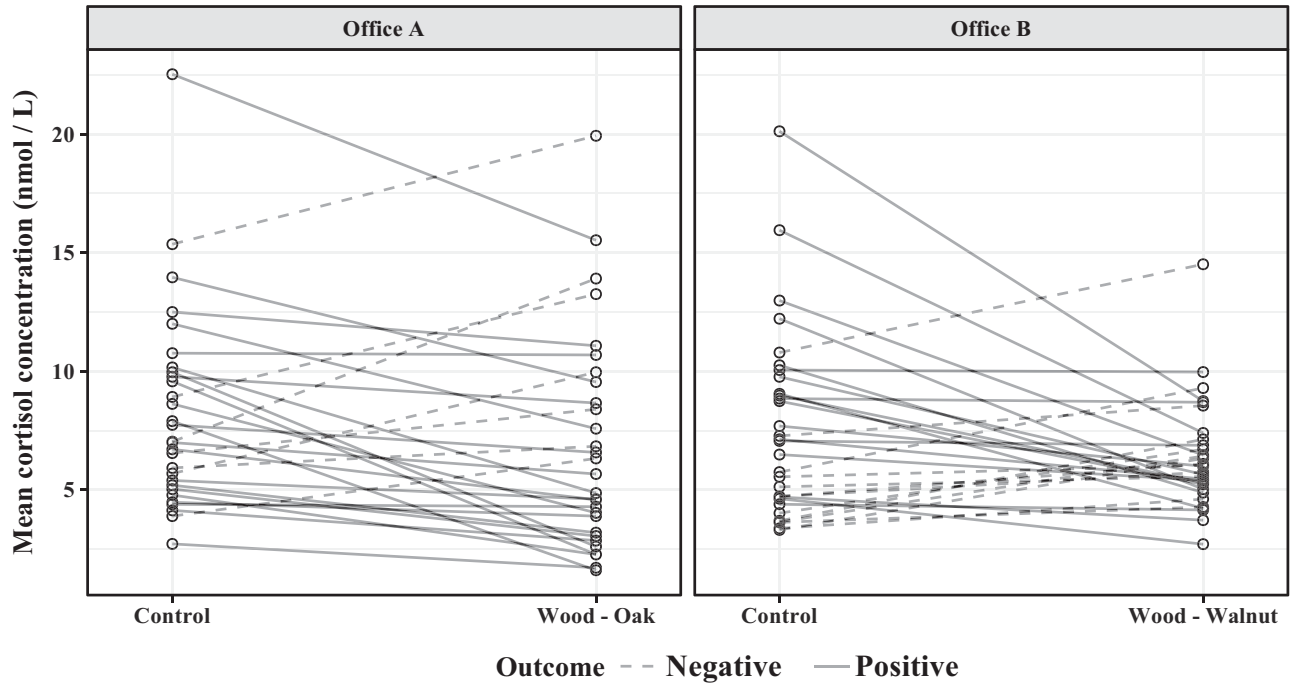

Figure 5. Full test duration mean cortisol concentration comparisons. Circles indicate mean values, lines connect subjects between test environments (control, wood).

the within-subjects difference varied greatly, with negative outcomes appearing.

Overall, mean cortisol concentration for the full test duration was greater in Office A:Control than in Office A:Oak (p-value: .015, Table 4), indicating a lower level of stress in the office with oak furniture. There was no statistically significant difference in the overall cortisol concentration between the Office B:Walnut and Office B:Control (p-value: .105, Table 4).

Since this comparison includes the period of the experiment where observed cortisol concentrations are most likely in relation to events preceding the beginning of the test, the baseline period (minutes 0, 15, and 25) was also compared. There was moderate evidence the mean cortisol concentration in saliva samples collected during the baseline were lower in Office A:Oak than in Office A:Control (median difference: 1.28 nmol/L; p-value: .028; 95% one-sided CI: greater than 0.313 nmol/L), while there was no evidence of a difference between Office B:Walnut and Office B:Control.

This outcome confuses the results as it makes it more difficult to attribute any experimental parameters as the reason for a difference in observed stress. However, the response period means (minutes 35 through 75) provide further evidence that the experimental stress and stress response differed between test conditions.

Table 4. Full test mean cortisol concentration comparison results.

Comparison	Median difference (nmol/L)	95% CI (1-sided)	*p*-Value
Office A:Control–Office A: Oak	1.33	0.25 to ∞	.015*
Office B:Control–Office B: Walnut	0.85	- 0.23 to ∞	.105

*Significant at the .05 level.

Table 3. Within-subjects difference between the mean cortisol concentration throughout the entire test period as a per cent of the concentration in the control room.

Environment	Group	Mean (%)	Standard deviation	Minimum (%)	Maximum (%)	*n*
Office A	Positive	34	23	0.0	80	22
Office A	Negative	−51	29	−98	−15	7
Office A	All	14	44	−98	80	29
Office B	Positive	32	21	0.0	59	18
Office B	Negative	−43	31	−93	−9	13
Office B	All	1.0	45	−93	59	31

Note: Negative values indicate the mean cortisol concentrations were greater in the treated room.

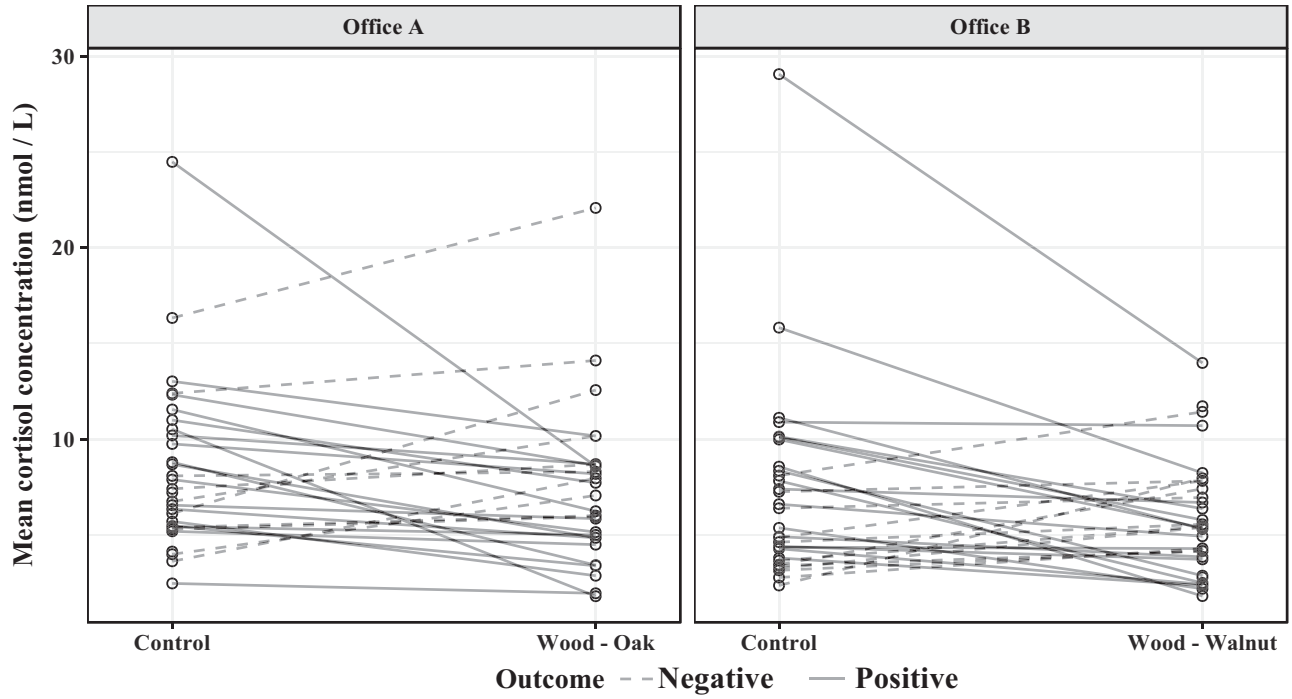

Figure 6. Response period (intervals 4, 5, 6, and 7; minutes 35 through 75) cortisol concentrations.

Response period cortisol concentration

The response period includes four saliva samples taken at minutes 35, 45, 60, and 75. Cortisol concentrations are expected to be influenced by the experiment during this period. The acclimated cortisol response and, when present, stress and recovery responses are included in this time frame.

During the response period, there were 19 positive responses and 10 negative responses in Office A; while in Office B, there were 17 positive and 14 negative responses. In Office A, the mean cortisol concentration for the response period was 13% (std. dev.: 46) greater in the control environment than in the wood environment. In Office B, the mean cortisol concentration was 2.7% (std. dev.: 47) greater in the wood environment than the control environment for the same period. Despite the greater cortisol concentration difference in Office B, the number of negative outcomes was greater than in the oak room, producing more uncertainty about the overall effect in this environment (Figure 6).

In both Office A and Office B, there was a single case where the magnitude of the difference between the control and wood environments was double the value in the control environment (values less than −100 in Table 5). In both of these cases, cortisol concentration during the response period was greater in the wood environment. The range of within-subjects differences was also greater in Office A than Office B.

There was evidence that within-subjects difference in cortisol concentration for the response period was lower in Office A:Oak than in Office A:Control (p-value: .017; 95% one-sided CI: median difference > 0.23 nmol/L, Table 6). There was no evidence of a difference between Office B:Walnut and Office B:Control (p-value: .108, Table 6).

Table 5. Within-subjects difference between the mean cortisol concentration during the response period as a per cent of the mean concentration in the control room.

Environment	Group	Mean (%)	Standard deviation	Minimum (%)	Maximum (%)	*n*
Office A	Positive	38	23	4.5	80	19
Office A	Negative	−33	42	−125	−0.0	10
Office A	All	13	46	−125	80	29
Office B	Positive	37	20	10	68	17
Office B	Negative	−39	33	−110	−1.1	14
Office B	All	2.7	47	−110	68	31

Note: Negative values indicate the mean cortisol concentrations were greater in the wood room.

Table 6. Response period (intervals, 4, 5, 6, and 7; minutes 35 through 75) cortisol concentration comparison results.

Comparison	Median difference (nmol/L)	95% CI (1-sided)	*p*-Value
Office A:Control–Office A: Oak	1.15	0.23 to ∞	.017*
Office B:Control–Office B: Walnut	0.98	−0.16 to ∞	.108

Table 8. Response magnitude cortisol concentration comparison results.

Comparison	Median difference (%)	95% CI (1-sided)	*p*-Value
Office A:Control–Office A:Oak	−5.4	−15 to ∞	.833
Office B:Control–Office B: Walnut	6.5	−2 to ∞	.098

Response magnitude

Another indicator of interest is the magnitude of the stress response itself. In this experiment, the magnitude of the stress response is the difference between the maximum cortisol concentration observed at minute 45, 60, or 75 and the minimum cortisol concentration observed at minute 25 or 35, as a per cent of the minimum. There was one case where there was no apparent stress response in either test setting (i.e. the minimum at minute 25 or 35 was higher than the maximum at minutes 45, 60, or 75). In this case, the response magnitude was considered 0. Reported magnitudes are the per cent difference between the minimum and maximum.

In Office A, there were 14 positive outcomes, 14 negative outcomes, and 1 neutral outcome. In Office B, there were 19 positive outcomes and 12 negative outcomes. The mean magnitude of the stress response in Office A was −6.5% (std. dev.: 26%) and 10% (std. dev.: 42%) in Office B. In Office A, the observed magnitude difference ranged from −64% to 42%; while in Office B, the magnitude ranged from −50% to 196% (Table 7).

There was no evidence of a within-subjects difference between control and wood environments in either Office A or Office B (*p*-values: .833 and .098, respectively; Table 8). Overall, the pattern of responses is less clear in this case than in either the full test duration means or response period means. It is worth noting, in the case of stress response magnitudes, the number of positive outcomes in the Office B environment was greater than in Office A, and the variance was lower in Office B as well. This is the opposite of the pattern observed in the response period or full test duration means.

Recovery magnitude

The magnitude of recovery is the difference between the maximum cortisol concentration observed in saliva samples from minutes 35, 45, 60, and 75 and the observed cortisol concentration at minute 75, as a per cent of the maximum. This parameterization introduces the possibility of recovery magnitudes equal to zero when the peak cortisol concentration observed is at minute 75. This occurred in 12 cases, 6 in Office A and 6 in Office B. In both Office A and Office B, the recovery magnitude was observed to be zero three times in the control environment and three times in the wood environment. This indicates it would be prudent to extend the test period in future experiments.

Overall, there was little difference in the degree of recovery observed in either office or between the wood and control environments (Table 9). There was no readily apparent pattern indicating that recovery magnitude was greater or there were more positive or negative outcomes in either the oak or walnut environments or in the control environments compared to the wood environments.

The number of positive and negative responses was nearly even in the case of recovery for both test environments.

There was no evidence that the recovery magnitude was greater in either wood environment compared to their respective control environments (Office A *p*-value: .559; Office B *p*-value: .580; Table 10).

Table 7. Within-subjects difference between the magnitude of the stress response (in nmol/L cortisol concentration).

Environment	Group	Mean (%)	Standard deviation	Minimum (%)	Maximum (%)	*n*
Office A	Positive	14	12	0.4	42	14
Office A	Negative	−28	19	−64	−5.6	14
Office A	All[a]	−6.5	26	−64	42	29
Office B	Positive	29	42	1.4	196	19
Office B	Negative	−19	17	−50	−1.4	12
Office B	All	10	42	−50	196	31

Notes: Negative values indicate the magnitude of the stress response was greater in the wood room. Neutral responses not included in calculations.
[a]For one subject there was no detectable stress response in either test environment of Office A. This case is not included in the positive or negative groups for Office A but is included in the All group.

Table 9. Within-subjects difference between the magnitude of the stress recovery.

Environment	Group	Mean (%)	Standard deviation	Minimum (%)	Maximum (%)	*n*
Office A	Positive	21	14	1	48	17
Office A	Negative	−15	12	−50	0	12
Office A	All	0.2	22	−50	48	29
Office B	Positive	16	9.5	0.4	39	14
Office B	Negative	−20	11	−42	−2.2	17
Office B	All	0.6	21	−42	39	31

Note: Negative values indicate the magnitude of the stress recovery was greater in the control room.

No substantial difference was observed or detected in the recovery from the stressor. This may be due to the short duration of the test period preventing recovery that occurred after the end of the test from being detected. It may also have been caused by time gap between measurements taken during the response and recovery period.

Discussion

The findings in this study were similar to previous studies examining the relationship between wood and occupant stress levels but were derived from a more robust experimental design. Some results were comparable to other intervention studies using salivary cortisol as an indicator of stress.

The full response period differences in cortisol concentration observed in (Office A:Oak) are similar to the skin conductance responses (frequency of non-specific skin conductance responses) in Fell's, 2010 experiment, which was also set in office-like environments. In both cases, subjects in wood offices experienced lower overall apparent stress levels. Another study monitoring stress responses using salivary free cortisol found similar results (lower overall stress activation during the test period) where the intervention between tested groups was therapeutic in nature (cognitive–behavioural training) as opposed to environmental (Gaab et al., 2003).

As may be expected from the full-period cortisol concentrations, the response period cortisol concentrations were also lower in Office A:Oak. Differences in stress responses during this period are the most telling in terms of potential usefulness for environmental interventions to improve the well-being of office workers.

Table 10. Recovery magnitude cortisol concentration comparison results.

Comparison	Median difference (%)	95% CI (1-sided)	*p*-Value
Office A:Control–Office A:Oak	−0.7	−9 to ∞	.559
Office B:Control–Office B: Walnut	−0.8	−7 to ∞	.580

Previously, evidence was found that frequency of non-specific skin conductance responses was lower in a wood test environment compared to a control environment, indicating lower stress levels, similar to results for Office A in this experiment. In Fell's study (2010), the wood furniture used was light in colour (birch veneer with a clear finish), which is more similar to the oak furniture than the walnut furniture used here.

While this study tested stress response magnitude, no difference was found between wood and non-wood environments. This is contrary to the salivary free cortisol response results reported in Gaab et al. (2003), where a difference in response magnitude between test groups (those receiving cognitive–behavioural training before the experiment and those receiving it after) was observed. This may be caused by the stressor itself not producing a strong enough effect, the small expected effect size, or the timing of the saliva sample collection. Revisions to the experimental setup could help detect magnitude differences by adjusting the timing of saliva sample collection and including a more effective secondary measure of stress response.

Conclusions

This study examined human stress responses in two offices with wood furniture (one with oak and one with American walnut) in comparison to an office with white furniture in a within-subjects design. Stress was induced in subjects and measured using salivary free cortisol concentration as an indicator. Sixty-one healthy adult subjects were observed over a period of 75 min so that stress responses and recovery could be analysed. Stress levels throughout the entire period and during the response period were significantly lower in the oak environment than in the control environment, but no differences were detected in the magnitude of the stress response or in the degree of recovery from it. No significant differences were detected for any tested response or recovery between the walnut environment and the control environment. It is worth noting that the effect size in question in this type of study is expected to be

small, and, consequently, the full impact on humans is expected to be cumulative rather than immediate. Even a small difference in stress response can be significant over a long period of time.

Although this experiment was moderate in scale, including only 61 subjects, the results indicate it is possible to use wood furniture as a passive environmental intervention to help office workers cope with stress. However, when selecting wood furniture, it is important to consider visual characteristics, amongst other aspects, and how they interact with other elements of the indoor environment (e.g. lighting). The oak furniture used in this experiment was noticeably lighter in colour and produced a noticeably brighter environment than the office with walnut furniture, even though lighting levels were the same in each room. Although the experimental design was generally effective in this study, future studies replicating it should consider two adjustments to the experimental procedure. First, the duration should be extended to at least 90 min to allow for a greater degree of recovery to be observed. Second, saliva samples should be collected with greater frequency in the later part of the test period (e.g. beginning 25 min after the stress event) to allow for peak stress and stress recovery to be observed in greater detail. Additionally, future studies should consider maintaining the same luminance in each test environment, rather than keeping lighting levels constant. Finally, it is recommended to include an emotional or affective scale in the test procedure to provide more contextual information about the stress response (i.e. to illicit the valence of the response in more detail).

The most common and effective approaches to reducing this type of stress response are therapeutic and social (McEwen, 1998). Regardless, environmental interventions show demonstrable reductions in the cortisol response to stress and may be a useful, affordable, and readily available way to improve the health of office workers.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The authors gratefully acknowledge the European Commission for funding the InnoRenew CoE project (Grant Agreement #739574) under the Horizon2020 Widespread-Teaming program and the Slovenian infrastructure programme IO-0035.

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References

Attaianese, E., & Duca, G. (2012). Human factors and ergonomic principles in building design for life and work activities: An applied methodology. *Theoretical Issues in Ergonomics Science*, *13*(2), 187–202. doi:10.1080/1463922X.2010.504286

Bamba, I., & Azuma, K. (2016). Psychological and physiological effects of Japanese cedar indoors after Calculation task performance. *Journal of the Human-Environment System*, *18*(2), 33–41. doi:10.1618/jhes.18.33

Bernadet, P. (1995). Benefits of physical activity in the prevention of cardiovascular diseases. *Journal of Cardiovascular Pharmacology*, *25*(1), S3–S8.

Bhatta, S. R., Tiippana, K., Vahtikari, K., Hughes, M., & Kyttä, M. (2017). Sensory and emotional perception of wooden surfaces through fingertip touch. *Frontiers in Psychology*, *8* (Mar), 1–12. doi:10.3389/fpsyg.2017.00367

Burnard, M. (2017). Bio-based materials and human well-being in the built environment. In D. Jones & C. Brischke (Eds.), *Performance of bio-based materials* (1st ed., pp. 365–372). Duxford: Woodhead.

Burnard, M. (2019). Human stress responses in office-like environments with wood furniture: Data processing and analysis. *Zenodo Data Repository*. doi:10.5281/zenodo.3362236

Burnard, M., & Kutnar, A. (2015). Wood and human stress in the built indoor environment: A review. *Wood Science and Technology*, *49*(5), 969–986. doi:10.1007/s00226-015-0747-3

Burnard, M., Nyrud, A. Q., Bysheim, K., Kutnar, A., Vahtikari, K., & Hughes, M. (2017). Building material naturalness: Perceptions from Finland, Norway and Slovenia. *Indoor and Built Environment*, *26*(1), 92–107. doi:10.1177/1420326X15605162

Cohen, S., Kessler, R., & Underwood-Gordon, L. (1995). *Measuring stress: A guide for health and social scientists*. New York: Oxford University Press.

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. doi:10.1037/0033-2909.130.3.355

Dolan, P., Foy, C., & Smith, S. (2016). The SALIENT checklist: Gathering up the ways in which built environments affect what we do and how we feel. *Buildings*, *6*(1), 9. doi:10.3390/buildings6010009

Fell, D. (2010). *Wood in the human environment: Restorative properties of wood in the built indoor environment*. Vancouver: University of British Columbia.

Finnegan, M. J., Pickering, C. A., & Burge, P. S. (1984). The sick building syndrome: Prevalence studies. *British Medical Journal (Clinical Research Ed.)*, *289*(6458), 1573–1575. doi:10.1136/bmj.289.6458.1573

Gaab, J., Blättler, N., Menzi, T., Pabst, B., Stoyer, S., & Ehlert, U. (2003). Randomized controlled evaluation of the effects of cognitive-behavioral stress management on cortisol responses to acute stress in healthy subjects. *Psychoneuroendocrinology*, *28*(6), 767–779. doi:10.1016/S0306-4530(02)00069-0

Greengrass, P. (2016). *Jason Bourne*. USA: Captivate Entertainment.

Hartig, T., Korpela, K., Evans, G. W., & Gärling, T. (1997). A measure of restorative quality in environments. *Scandinavian Housing and Planning Research*, *14*(4), 175–194. doi:10.1080/02815739708730435

Ikei, H., Song, C., & Miyazaki, Y. (2017). Physiological effects of wood on humans: A review. *Journal of Wood Science*, *63* (1), 1–23. doi:10.1007/s10086-016-1597-9

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

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182. doi:10.1016/0272-4944(95)90001-2

Kellert, S. R. (2008). Dimensions, elements and attributes of biophilic design. In S. R. Kellert, J. Heerwagen, & M. Mador (Eds.), *Biophilic design: The theory, science and practice of bringing buildings to life* (1st ed., pp. 3–19). Hoboken: Wiley.

Kirschbaum, C., & Hellhammer, D. H. (1994). Salivary cortisol in psychoneuroendocrine research: Recent developments and applications. *Psychoneuroendocrinology*, *19*(4), 313–333. doi:10.1016/0306-4530(94)90013-2

Kirschbaum, C., Preussner, J., Stone, A., Federenko, I., Gaab, J., Lintz, D., … Hellhammer, D. H. (1995). Persistent high cortisol respnoses to repeated psychological stress in a subpopulation of healthy men. *Psychosomatic Medicine*, *57*, 468–474.

McEwen, B. S. (1998). Protective and damaging effects of stress mediators. *New England Journal of Medicine*, *338*(3), 171–179. doi:10.1056/NEJM199801153380307

McEwen, B. S. (2008). Central effects of stress hormones in health and disease: Understanding the protective and damaging effects of stress and stress mediators. *European Journal of Pharmacology*, *583*(2), 174–185. doi:10.1016/j.ejphar.2007.11.071

McEwen, B. S. (2009). Stress mediators. *European Journal of Pharmocology*, *583*(2–3), 174–185.

Nyrud, A. Q., & Bringslimark, T. (2010). Is interior wood use psychologically beneficial? A review of psychological responses toward wood. *Wood and Fiber Science*, *42*(2), 202–218.

Park, B.-J., Tsunetsugu, Y., Kasetani, T., Hirano, H., Kagawa, T., Sato, M., & Miyazaki, Y. (2007). Physiological effects of Shinrin-yoku (taking in the atmosphere of the forest) – Using salivary cortisol and cerebral activity as indicators. *Journal of Physiological Anthropology*, *26*(2), 123–128. doi:10.2114/jpa2.26.123

Pedersen, T. L. (2016). *ggforce: Accelerating 'ggplot2'*. Retrieved from https://cran.r-project.org/package=ggforce

R Core Team. (2017). *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. Retrieved from https://www.r-project.org/

Rice, J., Kozak, R. a., Meitner, M. J., & Cohen, D. H. (2006). Appearance wood products and psychological well-being. *Wood and Fiber Science*, *38*(4), 644–659.

Ritz, C., Baty, F., Streibig, J. C., & Gerhard, D. (2015). Dose-response analysis using R. *PLoS One*, *10*(12), 1–13. doi:10.1371/journal.pone.0146021

Rovio, S., Kareholt, I., Helkala, E.-L., Viitanen, M., Winblad, B., Tuomilehto, J., … Kivipelto, M. (2005). Leisure-time physical activity at midlife and the risk of dementia and Alzheimer's disease. *The Lancet. Neurology*, *4*(11), 705–711. doi:10.1016/S1474-4422(05)70198-8

RStudio Inc. (2017). *RStudio*. Retrieved from http://rstudio.com

Sakuragawa, S., Miyazaki, Y., Kaneko, T., & Makita, T. (2005). Influence of wood wall panels on physiological and psychological responses. *Journal of Wood Science*, *51*(2), 136–140. doi:10.1007/s10086-004-0643-1

Soderbergh, S. (2012). *Haywire*. USA: Relativity Media.

Topp, C. W., Østergaard, S. D., Søndergaard, S., & Bech, P. (2015). The WHO-5 well-being index: A systematic review of the literature. *Psychotherapy and Psychosomatics*, *84*(3), 167–176. doi:10.1159/000376585

Tsunetsugu, Y., Miyazaki, Y., & Sato, H. (2002). The visual effects of wooden interiors in actual-size living rooms on the autonomic nervous activities. *Journal of Physiological Anthropology and Applied Human Science*, *21*(6), 297–300. doi:10.2114/jpa.21.297

Tsunetsugu, Y., Miyazaki, Y., & Sato, H. (2007). Physiological effects in humans induced by the visual stimulation of room interiors with different wood quantities. *Journal of Wood Science*, *53*(1), 11–16. doi:10.1007/s10086-006-0812-5

Tyrväinen, L., Ojala, A., Korpela, K., Lanki, T., Tsunetsugu, Y., & Kagawa, T. (2014). The influence of urban green environments on stress relief measures: A field experiment. *Journal of Environmental Psychology*, *38*, 1–9. doi:10.1016/j.jenvp.2013.12.005

Ulrich, R. S. (1991). Effects of interior design on wellness: Theory and recent scientific research. *Journal of Health Care Interior Design : Proceedings*, *3*(11), 97–109.

White, A., & Kleinböhl, D. (2013). *TCX parser: An R library for parsing Garmin TCX files*. Retrieved from https://github.com/shiroandy/garmin-tcx-parser

Wickham, H. (2009). *Ggplot2: Elegant graphics for data analysis*. New York: Springer. Retrieved from http://ggplot2.org

Wilson, E. O. (1984). *Biophilia*. Harvard University Press. Retrieved from http://www.hup.harvard.edu/catalog.php?isbn=9780674074422&content=reviews

World Health Organization. (1998). *Wellbeing measures in primary health care/The Depcare Project*. Report on a WHO Meeting, 45. Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0016/130750/E60246.pdf

Zhang, X., Lian, Z., & Wu, Y. (2017). Human physiological responses to wooden indoor environment. *Physiology and Behavior*, *174*, 27–34. doi:10.1016/j.physbeh.2017.02.043