



Psychological and physiological effects of a wooden office room on human well-being: Results from a randomized controlled trial

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ABSTRACT

Natural materials and elements are considered to support human well-being. Wooden interior well-being effects were studied using a randomized controlled trial with a cross-over design ($n = 61$) in two rooms: a room with wooden elements and a control room without wood. The participants first performed cognitive tasks by the computer to imitate typical office work and increase their stress level and then had a rest period in an armchair in the same room. The restoration felt, energy level, mood, anxiety, sustained attention, heart rate variability, and skin conductivity were measured in both rooms. The results were analyzed using a Bayesian approach. The anxiety felt was clearly lower at the end of the experiment in the wooden room than in the control, while the other psychological measures showed only a slight indication that the wooden room was more beneficial for relaxation. Performances in sustained attention to the response task were similar in both rooms. Contrary to expectations, the sympathetic nervous system was more active in the wooden room, during and after rest and at the beginning of experiment. Overall, the results support slight positive effects of wooden material on mood on humans in the office environment.

1. Introduction

People's lifestyle is increasingly concentrated indoors, especially in high-income countries. Not only work but also a large part of free-time activities take place in indoor environments. Research has increasingly focused on whether it is possible to improve well-being and the quality of life by supporting performance and creativity to reduce stress and enhance mood with the choice of indoor materials and interior design elements (Douglas et al., 2022; Pasini, Brondino, Trombin, & Filippi, 2021; Shen, Zhang, & Lian, 2020; Yin, Zhu, MacNaughton, Allen, & Spengler, 2018). The accumulating evidence that distress and worry increase cardiovascular risk factors (e.g., Gan et al., 2014; Koch, Salzmann, Rief, & Euteneuer, 2019; Pieper, Brosschot, van der Leeden, & Thayer, 2007) makes it even more important to support human well-being and to design restorative indoor environments.

Given that most adults spend around one-third of their time in the working environment, it is crucial to recognize the important role of the physical environment as a factor in work satisfaction and productivity,

together with social and organizational factors (Dul, Ceylan, & Jaspers, 2011). Introducing natural elements, such as indoor plants (e.g., Bringslimark, Hartig, & Patil, 2009; Han, Wen-Huan, & Liao, 2022), providing window views (e.g., Lottrup, Stigsdotter, Meilby, & Claudi, 2015), and utilizing natural materials, can enhance well-being, creativity, work satisfaction, and work productivity (e.g., review by Colenbergh, Jylhä, & Arkesteijn, 2021; Douglas et al., 2022). Natural materials and colors are also preferred in break areas (Pasini et al., 2021). Taking regular breaks from work are crucial to reducing stress and preventing burnout. Research has shown that work breaks lasting at least 10 min are most efficient, as they not only alleviate fatigue and boost energy levels but also tend to improve work productivity (Albulescu et al., 2022). Therefore, establishing restorative work environments that can significantly positively impact employees' ability to cope with work-related stress is essential.

The psychological and physiological effects of wooden material on human well-being have been studied since the beginning of the twenty-first century (reviews by Burnard & Kutnar, 2015; Ikei, Song, &

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Miyazaki, 2017a; Alapieti, Mikkola, Pasanen, & Salonen, 2020; Lipovac & Burnard, 2020). Regarding the psychological self-reported effects of wood, the research evidence is more unanimous, while the effects of wood on physiology remains elusive. Many studies positively assess wood as a restorative, pleasant, warm, and soft material (Rice, Kozak, Meitner, & Cohen, 2006; Demattè et al., 2018; Poirier, Demers, & Potvin, 2019). Studies in which subjects were in an experimental setting inside a room have shown an increase in positive emotions, a decrease in negative emotions, and a decrease in fatigue in wooden rather than control rooms (Bamba & Azuma, 2015; Zhang, Lian, & Ding, 2016; Demattè et al., 2018). One recent study indicated that in room with natural materials, including wooden tables and chairs, participants' immediate stress response decreased in both the self-reporting of negative arousal and physiological (skin conductivity) measures compared to a room with artificial materials (Douglas et al., 2022). In these studies, materials were sensed through different senses simultaneously, including visual, tactile, and olfactory.

Wood materials emit special wood-smelling compounds into indoor spaces (Bamba & Azuma, 2015; Muilu-Mäkelä et al., 2021). In general, a moderate scent of wood is well accepted, and some compounds have been shown to evoke positive feelings (Shreiner et al., 2020) or relaxing effects by themselves (Ikei, Song, & Miyazaki, 2016). The material's thermal conductivity seems to play a major role in how pleasant the material feels to the touch, and the tactile impression may contrast with visual evaluations (Loredan, Lipovac, Jordan, Burnard, & Sarabon, 2022). Wood has low thermal conductivity and touching a smooth natural wood surface with the fingertip (tactile touch) was perceived more positively than coated wood (varnished, waxed) (Bhatta, Tiippana, Vahrikari, Hughes, & Kyttä, 2017). This finding was supported by a study by Ikei, Song, and Miyazaki (2017b), where mirror-coated (piano-coated) wooden material was found to increase, and untreated wood to decrease, sympathetic nervous system (SNS) activity as measured by heart rate variability (HRV) parameters and brain oxygen concentration.

There are therefore some indications that wood interior elements may influence SNS activity. It has been reported that viewing a wooden material (short 90 s visual contact) may reduce SNS activity as measured by HRV parameters (Tsunetsugu, Miyazaki, & Sato, 2002, 2007) or blood pressure (Sakuragawa, Miyazaki, Kaneko, & Makita, 2005; Tsunetsugu, Miyazaki, & Sato, 2007). However, in these studies, where the visual exposure time was less than 2 min, the physiological results remained contradictory. Some within subject studies of a slightly longer duration (10–75 min) have found no difference between wood and other materials in SNS activity (e.g., Bamba & Azuma, 2015; Zhang, Lian, & Wu, 2017). Burnard and Kutnar (2020) indicated that salivary cortisol levels decreased in front of a light-colored oak desk, whereas cortisol levels were unaffected by a dark walnut desk compared to the control in a 75-min measurement. However, due to individual differences and variation in the time of day, it turned out to be difficult to estimate the exact time, expressed in minutes, when the cortisol levels were potentially at their highest following a stressful stimulus. According to Lipovac and Burnard (2020), visual exposure to wood seems to mainly have positive outcomes on humans, with some reservations about the design of the study.

Restorative environments promote attention restoration and stress reduction. The attention restoration theory (ART) (Kaplan and Kaplan, 1989) and the stress reduction theory (SRT) (Ulrich, 1983; Ulrich et al., 1991) explain how and why nature and/or elements of nature affect people. According to ART, nature captivates involuntary attention in a soft manner, thereby allowing voluntary attention to rest. (Kaplan and Kaplan, 1989). SRT claims that because of human adaptation to nature through evolution, natural environments reduce stress by providing safety and maintenance of everyday needs. Several studies have shown support for these hypotheses. For example, exposure to nature is shown to increase felt restoration, positive affect, and the domination of the parasympathetic nervous system (PNS), both outdoors (e.g., Lanki et al., 2017; Park, Tsunetsugu, Kasetani, Kagawa, & Miyazaki, 2010; Pasanen,

Johnson, Lee, & Korpela, 2018; Tyrväinen et al., 2014) and indoors (e.g., Bernardo, Loupa-Ramos, Matos Silva, & Manso, 2021; Brown, Barton, & Gladwell, 2013; Raanaas, Evensen, Rich, Sjøström, & Patil, 2011; Van den Berg et al., 2015). There is solid proof that nature or the representation of nature increases human well-being in these terms, with some limitations of number of studies, heterogeneity of outcomes, and research designs (before-after measures) (e.g., see reviews by Bowler, Buyung-Ali, Knight, & Pullin, 2010; McMahan & Estes, 2015; Ohly et al., 2016).

With a few exceptions (e.g., Burnard & Kutnar, 2020; Demattè et al., 2018), these theories have not been explicitly applied in studies focusing on wooden interior effects. However, the majority of experimental work in this field interprets its results based on these theories (Lipovac and Burnard, 2020). For example, the activation of the PNS and increase of energy and a positive mood are related to the SRT (e.g., the used measures such as the EEG; emotional states (a profile of mood states (POMS), McNair, Lorr, & Doppleman, 1971; the positive and negative affect scale (PANAS), Watson, Clark, & Tellegen, 1988); and the measures of attention restoration, or cognitive performance, are related to the ART (e.g., backward span task, Wechsler, 1955; Vuksanović & Gal, 2007; Traina, Galullo, & Russo, 2011; sustained attention to response task (SART), Robertson, Manly, Andrade, Baddeley, & Yiend, 1997).

Many of the previous studies have used photographs or material samples instead of using actual wooden indoor environments. The paucity of studies using real wooden indoor environments and several methodological shortcomings (small sample sizes, no before-after measures or control conditions) (e.g., Sakuragawa et al., 2005; Tsunetsugu et al., 2013, 2007; Bamba & Azuma, 2015; Zhang et al., 2016, 2017; Lipovac, Podrekar, Burnard, & Sarabon, 2020; Shen et al., 2020) in the research design make it difficult to assess the effects of wood material on humans and how wood material relates to ART and SRT. Although several studies have focused on the natural elements indoors, and on how building or interior materials affect human well-being, the effects are still unclear.

1.1. The current study

The present study's aim was to evaluate the effect of indoor surface wooden material on human emotions, the activity of autonomic nervous system (ANS), and attention capacity during cognitive tasks and rest periods in authentic office environments by versatile psychological and physiological measures with a sufficient sample size. The workplaces should provide environments that help employees take microbreaks, reduce stress (SRT), and recover from attentional fatigue and cognitive depletion (ART). We need information concerning whether wooden environments are more restorative and relaxing than a room without wood.

Our main questions were: Do people 1) experience less psychological and physiological stress and enhanced recovery; and 2) perform better in a wooden room than in a control room? The hypotheses were:

- H1.** Exposure to a wooden room has stress- and anxiety-relieving effects compared to the control room. We expect people to experience more restoration, more energy, more positive and less negative feelings, and less anxiety after a rest period in the wooden room.
- H2.** People perform better (are faster and make fewer mistakes) in a sustained attention task after a rest period in the wooden room.
- H3.** The PNS is more active, and the SNS is less active, in the wooden room during a rest period.

2. Materials and methods

2.1. Recruitment and sample size calculation

Prior to the experiment, the Tampere University Hospital Ethics

Committee gave an ethical review statement, and the experiment followed the principles of the Declaration of Helsinki. The volunteers were recruited from Tampere University Hervanta campus. They were told that this study was about performing work-like assignments in different office environments, without any further details about the rooms. The exclusion criteria for participation were a medication affecting the central nervous system, continuous medication for cardiovascular diseases, asthma, hypertension, or a neurological condition (incl. clinical depression). An information letter about the experiment was emailed to the ones who showed interest in participating. When first arriving for the experiment, the volunteers had an opportunity to ask questions about the study, and they were informed of their rights and the course of the experiment. The volunteers signed a written informed consent form, after which Moodmetric skin conductivity measurement rings (Vigofere Ltd., Finland, since 2023 Nuanic Ltd.) with instructions were given to them to use throughout the two-week experimental period (see 2.4.

Experimental design). The experiment was carried out between August and November 2020.

Sample size and power calculations were carried out to ensure adequate statistical power. The calculations were made utilizing a logarithmically transformed standard deviation of NN intervals (SDNN), for which prior knowledge about the variation ($SD = 0.27$) based on 27 studies was readily available (Nunan, Sandercock, & Brodie, 2010). Assuming that a 10% difference in SDNN is considered clinically relevant and that the individual's measurements are correlated at $r = 0.50$, a power of 0.90 could be obtained with $N = 59$ subjects with three-measurement-cross-over design if the dropout rate was zero. This estimation was conservative in the sense that a reduction in variation related to controlling for covariates was not considered. The power calculations were made using the software PASS (PASS, 2019).

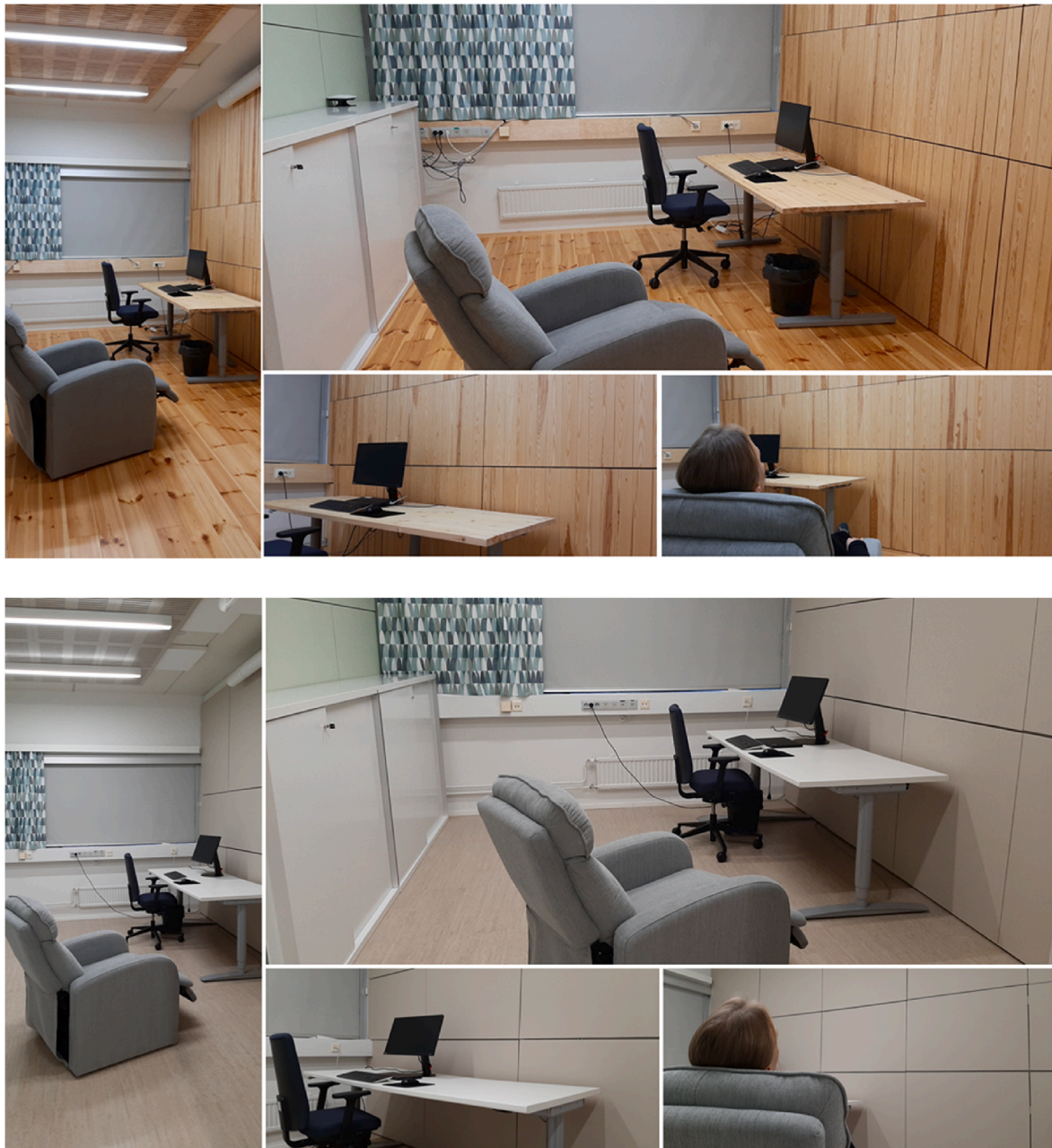


Fig. 1. Wooden (above) and control (below) rooms used in the experiment.

2.2. The wooden and control office rooms

The experimental rooms were set in the Hervanta campus area, hosting various departments of Tampere University, state research offices, and private companies.

The wooden and control office rooms were situated next to each other. Both 17 m² experimental rooms were designed as harmonious entities, and besides the difference in the materials of the floor, one wall, ceiling, and a tabletop were otherwise identical. In the wooden room, 50% of the surface material was pinewood. Pine is a commercially important tree species and a main species in wooden construction. The floor was made of lacquered pine parquet, and one wall was panelled with untreated pine panel. It had an acoustic veneer ceiling, and the tabletop material was glued laminated timber and pine. The flooring in the control room was vinyl cork, and one wall had a gray-painted plasterboard panel. In the control room, the ceiling was a gray-painted acoustic panel, and a white laminate board was used for the tabletop. One wall in both rooms had a plasterboard panel surface and was painted light green. The rooms had no window view. See Fig. 1. The rooms were renovated 18 months before the start of the experiment, and they no longer smelled of paint or varnish.

Light intensity (lux), noise (dB), temperature (°C), relative humidity (%), and air pressure (mbar) were continuously measured by Netatmo Healthy Home Coach (Netatmo, Legrand, Boulogne-Billancourt, France) and a Philips Hue motion sensor (Koninklijke Philips N.V., Netherlands) to monitor indoor environmental circumstances during visits.

2.3. Participants

The recruited participants were healthy full-time students and workers whose study and/or workplace was on the campus. A total of 61 volunteers, of whom 31 were women, participated in the study. Their mean age was 24 years (SD = 3.41). Of the participants, 84% were students. During the study, almost all participants lived in the city of Tampere (93.4%), of whom 72% lived in an apartment building with more than three floors, 15% in an apartment building with two to three floors, and 13% in something else, were unsure, or preferred not to provide this information. Of the participants, 11.5% lived in a wooden building, 65.6% in one made of stone, and the rest in a building made of other materials, were unsure, or preferred not to provide this information. A nature related hobby had 67.8% of the participants (e.g., hiking, orienteering, running, biking, walking, picking mushrooms and/or berries), 52.4% had a close relative owning forest and a few reported to own forest themselves. In addition, 15.2% had an experience either working in forest or in the wood industry. The participants were on average satisfied with their life in general (Mean = 3.93, SD = 0.79), and most also reported their general health as good (M = 4.23, SD = 0.67), and their self-reported general stress level was average (M = 3.11, SD = 0.90) on a 5-point Likert scale.

2.4. Experimental design

The participants were divided into three groups of 20, 20, and 21 people by experimental running time interval. The last group had to use medical face masks during their visit because of the coronavirus pandemic. Other than that, the coronavirus pandemic did not affect the experiment.

The participants visited the experiment three times in randomized order, always having one week between each visit. Half the participants started in the wooden room, and the other half in the control room. The aim of the first visit was to consider the novelty effect of the experiment. The last two visits were in the wooden and in the control rooms in randomized order. The participants visited each room at least once.

The participants chose the experimental dates according to their schedule, but the intervals between the three separate sessions were fixed. To avoid variation related to the participant's circadian rhythm,

for each participant, the visits were conducted at approximately the same time of the day. The earliest visiting times were at 8 a.m., and the latest at 4 p.m.

The participant did not know beforehand which type of room and how many different rooms they were going to visit. The participants were told that the study was about the effect of office environments on work efficiency, without any further details. One visit took approximately 45–50 min, during which time the participant was always with an experimenter. The experimental plan is shown in Fig. 2.

At the beginning of each visit, the participant's Moodmetric ring (a skin conductivity measure) was connected by Bluetooth to the experimenter's mobile phone, which had the Mobile Scope app for recording the Moodmetric index values. An ambulatory electrocardiogram (ECG) device (Faros 180, Bittium Ltd.) was then attached to the participant's chest. The participant was then instructed to sit by the desk in front of a computer screen and to relax for 2 min without moving and with their eyes open. The participant then completed the first questionnaire with psychological measures on the computer, after which the manipulation phase started and lasted for the next 10 min to increase the stress level and fatigue between all the participants. During the first 5 min, the participants performed a backwards digit span task (Vuksanović & Gal, 2007; Traina, Cataldo, Galullo, & Russo, 2011), in which they subtracted seven from 1000 as many times as they could. The last result was not shown and needed to be remembered. After a mistake, the counting started from the beginning. The task was similar during all the visits, except the subtracted number changed, being 7, 13, and 17 during the first, second, and third visits respectively. The mathematical task was followed by a 5-min reading comprehension task. The reading task was like a language proficiency test, a text followed by questions. After the manipulation phase, the participants took the first SART and completed the questionnaire for the second time, after which they moved to a comfortable armchair and were asked to relax, keeping their eyes open. A computer alarm marked the end of the rest period. The participant moved to the computer again and performed the second SART and completed the questionnaire for the third and final time. Additional questions about the room environment were now included. The ECG device was then removed. After the third visit, some extra background questions were asked about the participant's living environment and about their interactions and experiences with wood as a material (family as forest owner, hobbies related to wood, etc.), and the volunteers returned the Moodmetric ring.

2.5. Measures of this study and data pre-processing

For this study, a web application was established to collect and manage the research data. This app implemented all the different tasks of the test series such as mathematical and reading tasks and SART, and synchronized the time points of the test series with the physiological measurements. The Google cloud platform (GCP) was used as a run environment for the application. Answers to the psychological questionnaires were collected using the Webropol questionnaire tool (<https://webropol.fi/>), linked to the study app.

2.5.1. Psychological measures

During the experiment, we used several valid psychological scales (Annerstedt et al., 2013; Ojala et al., 2022; Tyrväinen et al., 2014), used previously in Finnish studies. All these scales' questions were asked before, during, and after each experimental session. The questionnaires also included other measures that were related to different hypotheses, independent of those investigated here.

The self-reported mood was measured by the PANAS (Watson et al., 1988). We calculated the PANASPOS from ten items indicating positive affect (e.g., active, excited, inspired), and the PANASNEG from ten items indicating negative affect (e.g., hostile, distressed, upset). We used the six-item restoration outcome scale (ROS) (Korpela, Ylén, Tyrväinen, & Silvennoinen, 2008; cf. Hartig, Lindblom, & Ovefelt, 1998; Staats,

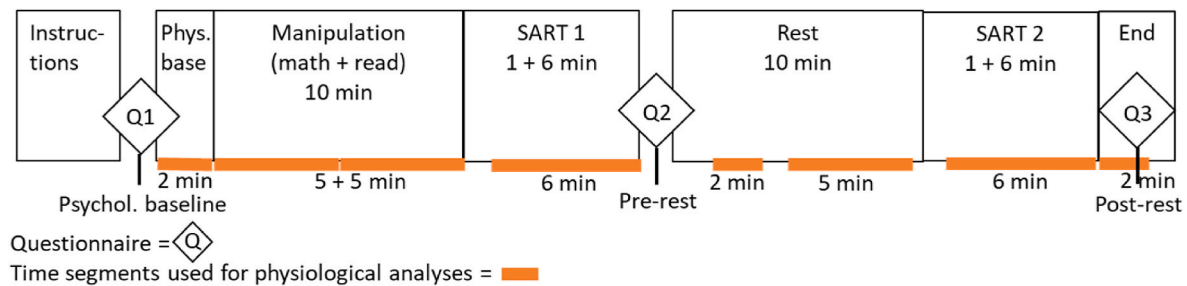


Fig. 2. Experimental design. The experiment consisted of seven different phases: instruction; physiological base; manipulation containing mathematical and reading tasks (math + read); sustained attention to the response task (SART 1); rest period; SART 2; and end. In between, the participants completed psychological questionnaires, indicated by Q. The time segments indicated with the bold orange line are the segments used to analyze physiological measurements. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Kieviet, & Hartig, 2003), to measure restorative experiences (Kaplan & Kaplan, 1989). In this scale, three items reflect relaxation and calmness (e.g., “I feel restored and relaxed”), one attention restoration (“I feel focused and alert”), and two reflect clearing one’s thoughts (e.g., “My thoughts are clear”). The four-item subjective vitality scale (SVS) (Ryan & Frederick, 1997), was used to measure self-reported perceptions of energy feelings (“I feel alive and vital,” “I have energy and spirit,” “I look forward to each new day,” and “I do not feel very energetic” (reversed item). All these scales were measured using Likert scales from 1 (not at all) to 7 (completely), and we calculated the summated index-based scale items. We measured felt anxiety using Marteau and Bekker’s (1992) measure, previously used in Finnish population studies (Konttinen, Haukkala, & Uutela, 2008). This measure has six items that describe irritability and feeling tense on a scale of 1 (does not describe at all) to 4 (describes very well).

The SART (Cheyne, Solman, Carriere, & Smilek, 2009; Robertson et al., 1997) was implemented using the script provided by Borchert (2020) as a basis. In the SART, the digits 1–9 were presented on a screen in random order over a period of 6 min 11 s. Each digit was presented 25 times in five different font sizes. The participants were instructed to be equally fast and correct when they pressed the space bar whenever they saw any digit (Go), except the digit 3 (No-Go). The stimulus that was shown for 250 ms was followed by a mask (a white cross within a circle) for 1400 ms. Both test rounds were preceded by a practice round, with 10 digits, in which the participants received feedback about the accuracy of the response (correct/incorrect). For response accuracy, we used the number of commission errors—the number of responses made to the No-Go digit ‘3’ (Manly et al., 2003), and omission errors—the number of non-responses to a Go digit. We excluded omission errors from the analyses as 89% of the cases had no omission errors, and therefore, there was insufficient variation to examine. Reaction time measures were the mean response time (MRT) and the standard deviation of response time (SDRT) which were calculated for the Go trials with reaction times >100 ms. A greater variability of SDRT indicates more attentional lapses (Manly et al., 2003; Robertson et al., 1997; Smilek, Carriere, & Cheyne, 2010). We also calculated inverse efficiency (IE), which is a measure (ms) of speed-accuracy trade-off, calculated as the ratio of reaction times over accuracy on the digits 1 to 9, except for 3 (non-lures) (Bruyer & Brysbaert, 2011; Cassarino, Tuohy, & Setti, 2019).

2.5.2. Physiological measures

Stress and recovery change the balance of the parasympathetic and sympathetic branches of the ANS. This balance is a useful indicator for studying the effects of different environments. The commonly used method for the evaluation of parasympathetic and sympathetic branches’ activity is based on HRV or skin conductivity measurements. The high fluctuation of heartbeat intervals, measured in milliseconds, indicates the dominance of the PNS, and the monotonic variation in HRV means higher SNS activity (Kim, Cheon, Bai, Lee, & Koo, 2018). PNS activity is commonly assessed in the time-domain analysis by the root

mean square of normal successive RR interval differences (RMSSD) (Shaffer & Ginsberg, 2017; Shaffer, McCraty, & Zerr, 2014), in the frequency-domain by the high-frequency (HF) band, and the power of HF in normalized units (nu) (Grossman & Taylor, 2007; Shaffer & Ginsberg, 2017). It is argued that a low-frequency (LF) band and the power of LF in a normalized unit (LF.nu) represent SNS activity respectively (Perini & Veicsteinas, 2003). The SNS controls the activity of endocrine sweat glands, producing changes in skin conductivity. Measurement of skin conductivity gives an assessment of SNS activity related to emotional and cognitive conditions (Bach & Friston, 2013). Simultaneous HRV and skin conductivity measurements enable a more reliable assessment of PNS and SNS functioning.

The ECG was registered with the Faros 180 ECG medical device (Bittium Ltd., Finland). Three disposable Ag/AgCl standard electrodes were attached to cleaned skin, two under the collarbone, and one under the left breast. The electrodes were connected to the measurement unit with snap-on electrode cables. After entering the test environment, the ECG device was attached to the test subject and turned on. The measurement was stopped after the test procedure, and the device was detached. The data were transferred and stored to a secured cloud service for the following processing and analysis. HRV analysis was performed with Kubios HRV Premium software (Kubios Ltd., Tarvainen, Niskanen, Lipponen, Ranta-Aho, & Karjalainen, 2014). The software was used to identify R peaks from the ECG data and to perform HRV analysis for predefined segments (see Fig. 2).

The skin conductivity measurements were performed with Moodmetric smart rings (Vigofere Ltd., Finland; since 2023 Nuanic Ltd.). The ring algorithm evaluates the user’s stress level, with the Moodmetric (MM) index having a scale of 0–100. The larger the MM index value, the more active the SNS, indicating stressed, excited, anxious, or frightened emotions. In the study by Pakarinen, Pietilä, and Nieminen (2019), the Moodmetric measurement was evaluated against the commercial BIOPAC research system. In the test, BIOPAC provided a 94.1% and the Moodmetric ring an 82.8% classification success rate. The Moodmetric measurement has been shown to be a relevant assessment method of self-perceived stress and arousal (Pakarinen et al., 2019).

The participant’s received the smart rings in the first visit, and they used the rings over a two-week period for an evaluation of their own well-being in their mobile phone with the Moodmetric app service (Vigofere Ltd., Finland). In addition, during each experimental session, the index values were recorded with a 3 Hz sampling rate with the Mobile Scope app (Vigofere Ltd., Finland). The means and standard deviations were determined for the same time segments as in the HRV analysis.

2.5.3. Covariates

The baseline work stress on the experimental day was measured once at the start of the experiment using a 5-point Likert scale from 1—“not at all stressful” to 5—“very stressful.” The relationship with nature was measured by the short version of the nature relatedness scale (NR6)

(Nisbet & Zelenski, 2013) consisting of six items on a 5-point Likert scale from 1—“strongly disagree” to 5—“strongly agree.” The other co-founders considered in the analyses were age (years), gender (woman/man), body mass index (BMI), noise level (dB), and CO₂ (ppm), measured in the experimental rooms.

2.5.4. Statistical analysis

The statistical analysis was carried out using a Bayesian approach (Gelman et al., 2013), where all parameters are treated as random variables. The models fitted for the psychological and physiological data for person i , visit j , and measurement number k (corresponding to baseline, pre-rest, and post-rest for psychological variables; SART1, SART2 for SART, and baseline, manipulation, SART1, 2-min rest, 5-min rest, SART2, end for physiological variables) are of the general form

$$y_{ijk} | \alpha_{ijk}, \sigma_k^2 \sim N(\alpha_{ijk}, \sigma_k^2)$$

$$\alpha_{ijk} = \mu_k + \Delta_k \text{Wood} + \pi_j + \sum_c \beta_c \text{CVR}_{ic} + u_i + v_{ij}$$

$$u_i | \sigma_u^2 \sim N(0, \sigma_u^2)$$

$$v_{ij} | \sigma_v^2 \sim N(0, \sigma_v^2)$$

where y_{ijk} is the response variable, $N(\alpha_{ijk}, \sigma_k^2)$ is a normal distribution with α_{ijk} as the expected value of and σ_k^2 its variance (which is measurement-number-specific), μ_k is the average value in the control set up with all covariate values at zero, the variable Wood gets the value 1 for the wooden room and 0 for control, and Δ_k is the difference in the response variable between the two rooms, π_j is the period effect, which is 0 for the first visit and potentially non-zero for the following two visits, the term $\sum_c \beta_c \text{CVR}_{ic}$ includes all the controlled covariates, and finally u_i is the individual random effect and v_{ij} is the random effect associated with the individual's particular visit, and σ_u^2 and σ_v^2 are the variances of the random effects. In [Supplementary Tables 6–41](#), we have also calculated the quantities $\Delta_{k,k'} = \Delta'_k - \Delta_{k'}$ for the reader's convenience, which represent the change in the difference between the two rooms for the two consecutive phases k and k' .

The models were fitted both with the covariates (baseline stress level, nature relatedness, BMI, age, sex, and CO₂ level) and without these covariates, i.e., with just the experimental design modeled. However, for the SART models, the parameters related to the visit-specific random effects failed to converge when the random effect v_{ij} was included in the model. This indicates that the person-specific random effect was sufficient to capture the covariance structure sufficiently well, and therefore, it was dropped. Highly non-informative prior distributions were used. For the final fit, we took 200,000 iterations with a 50,000 burn-in period from five Markov Chains. The convergence was graphically checked for each marginal posterior separately. The effective sample sizes were smallest for the variables μ_i , roughly 5,000, while for the other variables, the effective sample sizes tended to be above 10,000. The models were fitted using JAGS (Plummer, 2003) and the statistical software R (R Core Team, 2022).

One of the variables used to measure SART performance was the number of commission errors, which is not a continuous variable but a non-negative integer. For this variable, the model was altered so that $y_{ijk} | \alpha_{ijk} \sim \text{Poisson}(\alpha_{ijk})$. For the MRT, SDRT, and IE of the SART measurements, as well as the RMSSD, SDNN, and LF/HF variables, the response variable was log-transformed to improve the fit.

In Bayesian statistics, the interpretation of the results is based on the posterior probability distribution of the parameters, and p -values are not used. For a given parameter θ , the probability of interest is $P(\theta > 0)$, which is the probability that the parameter is greater than zero. If $P(\theta > 0)$ is less than 5%, we take this as evidence for the parameter being

negative for the one-tailed hypotheses considered in this study, and a probability greater than 95% as evidence for the parameter being positive. These limits are analogous to one-tailed classical tests with a p -value < 0.05 as the limit for statistical significance. The 95% probability intervals (95% P.I.), also known as Bayesian intervals or posterior intervals, play a similar role to the 95% confidence intervals in frequentist statistics, but the interpretation is more straightforward: Based on the model and data, there is a 95% probability that the parameter value will be included in the 95% probability interval.

The hypotheses H1, H2, and H3 stated in Section 1.1 involve several different outcome measures. One possible way to interpret the hypothesis would be that the hypothesis is supported by all the various outcome measures. However, this would be excessively conservative, so we have chosen that more than 50% of the outcome measures (e.g., 3/5) must be consistent with the hypothesis. Our hypothesis H1 relating to the psychological measures was that PANASPOS, ROS, and SVS would be higher post-rest in the wooden room, and PANASNEG and ANXIETY would be lower. We consider the parameter space in which at least three (i.e., more than half) of these outcomes occur consistently with the hypothesis. H2 was measured by mean response time and commission errors, so the parameter space in which the response times in the wooden room were faster, and there were fewer commission errors, was considered to be consistent with the hypothesis. Hypothesis H3 was that during rest period, the PNS was more active, and the SNS less active, in the wooden room, i.e., RMSSD would be higher, LF.nu/HF.nu-ratio would be lower, and skin conductivity (MM) would be lower in the wooden room. The parameter space in which at least two of these conditions (again, more than half) were met was considered to favor the hypothesis, while the rest of the parameter space was considered to be evidence against the hypothesis.

3. Results

3.1. Hypothesis testing

3.1.1. Change in positive and negative affect, felt restoration, energy, and anxiety

The three timepoints at which the questionnaire was completed are referred to here as baseline, pre-rest, and post-rest ([Fig. 2](#)). The main observations related to psychological variables were that positive affect (PANASPOS), felt restoration (ROS), and energy level (SVS) were at a higher level in the wooden room at the beginning of the experiment ([Fig. 3](#)). Negative feelings (PANASNEG) were at a lower level throughout the experiment, and there was a decreasing effect on ANXIETY in the wooden room at the end of the experiment. Differences at the baseline or pre-rest were not anticipated when the experiment was designed.

Descriptive statistics of psychological variables are presented in [Supplementary Tables 1–3](#), and of physiological variables in [Supplementary Tables 4–5](#).

Our hypothesis H1 relating to the psychological measures was that PANASPOS, ROS, and SVS would be higher post-rest in the wooden room, and PANASNEG and ANXIETY would be lower. At post-rest, the mean for PANASPOS was 0.041 points higher in the wooden room (95% P.I. (−0.172, 0.253)), and we can be 64.7% certain that the value would be higher in the wooden room ([Supplementary Tables 6–7](#)). For PANASNEG, the mean was 0.10 points lower in the wooden room (95% P.I. (−0.22, 0.02)), and our confidence that the value would be lower in the wooden room was 95.4% ([Supplementary Tables 8–9](#)). For ROS, the mean was 0.15 points higher in the wooden room (95% P.I. (−0.06, 0.37)), and we can be 92.2% certain that the value would be higher in the wooden room at post-rest ([Supplementary Tables 10–11](#)). For SVS, the difference was 0.025 points (−0.184, 0.234), and we can only be 59.5% certain that the mean would be higher in the wooden room ([Supplementary Tables 12–13](#)). For ANXIETY, the mean was 0.72 points lower in the wooden room (95% P.I. (−1.32, −0.12)), and we can be

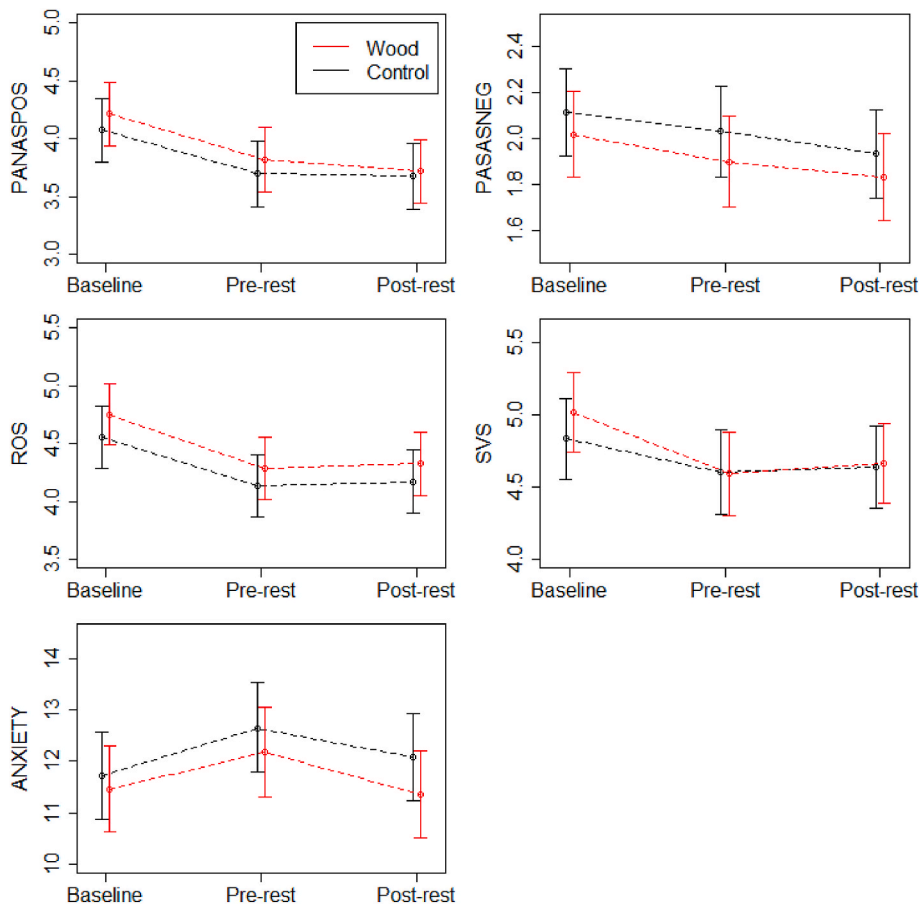


Fig. 3. Predicted psychological effects and their 95% probability intervals for wooden and control rooms fitted with covariates at the baseline, and before and after resting in an armchair (pre- and post-rest).

99.0% certain that the value would be lower in the wooden room (Supplementary Tables 14–15).

Since the five different psychological measures used are not on the same scale (and cannot be easily transformed to a continuous scale on which the values would be directly comparable), we aggregate the results on a discrete scale where each measure is either supporting or against the hypothesis. For PANASPOS we have 64.7% support and 100%–64.7% = 35.3% against the hypothesis, for PANASNEG we have 95.4% support and 4.6% against, for ROS 92.2% support and 7.8% against, for SVS 59.5% support and 40.5% against, and for ANXIETY 99.0% support and 1% against. With the interpretation choice made in this work, we accept as evidence for the hypothesis either 5/5 measures, 4/5 measures, or 3/5 measures supporting the hypothesis. These probabilities can be calculated by straight forward arithmetic calculations (e.g., probability that 5/5 measures support the hypothesis is $0.647 \times$

$0.954 \times 0.922 \times 0.595 \times 0.990 = 33.5\%$. As an example of why the adopted method makes sense, imagine if for all five measures we would have obtained support of 99% (analogous to a p-value of 0.01), the 5/5 support would have still only been $0.99^5 = 95.1\%$, demonstrating how overly conservative this choice would be. With the procedure used here this would give support >99.99%). Aggregating the results, the support for hypothesis H1 (i.e., for at least 3/5 measures) is 97.9%, confirming the hypothesis.

In Figs. 3–6, the model predictions and uncertainties are presented for a first visit for a female, aged 24, BMI 24, 700 ppm CO₂, self-reported stress level of 3 on a Likert-scale of 1–5, and a nature relatedness score of 3.667 (sample average). Note that the uncertainties are correlated to a high degree. Of the covariates, the most important proved to be the self-reported stress measurement. Both PANASNEG and ANXIETY measurements were elevated if the participant reported their daily stress

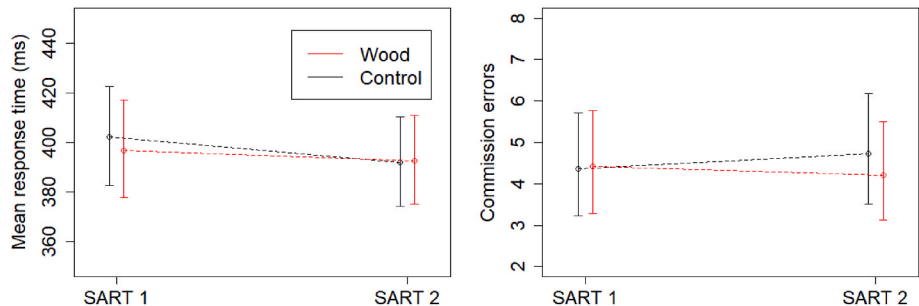


Fig. 4. Predicted SART measures effects and their 95% probability intervals for wooden and control rooms fitted with covariates. The MRT is in milliseconds (ms), and the commission errors are given as the total number of errors during the test.

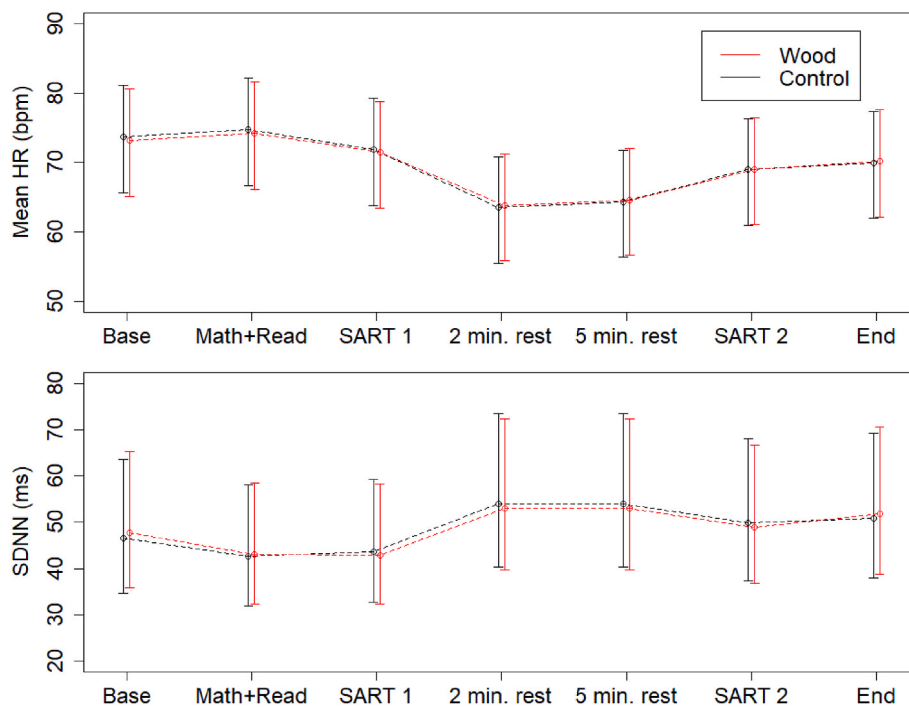


Fig. 5. The mean heart rate (HR) (above) and SDNN (below) model predictions and their 95% probability intervals fitted with covariates.

level to be higher ($P(\beta_{Stress} > 0) > 99.9\%$), and correspondingly, the variables PANASPOS, SVS, and ROS were lower ($P(\beta_{Stress} > 0) \leq 0.1\%$). The first visit differed from the other two visits, with both less positive and negative feelings reported. For the psychological variables, the inter-person variation, inter-visit variation, and the residual variance were roughly the same, meaning that a substantial fraction of the variation is due to differences between people and the daily variation in the individual's mood.

3.1.2. Sustained attention to response task

For SART, there were no clear differences in the MRT, SDRT, or IE (Fig. 4, Supplementary Tables 16–21) at pre- (SART 1) and post-rest (SART 2).

Hypothesis H2 was that in the post-rest SART measurement, the individuals are faster (i.e., the MRT is faster), and that response accuracy is higher (e.g., fewer commission errors are made) in the wooden room. For MRT, the individuals were on average 0.8 ms slower than in the control room (95% P.I. (−10.1, 12.4)), where the average result was 407.5 ms post-rest. The probability of the result being higher in the control room was 55.8%, indicating no difference between the means (Fig. 4 and Supplementary Tables 16–17; note the log-transformation). In the control room, 4.7 commission errors happened on average in the second test, while in the wooden room, the average number of errors was 4.2. Based on the model and the data, people made an average of 0.5 more commission errors in the control room (95% P.I. (−0.2, 1.2)). The probability of fewer mistakes being made in the wooden room post-rest was 93.4% (Fig. 4 and Supplementary Tables 22–23).

When the results from the two measures were aggregated, the probability that hypothesis H2 was true was 41.3%, and the hypothesis could not therefore be confirmed using the data. For the SART variables, the inter-person variation and the residual variance were roughly the same, meaning that a substantial portion of the variation was due to differences between people.

3.1.3. The physiological measures

Mean heart rate (HR) and SDNN results indicated that the different activity periods of the experimental test setup affected the balance of ANS. Manipulation phase (math + read) and the first SART increased the

activity of the SNS, shown by higher HR (72 beat/min) and lower SDNN (40 ms) than in the rest period (5-min rest (61 beat/min and 55 ms respectively)) in an armchair. In other words, HR and SDNN were at higher (15%) and lower levels (3.6%) respectively during manipulation (math + read) than in the 5-min rest phase in both rooms (Fig. 5 and Supplementary Tables 24–25 and 26–27). No differences in mean HR or SDNN values were observed between the rooms in the time segments.

Descriptions of the physiological measures are presented in Supplementary Tables 4–5. Hypothesis H3 was that during rest period, the PNS was more active, and the SNS less active, in the wooden room, i.e., RMSSD would be higher, LF.nu/HF.nu-ratio would be lower, and skin conductivity (MM) would be lower in the wooden room.

In the 5-min rest phase, the RMSSD was an average of 73.2 ms in the control room, and 69.9 ms in the wooden room (Supplementary Tables 28–29). Based on the model and collected data, the difference was −6% (95% P.I. (−15%, 7%)). The probability that, contrary to H3, RMSSD was greater in the control room was 78.8%. For LF/HF, the average at rest period was 0.26 in the control room, and 0.30 in the wooden room (Supplementary Tables 34–35). The difference was thus +17% (95% P.I. (−8%, 49%)). Again, contrary to H3, the probability that LF/HF was lower in the control room was 90.6%. Skin conductivity (MM) also indicated higher SNS activity during rest period in the wooden room, with a difference of 8.2 points (95% P.I. (0.3, 16.1)) and a 97.9% probability of the sign of the difference. LF/HF therefore indicated higher SNS activity at the beginning of/throughout the experiment, whereas skin conductivity (MM) value was lowest in the control room during the 5-min rest period (Supplementary Table 36–37, Fig. 6).

Aggregating these results, the probability of H3 was 2.5%, so the hypothesis is not confirmed, and we have clear evidence that the hypothesis is opposite to the reality. For the physiological variables, the inter-person variation was dominant, with inter-visit variation and the residual variance roughly similar, meaning that most of the variation not due to the rooms was related to the natural variation between people.

3.2. Further observations from the data

An interesting feature of the psychological variables plotted in Fig. 3 is that the difference between the two rooms was immediate. For ROS

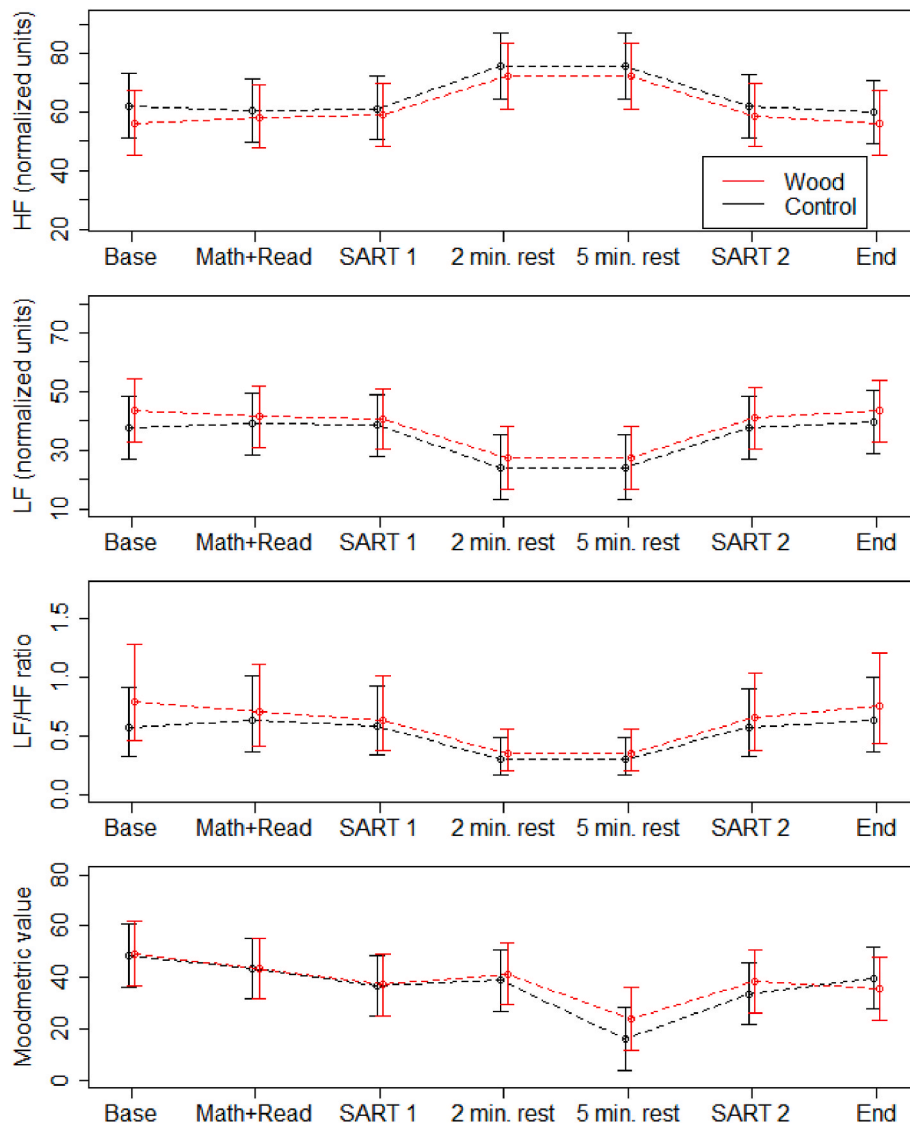


Fig. 6. Predicted HF, LF, LF/HF, and Moodmetric values and their 95% probability intervals for wooden and control rooms fitted with covariates.

and PANASNEG the difference was essentially constant throughout the three phases of the experiment with the average difference for ROS varying between 0.142 and 0.198 ($P(\Delta_{1,2,3} > 0) = 91.1\text{--}97.3\%$), and that of PANASNEG varying between -0.094 and -0.131 ($P(\Delta_{1,2,3} > 0) = 3.2\text{--}4.6\%$). For PANASPOS, SVS, and ANXIETY, there was a difference at the beginning, which closes for PANASPOS and SVS during the visit (for PANASPOS $\Delta_1 = 0.139$, $P(\Delta_1 > 0) = 92.0\%$ and $\Delta_3 = 0.041$, $P(\Delta_3 > 0) = 64.7\%$; for SVS $\Delta_1 = 0.182$, $P(\Delta_1 > 0) = 96.5\%$ and $\Delta_3 = 0.025$, $P(\Delta_3 > 0) = 59.5\%$) but which widens for ANXIETY as time progresses ($\Delta_1 = -0.257$, $P(\Delta_1 > 0) = 19.1\%$ and $\Delta_3 = -0.721$, $P(\Delta_3 > 0) = 99.0\%$).

For the number of commission errors in SART the results were very similar at the beginning, (on the log-scale $\Delta_1 = 0.023$, $P(\Delta_1 > 0) = 61.9\%$) but the difference in the second experiment was larger ($\Delta_2 = -0.107$, $P(\Delta_2 > 0) = 7.4\%$). Furthermore, in the control room the trend in the number of commission errors was upwards while in the wooden room it was downwards. At the same time, the mean response times were similar in both rooms in the first SART (on the log-scale $\Delta_1 = -0.013$, $P(\Delta_1 > 0) = 25.3\%$) as well as in the second SART measurement ($\Delta_2 = 0.002$, $P(\Delta_2 > 0) = 55.8\%$).

Concerning the physiological variables, the difference in the LF/HF-ratio between the rooms was largest at the beginning (on the log-scale $\Delta_{base} = 0.335$, $P(\Delta_{base} > 0) = 99.5\%$) and the end of the visit ($\Delta_{end} =$

0.196 , $P(\Delta_{end} > 0) = 95.6\%$) and seems to disappear during cognitively demanding tasks (e.g., $\Delta_{sart1} = 0.096$, $P(\Delta_{sart1} > 0) = 87.2\%$). For the Moodmetric measurements, there appears to be no difference between the two rooms except during the rest period ($\Delta_{rest5} = 8.185$, $P(\Delta_{rest5} > 0) = 97.9\%$), where the drop in the value was notably smaller in the wooden room than in the control room.

The wooden and control rooms did not differ in mean temperature ($20.5^\circ\text{C} \pm 0.61$; $20.4^\circ\text{C} \pm 0.59$), moisture ($47\% \pm 7$; $46\% \pm 8$), noise level ($39.7\text{ db} \pm 3.0$; $39.0\text{ db} \pm 3.2$) or level of lightning (213.8 lux ; 213.8 lux), respectively. However, there was a small difference in the mean CO_2 level, which was an average of 667 ppm in the control room and 729 ppm in the wooden room. The levels varied between 520 and 781 ppm in the control room, and between 513 and 892 ppm in the wooden room with the exception of one outlier event where the CO_2 reached 1032 ppm during one visit to the wooden room. Overall, these levels are consistent with the range 400–1000 ppm, which can be expected from a well-ventilated office space.

4. Discussion

Many studies have shown that being in nature or viewing nature outdoors or indoors (window views, photos, virtual nature) has calming, stress-relieving effects, and people experience an increase of positive

feelings and a decrease of negative feelings after spending some time in these environments (e.g., Ojala, Korpela, Tyrväinen, Tiittanen, & Lanki, 2019; Pasanen et al., 2018; Yeo et al., 2020). Previous findings indicate that wooden material indoors can have similar positive effects on people (e.g., Demattè et al., 2018; Douglas et al., 2022), and people also prefer wooden material to other materials (e.g., Bhatta et al., 2017; Loredan et al., 2022).

In the present study, the psychological self-reported measures partly supported these previous findings. Felt anxiety clearly reduced in the wooden room after rest period compared to the control at a high probability, thus confirming H1. In addition, at an aggregated level, there was solid support for H1. The participants experienced fewer negative emotions in the wooden room throughout the experiment, and the feelings of restoration, energy, and positive affect were at a higher level in the wooden room, especially at the beginning of the experiment. These results expand our original hypothesis and add indications of wood as a material with an immediate positive effect.

Regarding improved response time and accuracy in the wooden room after the recovery period (SART measures), H2 was only partly supported by an indication that fewer errors were made in the wooden room. However, this change was small, and there was no difference in reaction time or other SART measures between the two rooms. At an aggregated level, the possibility of H2 being true was very small. Two previous studies have investigated the effects of a wooden environment on cognitive performance (Lipovac et al., 2020; Shen et al., 2020). Shen et al. (2020) conducted a study using different measures of cognitive performance. The participants reported more correct answers in wooden rooms than in a concrete environment. On the other hand, Lipovac et al. (2020) study did not find any differences in cognitive performance induced by different table materials. However, it is important to note that both studies had complex experimental settings with numerous comparisons and relatively small sample sizes. In such cases, the potential influence of chance becomes more significant than the actual effect of the subject. When there are multiple elements to compare in an experimental setting and limited participant numbers, random chance can overshadow actual differences. Moreover, there are several attempts to capture nature's positive effects on attention restoration using SART. Berto (2005) found strong support that digital nature images positively affected sustained attention. The later replication studies have failed to obtain the same results (Neilson, Craig, Curiel, & Klein, 2021). Cassarino et al. (2019) found no effect of nature vs. urban images in older adults on sustained attention. Pasanen et al. (2018) found that walking in actual nature affected SART, especially in some measures (e.g., commission errors) but not in others (e.g., response time). The different SART measures therefore seem to be sensitive in experimental and environmental settings. The ANS activity is also found to be related with cognitive performance, but more studies are needed as different cognitive domains are related to HRV parameters differently (Forte, Favieri, & Casagrande, 2019). In our study, there was no difference between rooms in ANS activity during SART. Clearly, there is the potential for improved attentional performance in wooden rooms, but the results should be replicated in future studies.

The results of our study did not support the third hypothesis (H3) that the PNS is more active and the SNS less active in the wooden room than in the control room during the rest period. Contrary to our hypothesis, average SNS activity indicated a slightly higher level in the wooden room at the beginning of the experiment, as well as during and after the rest period, indicating a higher alertness level in the wooden room. Accordingly, skin conductivity measurements (MM) indicated higher physiological arousal during the last 5 min of rest in the wooden room than in the control.

The differences between HR and SDNN during the experimental period show that we succeeded in developing an experimental design in which the SNS was raised during the manipulation phase and lowered during the rest period. The manipulation phase diminished physiological differences between the rooms. The differences that existed at the

beginning appeared again after the rest period (especially seen in the HF.nu, LF.nu, and LF/HF parameters), indicating that concentration on cognitive tasks diminished the importance of the environment. During the rest period, the importance of the physical environment again increased.

The finding that self-reported positive affect, and energy level were higher, and negative affect lower right at the beginning of the experiment (although with a small probability) may support the SRT in the sense that nature or natural elements gave a fast positive response. The negative affects, and especially separately measured anxiety, were at a lower level at the end of the experiment in the wooden room, clearly indicating the possibility of stress relief in the wooden room in terms of diminished negative emotions. The probability of having higher felt restoration was also higher in the wooden room during the whole experimental period. Overall, based on psychological measures, there was more support for general positive mood than for enhanced felt restoration and improved sustained attention during the stay in wooden room.

The contradiction between psychological (self-reported) and physiological findings deserves further attention. Usually, positive emotions are related to increased PNS activity and negative emotions are associated to PNS withdrawal and SNS activity (Gordon & Mendes, 2021; McCraty, Atkinson, Tiller, Rein, & Watkins, 1995). On the other hand, the response to specific emotions may vary. For example, joy or happiness may in some conditions be related to SNS activity (Kreibig, 2010).

Previously, a fast 90-s visual stimulus of wood on the human being has indicated that even a short exposure to wood evokes positive feelings and induces physiological responses (Sakuragawa et al., 2005; Tsunetsugu et al., 2007). There have also been some indications of relaxation and lower SNS activity in wooden environments in other studies (Burnard & Kutnar, 2020; Douglas et al., 2022; Fell, 2010; Ikei et al., 2017b) or no difference between wood and other materials in SNS activity (Bamba & Azuma, 2015; Zhang et al., 2017). However, many of these studies have some limitations related to small sample sizes (Sakuragawa et al., 2005; Tsunetsugu et al., 2013; Bamba and Azuma, 2015; Zhang et al., 2017; Lipovac et al., 2020), improper randomization (Fell, 2010), and control of other indoor environmental quality factors (Sakuragawa et al., 2005; Tsunetsugu et al., 2013; Fell, 2010). In Burnard and Kutnar (2020) study, it was challenging to estimate the exact time when the stress response was expected to be visible in salivary cortisol levels, and the results remained relatively elusive. The results of Douglas et al. (2022) indicated lower self-reported stress levels and physiological stress measured by skin conductivity during stress test in a work environment with natural materials, a wooden table, and chairs than in a room with artificial white furniture. This was a between-subject study with a relatively high sample size (ca. 50/test setup). The value used for the skin conductivity was an average of the values measured during the stress task (5–10 min). It would be better to measure the restorative effects as a change within an individual between different environments and stress level influencing periods, because there is a high individual variation in physiological parameters, as also seen in the present study.

In some cases, PNS activation is related to higher nature immersion in which more senses are included, as in virtual nature conditions where sound and virtual nature together activate the PNS compared with only video or no stimulus condition (Annerstedt et al., 2013). In the study by Yin et al. (2020), the biophilic environments mediated by virtual reality glasses (indoor and outdoor greenery and the combination of both compared to the stimulus condition without nature) supported faster recovery after the stressor, and thus activated the PNS. Scott et al. (2021) examined changes in heart rate and heart rate variability after longer exposure to nature and found, contrary to their expectation, that immersion in nature was associated with an increased activation of the sympathetic nervous system. Possible explanations for these results include the effect of high-arousal pleasant emotions (see also Kreibig, 2010). Ketonen, Salonen, Lonk, & Salmela-Aro (2023) found that

self-reported excitement (high-arousal pleasant emotion) was associated with higher HR and lower HRV, indicating SNS activation. On the other hand, self-reported boredom was related to lower HR and unrelated to HRV, indicating low arousal. The results of our study may suggest that the wooden room was associated with increased high-arousal pleasant emotions, reflected by slightly increased sympathetic activation, potentially leading to (slightly) improved cognitive performance. It would be worthwhile to further investigate how physical working environments might influence alertness which in turn may have implications to work performance and job satisfaction.

4.1. Limitations of this study

Measuring well-being effects is complex, and evaluation requires research from many different perspectives. One limitation of our study is that we did not have a “neutral” room at the start of our experiment. This was partly for practical reasons, but also because it would have been quite difficult to identify a true neutral office room that contained something other than the materials used in the study. Visiting order (half the participants visited one or the other room twice) had some influence, which meant the room visited for the second time was already familiar to the participants. However, the first order was randomized, and we took the visiting effect into account in statistical modeling. Based on this study, we cannot make any assumptions about the long-term effects of wooden environments. The wooden material effects among different populations are also worth studying further, as the population in our study was relatively homogeneous—mostly young university students with lots of contact with nature (hobbies, forest owning families).

4.2. Future perspectives

There is still no consensus on what could be considered a significant difference in the wooden-room context for all the various measures considered. The Bayesian approach used in this study allows the calculation of the required number of participants and the smallest expected effect differences for future studies investigating the effects of indoor environments. With the obtained results for variability, this study's results can be used to carry out power calculations and thus design optimal experiments to study the effects of indoor environments on individuals.

The results indicated that the difference between the rooms created by the first impression was restored when attention was paid to the environment again after manipulation. In the future, research should focus more on how design and materials affect the user's well-being measures and performance. Furthermore, additional evidence is also needed to evaluate the effects of indoor materials and design on long-term well-being and consequent work efficiency.

This study indicates the material choice importance of indoor office materials, and that choosing wood may influence job performance in the real world during the longer period. Psychological factors, rather than economic or practical factors, have been shown to be the most important reasons for choosing wood as a surface material so far (Jimenez et al., 2016). There may be economic factors in addition to psychological ones if workers made fewer mistakes or have a better mood in the real work situation that might be measurable in economic terms in the future.

4.3. Conclusion

In the study, subjects performed a within-subject experiment in two different rooms, one of which used 50% wooden materials. The subjects visited crossover trial three times in randomized order. Both rooms received an equal number of visits. Self-assessment measures showed that from the outset of the study, positive affect, felt restoration and energy levels were slightly higher in the wooden room than in the control. At the same time, however, LF/HF, LF.nu, and HF.nu parameters indicated higher SNS activity in the wooden room at the beginning

of the study. Some of these differences observed at the beginning disappeared during the manipulation phase but reappeared at the end of the experiment. Skin conductivity was also higher during resting period in the wooden room. The level of negative affect was consistently lower in the wooden room, and there was clearly less felt anxiety in the wooden room at the end of the experiment. The study design was successful, with the expected change in heart rate variability and skin conductance during the experiment between the stress-inducing and recovery phases in both rooms. The experimental design shows that wooden material does not have an unambiguous downward effect on SNS levels. This may be because the room decorated with wooden material was more pleasant and hypothetically related to appropriate alertness and therefore perhaps related to slightly higher SNS activity and improved sustained attention. It will therefore be necessary to further investigate the effect of a wooden room on human well-being. If the results can be repeated, it will have major implications for the design of work environments.

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CRediT authorship contribution statement

Ann Ojala: Conceptualization, Methodology, Formal analysis, Writing - original draft, Visualization, Supervision, Resources, Funding acquisition. Joel Kostensalo: Methodology, Formal analysis, Writing - original draft, Visualization. Jari Viik: Conceptualization, Methodology, Writing - original draft, Funding acquisition. Hanna Matilainen: Investigation, Data curation, Writing - original draft. Ida Wik: Investigation, Data curation. Linda Virtanen: Investigation, Data curation. Riina Muilu-Mäkelä: Conceptualization, Methodology, Formal analysis, Data curation, Writing - original draft, Visualization, Supervision, Investigation, Resources, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jenvp.2023.102059>.

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