UNIVERSITY OF PRIMORSKA
FACULTY OF MATHEMATICS, NATURAL SCIENCES AND INFORMATION TECHNOLOGIES

DOKTORSKA DISERTACIJA
(DOCTORAL DISSERTATION)

PREFERENCE LJUDI DO LESNIH MATERIALOV IN VLOGA LE-TEH V RESTORATIVNIH OKOLJIH

(HUMAN PREFERENCE FOR WOODEN MATERIALS AND THEIR ROLE IN RESTORATIVE ENVIRONMENTS)

DEAN LIPOVAC

KOPER, 2022

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MENTOR: DOC. DR. MICHAEL D. BURNARD

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Abstract

Human preference for wooden materials and their role in restorative environments

This doctoral thesis consists of five studies that examined how people perceive and respond to wooden materials. The first study reviewed the methodology and results of studies that had examined how people respond to wood in terms of their affective states, physiological activity, and cognitive performance. The review uncovered several opportunities for improving methodology in the field and identified promising but limited evidence that visual exposure to wood impacts people positively.

The second study investigated how people across two countries—Slovenia and Norway—perceive different types of unmodified and modified wood when wood is applied to handrails and examined tactilely and visually. The results show that unmodified and modified wood handrail samples received comparable preference ratings and they were both generally preferred to the control (steel) sample in both countries. Several perceived material properties, such as warmth, correlated with the preference, and the tactile experience was important in the overall evaluation of materials.

The third study examined people's preferences for different wooden desk materials and desk designs. The results show that preference for different materials and desks varies greatly from person to person, but several evaluated items are on average preferred to others. Material type, amount of material, and desk design all have a significant role in human preference for the visual appearance of desks.

The fourth study investigated people's affective states and cognitive performance after they had spent 15 minutes at each of 10 small desks with differing top surfaces. The affective and cognitive outcomes did not differ between the desk surfaces, suggesting that the exposure to small wooden desktop surfaces is unlikely to lead to large impacts.

The fifth study primarily aimed to examine the suitability of the Mental Arithmetic Task and single-item measures of affective states to assess affective, physiological, and attention restoration at a wooden desk. The secondary aim of the study was to investigate if these outcomes differ between a wooden and a control (white) larger desk. The results show that single-item measures of affective states were robust, and we encourage other researchers to use them. The Mental Arithmetic Task did not induce stress reliably or lead to cognitive fatigue, indicating the need to apply more stressful and cognitively demanding tasks. The affective, physiological, and cognitive outcomes did not differ *between the wooden and white desk. It should be noted, however, that the study exhibited low statistical power for this part of the analysis, and only large effects of wood were likely to be detected.*

Taken together, the results of studies reported in this thesis show that people tend to prefer wood in different contexts but that exposure to smaller wooden surfaces is unlikely to considerably impact affective states, physiological activity, and cognitive performance. These findings extend the existing knowledge by providing insight on how people perceive and respond to wood used in different settings and how this relates to specific properties of wood or its application. The gained knowledge can inform the preparation and implementation of wooden materials to indoor spaces with the goal of improving occupant comfort.

Key words: wood, restorative environments, material preference, biophilic design, stress response, attention restoration

Povzetek

Preference ljudi do lesnih materialov in vloga le-teh v restorativnih okoljih

Doktorska disertacija je sestavljena iz petih raziskav, ki so preučevale, kako ljudje zaznavajo lesne materiale in kako se nanje odzivajo. Prva raziskava je pregledala metodologijo in rezultate študij, ki so preučevale, kako se ljudje odzivajo na les v smislu njihovih čustvenih stanj, fiziološke aktivnosti in kognitivne zmogljivosti. Ta pregled literature je razkril več priložnosti za izboljšanje metodologije na tem področju in opredelil obetavne, vendar omejene dokaze, da vizualna izpostavljenost lesu pozitivno vpliva na ljudi.

Druga raziskava je preučevala, kako ljudje v dveh državah—v Sloveniji in na Norveškem—zaznavajo različne vrste nemodificiranega in modificiranega lesa, ko je les predstavljen v obliki ograjnih ročajev ter zaznan taktilno in vizualno. Rezultati kažejo, da so vzorci nemodificiranega in modificiranega lesa ograjnih ročajev prejeli primerljive preferenčne ocene, ki so bile v obeh državah v splošnem višje kot pri kontrolnem (jeklenem) vzorcu. Več zaznanih lastnosti materialov, kot je toplota, je bilo povezanih s preferencami, pri splošni oceni materialov pa je bila pomembna tudi taktilna izkušnja.

Tretja raziskava je preučevala preference ljudi do različnih lesnih materialov za mize in dizajne miz. Rezultati kažejo, da se te preference od osebe do osebe zelo razlikujejo, vendar so nekatere mize oz. materiali kljub temu bolj priljubljeni od drugih. Tako dizajn mize kot tudi vrsta in količina materiala imajo pomembno vlogo pri preferencah ljudi do videza miz.

Četrta raziskava je preučevala čustvena stanja in kognitivno zmogljivost ljudi, potem ko so 15 minut sedeli za vsako od 10 majhnih miz z različnimi zgornjimi površinami. Čustvena stanja in kognitivna zmogljivost ljudi se med površinami miz niso razlikovali, kar kaže na to, da izpostavljenost majhnim lesenim miznim površinam verjetno nima velikih pozitivnih učinkov

Namen pete študije je bil predvsem preveriti primernost mentalne aritmetične naloge in mer čustvenih stanj z eno postavko za oceno čustvene, fiziološke in kognitivne restoracije ob leseni pisalni mizi. Sekundarni cilj študije je bil raziskati, ali se ti izidi razlikujejo med leseno in kontrolno (belo) večjo mizo. Rezultati so pokazali, da so bile mere čustvenih stanj z eno postavko robustne, zato druge raziskovalce spodbujamo k njihovi uporabi. Mentalna aritmetična naloga ni zanesljivo izzvala stresa ali povzročila *kognitivne izčrpanosti, kar kaže, da je potrebno uporabiti bolj stresne in kognitivno zahtevne naloge. Čustveni, fiziološki in kognitivni izidi ljudi se med leseno in belo mizo niso razlikovali. Vendar je treba opozoriti, da je imela študija za ta del analize nizko statistično moč in da je bilo z večjo verjetnostjo možno zaznati le velike učinke lesa.*

V celoti gledano rezultati raziskav iz te disertacije kažejo, da imajo ljudje v različnih kontekstih raje les, vendar je malo verjetno, da bi izpostavljenost manjšim lesenim površinam bistveno vplivala na afektivna stanja, fiziološko aktivnost in kognitivne zmogljivosti. Te ugotovitve razširjajo obstoječe znanje, saj omogočajo vpogled v to, kako ljudje zaznavajo in se odzivajo na les, uporabljen v različnih okoljih, in kako je to povezano s posebnimi lastnostmi lesa ali njegovo uporabo. Pridobljeno znanje je lahko podlaga za pripravo in uporabo lesenih materialov v notranjih prostorih s ciljem izboljšati udobje prebivalcev.

Ključne besede: les, restorativna okolja, preference do materialov, biofilni dizajn, odziv na stres, restoracija pozornosti

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Chapter 1

Introduction

Places where people spend their time can affect their health and wellbeing [1,2]. Humans are drawn to natural environments: not only do they find them attractive, but they also show improved functioning and wellbeing after spending time in them [2–5]. This affinity for nature is not surprising given the strong ties that have connected people and nature during the evolution of the human species [6]. Recently, however, people have distanced themselves from the natural environments: a typical person from a developed country spends most of their time indoors [7], which hardly resembles the environment to which humans are adapted as a species. People in (post-)industrialized societies are thought to experience stress more frequently than people living in hunter-gatherer societies—societies that occupied most of human history [6]. Stress can directly or indirectly lead to debilitating mental illnesses, including anxiety and depression, and other threatening conditions, such as cardiovascular disease and perhaps even cancer [8–10].

Natural environments may provide conditions conducive to stress recovery [3]. People exposed to elements of nature exhibit lowered physiological arousal, more pleasant affective states, and improved cognitive performance [2]. Due to these effects, natural environments are thought to be restorative, as they restore (or improve) human wellbeing. This is usually explained by the attention restoration theory (ART) [11], which proposes that exposure to nature replenishes diminished cognitive resources, or stress reduction theory (SRT) [12], which claims that contact with nature reduces stress by managing affective and physiological states of people. As most modern life takes place indoors [7], people may have a limited access to nature and its positive effects. Fortunately, bringing nature to interior spaces can be a viable and effective solution: the presence of nature indoors can be increased simply by introducing photos of landscapes, potted plants, or the scent of fresh flowers [2].

The positive effects that people experience when in contact with (elements of) nature are reflected in human environmental preferences: people consistently prefer natural over built environments. Environments with higher perceived potential for restoration (nature) receive higher preference ratings, and individuals in higher need of restoration (those experiencing stress) display even higher preferences for natural over built environments [13,14]. This suggests that environmental preference can be used as an indicator of environmental restorativeness: spaces that occupants find attractive are more likely to improve their wellbeing.

Wood, as a natural material, is of particular interest in bringing nature indoors. Unlike most elements of nature, it can be used in structural and functional elements of the building, such as trusses, flooring, and furniture [15]. The versality of wood stems from its favourable mechanical properties, including a high strength to weight ratio, machinability, and dimensional stability [16]. Most depictions of biophilic design include spaces furnished with wood [17,18], and existing studies suggest that contact with wood is beneficial for building occupants. People prefer wooden materials and environments and, after being exposed to indoor wood, tend to be more relaxed and perform better on tests of cognitive functioning [19–21]. However, positive effects of wood furnishings are not always observed [17,22–24]. This discrepancy could result from studies testing different types of wood, which are applied in various colours, patterns, amounts, and layouts. These varying characteristics of wooden furnishings to which people are exposed could play a crucial role in human response to wooden indoor spaces. However, it is unclear which properties of wood are most important in eliciting a positive response. Most studies examine how people perceive one or few types of wood compared to other everyday materials [25], but rarely are several types of wood compared to each other.

Wood is derived from a natural, renewable resource which exhibits wide within- and between-species variations and leads to varying physical, visual, and olfactory properties. Variations, especially between tree species, are reflected in the visual appearance of wood, as they affect colour, grain patterns, the number and size of knots, and other features. These variations are caused by 1) natural differences in the growth rate of trees, colour contrast between earlywood and latewood, anatomical variation in vessel placement/rays, climatic conditions, 2) production choices, such as exposing different wood surfaces (i.e., radial, tangential, or longitudinal) or applying various treatments (coatings, heat, etc.), and 3) conditions of wood use, such as exposure to light and humidity, which lead to natural degradation that changes colour and surface properties of wood.

Within species variations in appearance of wood are most apparent in grain patterns and result primarily from the following differences:

- differences in the size and number of knots which vary with the size, number, and placement of branches, and
- differing growth patterns caused by seasonal variations (e.g., weather, climate, fires, etc.), elevation differences, disease, insects, or soil and water variations that lead to varying grain patterns [26].

Between species variations in wood appearance are even more pronounced than within-species variations:

- European tree species result in wood in six major colours: yellow, light-brown, brown, reddish, greenish, and dark. Hardwoods tend to exhibit a wider range of colour variation, while softwoods tend to be more consistently on the lighter end of the spectrum. Trees growing in subtropical forests are characterized by an even broader range of colours; virtually all colours except blue, including purple, red, and black [27].

- Fast-growing tree species (e.g., poplar) form wide growth rings, while slow-growing species (e.g., yew) form narrow growth rings [27].
- The most pronounced growth rings are present in softwoods, due to a substantial difference between earlywood and latewood colours [27].
- Differing anatomical and chemical properties of tree species lead to differences in surface roughness [28] and thermal properties of wood [29].

Manufacturing choices and weathering are additional sources of variation in wood properties:

- The colour of wood changes with long-term exposure to light and air. Wood exposed to air turns grey, due to partial leaching of chemical compounds, changes from fungal activity, or reactions of tannins in wood with water [27].
- The gloss of wood depends on the amount and angle of light that hits the surface, material refractive index (i.e., how fast light travels through the material), and the surface shape and roughness [30]. The gloss of untreated wood is hardly visible, while the gloss becomes more intense in smooth (e.g., polished) surfaces [30] and the radial sections of hardwood species, which have broad and high tree rays [27].
- Commonly used coatings, such as varnishes, stains, waxes, or oils can change the wood surface colour and texture [30].
- Wood drying conditions and modification methods can also change the appearance of wood [31,32].
- Machining choices can affect thermal properties [29] and surface roughness [28] of wood, too.

These variations in wood properties affect human perception of material qualities, including visual homogeneity [33], perceived naturalness [34], temperature, hardness, and other features [35–37]. Existing research has identified certain material properties that are related to material preference. For example, when people sense wood by touch, they prefer untreated wood surfaces (compared to coated surfaces) and surfaces they perceive as smoother [36,37]; and when they assess the wood visually, people prefer surfaces that are shinier, less knotty, and have homogeneous colour [33,36,38,39]. However, as relatively few materials have been studied in few contexts, it remains unclear how material properties influence preferences for wooden materials.

In summary, current research suggests that exposure to wood in the built environment can improve human well-being. However, some studies did not detect significant well-being effects of wood exposure on humans, suggesting that specific wood properties and applications play a crucial role. A critical appraisal of the literature is necessary to gain a deeper insight into the methodology and findings of existing studies. The field then needs to move forward with empirical studies that build on current knowledge and assess human preference for and response to wooden environments using a combination of fitting measures. The results of these studies will help inform both research and practice aimed at improving the built environment for all occupants.

1.1 Problem and Purpose

1.1.1 Wood as a Material in Biophilic Design

Nature can be brought indoors in a variety of ways. The six guiding principles of biophilic design [40] suggest that indoor spaces could connect the occupants with nature by implementing the following approaches:

1. Environmental features (such as plants, water features, or natural materials).
2. Natural shapes and forms (elements that replicate features of nature, for example, tree-like shapes).
3. Natural patterns and processes (elements that remind us of processes of nature, by being, for example, rich in information or offer a lot of variability to our senses).
4. Features of light (e.g., natural light) and space (e.g., spaciousness) that are reminiscent of nature.
5. A connection of the built environment to the cultural and other characteristics of the area (e.g., including aquariums in an area where fishing is culturally important).
6. Nourishment of our evolved relationship with nature (e.g., in natural environments we often sought refuge, so indoor settings should make us feel protected).

Even though these guiding principles are distinct, certain indoor elements could address many of them simultaneously, and wood could address each principle [19]:

1. Wood itself is a feature of nature and using wood indoors, therefore, provides a direct link with the natural environment.
2. Grain patterns in wood consist of naturally developed shapes.
3. Wood grain patterns are a record of at least some natural processes, such as growth.
4. Wood can be stained in a variety of colours and be deployed in various sizes, which can be useful in shaping the aspects of light and space to be reminiscent of nature.
5. Using locally sourced wood may connect building inhabitants to their region.
6. Trees and wood were widespread throughout human evolutionary history

With different ways it can relate to the biophilic design principles, it seems that wood can be an important part of biophilic design. This is supported by many depictions of biophilic design that include spaces furnished with wood [17,18]. However, most of the existing research that examined how biophilic design impacts people focused on other elements of nature, such as potted plants and photos of landscapes [2]. Perhaps the reason is that elements like plants and landscape photos represent nature more directly, while wood—a processed part of a tree—offers a less direct experience of nature. However, wood has an important advantage: unlike many other elements of nature, it can be used in various structural and functional elements of the building.

When indoor spaces are furnished with elements of nature, it is important to ask why this would improve the wellbeing of occupants. The two most popular theories in the field are ART [11] and SRT [12]. According to SRT, stress is the culprit which leaves the individual in need of psychophysiological restoration. The theory proposes that contact with nature results in favourable changes in (physiological) arousal and affective states [11]. ART, on the other hand, is centred on the exhaustion of attentional resources. It proposes that we often operate on voluntary (or ‘directed’) effortful attention which is susceptible to depletion and must be periodically allowed to rest by activating involuntary attention, which often occurs in natural environments [11].

The theoretical underpinnings of SRT and ART need further development [41–47]. Among other issues, neither theory convincingly unifies affective and physiological states (advocated by SRT) and attention (advocated by ART), even though these constructs overlap substantially and rarely operate independently of each other.[45,46] Additional issues arise when ART and SRT are recruited to account for human responses to single elements of nature (e.g., to plants), considering that both theories primarily explain human response to rich natural environments. New theoretical developments would be useful to better account for human responses towards specific elements of nature, especially when these are applied indoors. For now, we can assume that at least some mechanisms proposed by SRT and ART are relevant even when trying to understand how people responds to natural elements outside of the context of rich natural environments.

According to SRT, human affinity for the natural is universal, originating from the evolutionary history of our species. However, potential cultural influences should not be overlooked. When it comes to wood, people can struggle in differentiating natural from artificial materials [48], and their ability to tell the difference can depend on their knowledge about wood treatments [49,50]. Perception of naturalness, in turn, can affect preference [37]. In a study from Burnard et al. [34], participants from Slovenia, Norway, and Finland rated several materials on perceived naturalness. Their ratings were generally consistent, but the ratings from Slovenia and the two Nordic countries did diverge in certain cases: Nordic participants perceived some processed wood samples as less natural than Slovenians. These differences may result from differences in knowledge and familiarity with wood and wood processing between the country populations, which could result from different practices of wood use. Wooden buildings have a rich tradition in the Nordic countries [51], whereas in Slovenia, relatively little wood is used for structural components of houses [52]. Since perceived naturalness and general preference of materials may vary between countries, studying wood perception and evaluation in countries with different wood practices may help us reach stronger conclusions about the (potentially) universal appeal of wooden materials.

The research examining how people react to wood has been lagging in comparison with studies examining the effects of other elements of nature. Still, several studies have tried to examine how people perceive wood and how they respond when exposed to it.

1.1.2 People’s Perception of Wood

The first line of empirical support for wood as a material in restorative, biophilic environments comes from the studies showing that people tend to perceive wooden materials [15,34,53] and spaces furnished with wood as natural [54]. Additional support is provided by the studies observing that wood tends to be more preferred than other commonly used materials, such as marble [15,53]. The latter findings are especially promising, as people's preferences for the environments can predict how they will feel and function in those environments [13,14]. This suggests that preferences can be a useful indicator of environmental restorativeness, including when it comes to preferences for wooden materials and spaces furnished with wood.

Some researchers have tried to pinpoint which properties of wooden materials are related to people's preferences for those materials. Preference for materials can be seen as the culmination of lower-level affective attributes (e.g., "interesting") and perceptions of the physical surface (e.g., "rough") [55,56]. When wood is examined by touch, people tend to prefer untreated over coated surfaces [35,57]. The most consistent finding seems to be that people prefer wood surfaces they perceive as smoother [35–37]. Some evidence suggests the same is true for surfaces perceived as denser, warmer, damper, softer, and more natural [36,37], although the results are inconclusive and further research is called for. Visual preference for wood is additionally influenced by other factors: people tend to prefer surfaces that are shinier, less knotty, and have homogeneous colour [33,36,38,39,58]. However, the preferences for particular properties of wood may heavily depend on the context of wood application. For example, people tend to prefer lighter colour of wood when the wood is intended for no particular application [36] but favour darker wood for an outdoor table top [59]. With so many diverse wooden materials and possibilities for their application indoors, how people perceive wood remains largely under-explored.

One of the important contexts in which wood perception should be studied is when wood is applied to desks, because many office workers may spend much of their time in contact with them. It is currently unclear how to design desks and apply wood to them to make them more visually appealing to people. Existing evidence-based design guidelines focus on ergonomic aspects, which recommend producing desks with qualities such as adjustable height, sufficient width, adequate knee space, and rounded edges [60]. However, designing desks in ways to improve their aesthetical qualities has not been (to our knowledge) discussed in peer-reviewed articles. In principle, the more visually appealing desks are more likely to lead to restorative effects, so the aesthetical qualities of desks should be explored. It is currently not known how people perceive different desk designs and how those perceptions are influenced by applying different types and amounts of wood to desks. Similar questions have only been answered in different contexts and they do not necessarily translate to the context of desks. For example, people seem to prefer a medium amount of wood coverage in a room [61] but it is unclear if the desired wood coverage is similar in a single piece of furniture, such as desk.

In some applications, the tactile experience of materials may be especially important (in addition to the visual experience), especially when people are expected to touch wood frequently (e.g., handrails). The tactile experience is particularly relevant when it comes to wood treatments, which are commonly applied to wood to improve its performance or inhibit degradation, but they also change tactile properties (e.g., dampness). Some wood treatments might inadvertently negatively impact the tactile experience of materials: when touching materials, people rate untreated wood as more liked than coated wood [35] and their physiological state indicates greater relaxation [57]. Additional reasons for the importance of tactile properties of materials come from studies examining how consistently people perceive materials between tactile and visual modalities. In a study conducted by Overvliet and Soto-Faraco [48], in which participants rated naturalness of materials, ratings were consistent between tactile, visual, and tactile–visual experience of wood, suggesting that the tactile experience significantly contributes to the overall perception of materials. The authors of the study concluded that vision and touch are equally good at predicting naturalness. Since the tactile domain seems to play an important role in general material perception, it should be further explored in different types of wood and different contexts of wood use. One important line of research is studying the tactile and visual experience of modified wood—wood that has undergone modification process that enhances its construction-related properties [62]. As a side effect, modification processes change material properties directly available to human senses, such as colour, dryness, or roughness [63,64]. Because of its enhancements, we can expect modified wood to become more widely used in the future; however, how modified wood is perceived has been rarely examined. The few studies that have investigated this topic report that certain thermally and chemically modified wood samples are similarly liked by both professionals and lay users as other types of wood in multiple settings [59,65]. However, more evidence is needed to confirm these findings in other settings and determine whether modified wood is suitable for use in restorative environments.

Continuing to study human preferences for wood is an important approach that can help us understand which wooden materials applied in which contexts and amounts have the largest potential to contribute to restorative environments.

1.1.3 People's Responses to Wood Exposure

Some studies investigated how people respond to wooden materials in terms of physiological activity, affective states, and/or cognitive performance. The earliest research on the topic comes from three similar studies conducted in Japan in the second half of 2000s [54,66,67]. These three studies exposed participants for a brief period of time (90s) to different spaces that were furnished with wood to a smaller or greater extent and monitored how people reacted in terms of their physiological activity and affective states (but not cognitive performance). The three studies differed primarily in the type of conditions that participants were exposed to:

- Sakuragawa et al. [66] exposed 14 participants to three conditions: facing either a wooden wall panel, a white steel wall panel, or a white curtain (control condition).
- Tsunetsugu et al. [67] first exposed 15 subjects to a room with intermediate amount of wood after which they were exposed to both a 'standard' (wood applied

mainly in flooring) and ‘designed’ room (wood applied also to walls and ceiling), in random order.

- In another study by Tsunetsugu et al. [54], participants similarly first spent time in the ‘practice’ room after which they were exposed to three rooms (in random order): the room treated with 0%, 45%, or 90% wood coverage.

The results on physiological activity were inconclusive in all three studies. The changes in physiological activity between conditions did occur but they are challenging to interpret given the overall design of the studies. Both positive (e.g. excitement, relaxation) and negative outcomes (e.g. nervousness, sadness) can be reflected in either increased or decreased physiological activation, depending on the context and the specific physiological measure used [68,69]. Neither study by Tsuentsugu et al. [54,67] observed any differences in affective states between the rooms, while Sakuragawa et al. [66] found that participants had improved affective states in the wooden setting compared to the other conditions.

Another similar study [23] compared physiological activity of participants viewing three image projections for 90s; the images consisted of grey colour (control condition), vertical wood grain, and horizontal wood grain. The differences between conditions in terms of physiological activity were inconclusive, while participants reported more pleasant affective states after viewing the wood images, and the affective states were even more favourable in the vertical wood grain image condition (compared to the horizontal wood grain image condition). Other studies on the topic employed longer exposure times to wood and generally produced clearer findings that favour wood, but the results were not entirely clear-cut [17,70–72]. Studies from Zhang et al. [70,71] and Demattè et al. [73] observed more favourable affective states in the wooden environment, but the scent of wood (instead of its visual properties) present in the experimental rooms could have been the main contributor to the observed differences in affective states. The most convincing findings showing potential positive influence of visual exposure to wood come from Fell’s [17] and Burnard and Kutnar’s [72] studies.

In Fell’s [17]study, each quarter of the total 119 subjects spent approximately 40 min in one of the four settings – a room with a wooden interior with plants, a room with a wooden interior without plants, a room with a non-wooden interior with plants or a room with a non-wooden interior without plants. In the room, subjects performed a cognitive task (Paced Auditory Serial Addition Test), which was used primarily to induce stress. The results showed that participants’ physiological (i.e., electrodermal) activity was lower in the wooden settings than in the non-wooden settings. Differences in cognitive performance among subjects were not found.

In Burnard and Kutnar’s study [72], 61 subjects spent 75 min in each of the two office-like rooms in random order. One of the rooms was a control room with white furniture, and the other room had either oak veneered or walnut veneered furniture. In each setting, participants were exposed to a stress-inducing video. The results showed that the average level of cortisol—a biomarker of stress—was lower in the oak veneered room compared to the control room (while the average cortisol level did not differ between the walnut veneered furniture and the control room).

Fell's and Burnard and Kutnar's studies provide promising evidence in favour of wood. However, both studies observed the differences between settings only when they compared *average* levels of physiological arousal, while they did not found differences in physiological arousal when they examined *recovery* after stress, which would be an expected effect of a restorative environment. This opens the possibility that factors other than wood exposure influenced the differences in average levels of physiological activity, especially in Fell's study, which did not follow a proper randomization process.

Several methodological issues are apparent in many of the studies described above. For example, several studies [54,66,67] measured physiological activity in each setting for only 90 seconds. Such an approach makes it challenging to differentiate between positive and negative (affective) outcomes, which are often manifested in overlapping patterns of physiological activity [68,69]. These studies coupled the measures of physiological activity with the Profile of Mood States [74]—a questionnaire examining affective states that may not be appropriate for the context. The questionnaire, originally named Psychiatric Outpatients Mood Scale, measures six specific states that were deemed important by psychiatrists assessing the effects of various drugs on patients, particularly on war veterans showing symptoms of post-traumatic stress disorder. Its primary targets were depression and anxiety (reflected in the scales 'depression' and 'tension'), while the scales 'anger', 'vigour' and 'fatigue' were of interest due to being related to common side effects of medication. 'Confusion' scale was added to assess potential disruptive effects of drugs on mental functioning [75]. It is unclear why these specific affective phenomena are expected to vary with exposure to different indoor settings, and the studies may have missed changes in affective states by failing to measure more relevant constructs. The methodology of the abovementioned studies could also be

improved by placing greater focus on examining cognitive performance. Investigating cognitive performance in (restorative) indoor environments is important for at least two reasons. First, directed (voluntary) attention, an important facet of cognitive performance [76], may play an important role in the aetiology of human stress [11]. Second, directed attention may be a common resource in executive functioning and self-regulation [77]. Recent findings show, for example, that exposure to nature delays gratification [78], inhibits aggressive urges [79] and boosts persistence and results on logical reasoning tasks [80]. Thus, a natural environment could not only enhance performance on a variety of cognitive tasks, but also lead to other health-related improvements that are associated with higher self-regulation ability, such as improved coping with stress and healthier food choices [45]. As natural environments may influence executive functioning without significantly changing affective or physiological states [45], important discoveries can be overlooked if cognitive tasks are not incorporated.

Taken together, the existing studies suggest that exposure to wood might influence people positively, but the studies need to be carefully reviewed both in terms of their results and methodology used before confident conclusions can be drawn and the field can move forward. New empirical studies need to be conducted that will employ a different methodology and contribute by both bringing new insights in how people respond to wood and how these responses should be tested in terms of methodology.

1.2 Research Aims and Goals

The overall aim of the proposed research was to determine the suitability of wood for use in restorative indoor environments, as reflected in human preference for different materials and settings, as well as physiological, affective, and attentional responses to different indoor environments. Our goal was to examine this topic through a set of five related studies. First, we critically evaluated the methodology and results of existing studies examining human responses to indoor wooden environments (Article 1). Next, we conducted four empirical studies examining human preference for and response to wooden materials (compared to non-wooden materials). The first empirical study (Article 2) examined human preference for six handrails made of different materials with different treatments. The second empirical study (Article 3) examined human preference for the selection of common wooden materials, desk designs, and desks that combine different materials and designs. The third empirical study examined the response of people exposed to 10 variations of a small desk surface (Article 4). The fourth empirical study tested the human response to a larger wooden desk surface while investigating the suitability of the study protocol for further research (Article 5).

1.3 Hypotheses

In general, we predicted that people would prefer wooden over non-wooden materials and that their physiological, affective, and attentional parameters of wellbeing will be higher in environments with wood than in those without wood. Specifically, we hypothesized that 1) all five wooden handrails will be preferred to the control material (Article 2); 2) wooden desk designs will be preferred to desk designs using less wood (Article 3), and 3) affective states, cognitive performance, and physiological arousal of individuals will be enhanced when exposed to wooden desktops compared to exposure to control materials (Articles 4 and 5).

1.4 Materials and Methods

1.4.1 Article 1

In Article 1, we conducted a systematic literature review examining the methodology and results of existing studies examining human response to wooden environments. We searched online databases for English-language studies that examined at least one physiological, affective, or attentional outcome in response to indoor visual wood exposure. Specifically, we searched Scopus, JSTOR, Web of Science, and Google Scholar for all titles that contain the word "wood" or "wooden" along with any of the following terms or their derivatives: psychology, emotion, affect, mood, physiology, arousal, human stress, stress response, attention, cognition. Articles resulting from this search were examined individually and those that met our criteria were selected for further review. In analysing these studies, we focused on critically evaluating both their methodology and results. The process of conducting and reporting this review followed the general principles recommended by the Cochrane guidelines for systematic reviews of interventions [81]and the PRISMA statement for reporting systematic reviews [82].

1.4.2 Article 2

In Article 2, we investigated human preference for a set of wooden materials and attempted to link preference ratings to subjective perceptions of various wood properties, such as roughness and naturalness. We used six cylindrical handrail samples; one made of stainless steel and five made of modified or unmodified wood. Specifically, we included handrails made of unmodified spruce, unmodified pine, acetylated radiata pine, thermally modified spruce, and thermally modified pine. The handrail specimens were 42 mm in diameter and 30 cm long. Each sample was mounted on a wooden base measuring approximately 30 cm x 15 cm x 5 cm, which was covered with white foil during the experiment.

100 older adults over 60 years of age from Slovenia and Norway participated in the study. The study consisted of three tasks. In the first task, participants were able to touch (but not see) the materials: they were instructed to keep their eyes closed during the test. Based on their tactile experience of materials, participants provided a response on a semantic differential scale that was read to them. The semantic differential scale was based on previous work investigating material perception; we selected sensory (e.g., dry) and affective (e.g., expensive) descriptors that we considered most relevant for evaluating the materials used in the study. After completing the tactile task, participants proceeded to the second part of the study: the tactile-visual task. This task was identical to the tactile task, except that in this case subjects were able to both touch and see the materials. The materials were presented to each participant in random order, but the order of the tactile task was repeated in the tactile-visual task for each participant to allow for a better comparison of the results of the two tasks. The third part of the study consisted of the ranking task. Participants were presented with all the materials at once to examine them

tactilely and visually. They were asked to rank the materials from most to least preferred by laying out cards with numbers from one (preferred) to six (least preferred).

1.4.3 Article 3

In Article 3, we examined human preference for a selection of common wooden materials, desk designs, and desks that combine different designs and materials. The study consisted of two phases. In the first phase, we prepared 1) images of 20 wooden materials used in other studies examining how people perceive and respond to wood and 2) images of 18 desk designs with systematically varied features (the desk designs were presented as 3D rendered models). Eighty-three participants rated their preference for (images of) all wooden materials and desk designs based on a 9-point rating scale (1 – exceptionally dislike, 5 – neither like nor dislike, 9 – exceptionally like). In the second phase of the study, we prepared images of 21 desks that were a mixture of the three most preferred wooden materials and desk designs tested in the first phase of the study, while the desks also varied based on the amount of included wood. Seventy-seven new participants rated their preference for images of those 21 desks using the same 9-point rating scale.

1.4.4 Article 4

In Article 4, we examined how people respond to sitting at different desktop surfaces in terms of their affective states and cognitive performance. The desktop surfaces were made of 10 different materials with dimensions of 80 × 80 cm. The materials included untreated spruce wood, oiled spruce wood, lacquered spruce wood, untreated oak wood, oiled oak wood, lacquered oak wood, untreated oak veneer, imitation wood laminate, glass (on laminate), and mineral-filled thermoplastic composite.

Affective states were examined with two single-item scales that capture states of pleasure and arousal [83]. The two administered items asked, "How pleasant/activated do you feel at this moment?" Participants will provide their responses on a 9-point rating scale (1 = especially unpleasant/activated, 5 = neutral, 9 = especially pleasant/activated). Cognitive performance was assessed with the Simon task [84].

A sample of 16 subjects participated in the study. Participants began with the baseline period where they were brought to a control desk. They rested in silence for 1 minute before performing the cognitive task and reporting affective states (CTAS). Subjects were instructed to keep their gaze on the desk surface during all rest periods throughout the experiment. After the baseline period, participants began the experimental part of the study by sitting at a desk consisting of one of 10 desk surface materials (the order was randomized). Before performing the CTAS for the second time, they again rested for 1 minute. Subsequently, subjects rested for 15 min, leaving their bare arms immobile and flat on the desk, and their gaze directed to the desk surface. After the rest period, subjects completed the CTAS for the third and final time. Subjects repeated the entire session 10 times, once for each desk material. They took 15-minute breaks between sessions if more than one session was completed in a day.

1.4.5 Article 5

In Article 5, we investigated whether the type, duration, and timing of tasks and measures can detect potential effects of the indoor environment on human response. We were also interested whether affective states, cognitive performance, and physiological activity of people differ if they sit at a larger desk with a wooden desktop or a desk covered with a white cloth. A convenience sample of 22 subjects participated in the study. Each participant began their experimental session at a small white desk and rested for 10 minutes. They then reported their affective states, performed a stress-inducing cognitive task—Mental Arithmetic Task (MAT), and reported their affective states for a second time. Afterwards, they relocated to either a larger wooden desk or a desk covered with white cloth (approximately 90 x 200 cm) where they rested for 10 minutes. Before completing the experiment, participants reported their affective states and performed the cognitive task for the third and final time. Participants' electrodermal and cardiovascular activity was monitored throughout the experimental session. Affective states were captured by two items assessing pleasure and arousal, based on the circumplex model of affect [83].

Chapter 2

Published Articles

2.1 Article 1

Title: Effects of visual exposure to wood on human affective states, physiological arousal and cognitive performance: A systematic review of randomized trials

Authors: Dean Lipovac, Michael D. Burnard

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Effects of visual exposure to wood on human affective states, physiological arousal and cognitive performance: A systematic review of randomized trials

Dean Lipovac[1,2] and Michael D. Burnard[1,2]

Abstract

Background: Bringing features of nature indoors can positively influence indicators of human stress. Since wood is a natural material, it may produce similar benefits. The objective of the review was to (1) examine the influence of visual (real or virtual) contact with either real or imitated indoor wooden surfaces on certain stress indicators, that is affective, physiological or cognitive performance outcomes (compared to non-wooden surfaces) and to (2) assess the methodological quality of the reviewed studies.

Method: We conducted a systematic literature search for English articles on Scopus, PubMed, Web of Science, Cochrane Central and Google Scholar on 6 August 2019. The results of the eligible studies were synthesized narratively in light of the identified methodological shortcomings.

Results: We reviewed nine studies with 386 participants in total. Studies with longer exposure times to wood generally observed improved affective states and decreased physiological arousal in wooden settings, but the results are not entirely clear-cut. We discuss several methodological issues uncovered in the reviewed studies and provide guidelines for future robust research.

Conclusions: Current evidence suggests that visual wood exposure may improve certain indicators of human stress, but additional research is needed to confirm the existing findings.

Keywords
Wood, Human stress, Emotions, Autonomic activation, Executive functions, Restoration

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Introduction

Currently, 55% of the world's population lives in urban areas; by 2050, this percentage is expected to increase to 68%.[1] As the population further shifts to urban environments, the effects of urban living must be carefully considered. People living in cities have an increased risk of suffering from mental disorders,[2] which could be related to their heightened sensitivity to stress[3] and repeated exposure to environmental (e.g. noise), social (e.g. greater social disparities) and behavioural stressors (e.g. increased competition).[4,5] Constantly adapting to these stressors may, in turn, lead to attentional fatigue, which can increase stress levels even further.[6] The experience of stress does not have to depend on adverse external factors. Stress can be induced by neutral or seemingly harmless occurrences that are cognitively appraised as negative[7] and

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the stress response can be sustained with persistent cognitive representation of stress-related content.[8] Accordingly, stress can be widespread even in the absence of obvious stress-inducing occurrences.

While acute – short and infrequent – stress responses typically do not represent a risk, chronic – persistent and long-term – stress responses may damage health by altering nervous, cardiovascular, endocrine and immune systems.[9,10] Chronic stress can directly or indirectly lead to debilitating mental illnesses, including anxiety and depression and other threatening conditions, such as cardiovascular disease and perhaps even cancer.[9,11,12] Reduced attentional capacity presents additional issues beyond exacerbating stress, including impaired problem-solving capabilities and inhibition of inappropriate behaviours.[13–15]

Various interventions are helpful in reducing stress and the subsequent harm stress may cause; for instance, physical exercise,[16] meditation[17] and cognitive-behavioural therapy[4] have received wide attention. Unfortunately, these interventions call for energy, time and commitment, and may not be attractive for stressed and fatigued individuals. Complementing these active approaches with passive interventions, introduced to places where people spend most of their time, could bring stress reduction to more people.

Exposure to nature or natural elements could be such an intervention, as it may lead to enhanced affective states (referring to subjective experience of feelings, emotions and moods), reduced physiological arousal and improved attentional capacities.[18–20] The restorative qualities of nature are usually interpreted through either stress reduction theory (SRT),[21] attention restoration theory (ART)[6,22] or both.

According to SRT, stress is the culprit which leaves the individual in need of psychophysiological restoration. The theory proposes that contact with nature (or natural elements) results in favourable changes in (physiological) arousal and affective states.[21]

ART, on the other hand, is centred on the exhaustion of attentional resources. It proposes that we often operate on voluntary (or 'directed') effortful attention which is susceptible to depletion and must be periodically allowed to rest by activating involuntary attention, which often occurs in natural environments.[6]

The theoretical underpinnings of SRT and ART need further development.[23–29] Among other issues, neither theory convincingly unifies affective and physiological states (advocated by SRT) and attention (advocated by ART), even though these constructs overlap substantially and rarely operate independently of each other.[27,28] Additional issues arise when ART and SRT are recruited to account for human responses to single elements of nature (e.g. to plants), considering that both theories primarily explain human response to rich natural environments.

Despite the theoretical shortcomings, a growing body of evidence shows that being in nature improves several indicators of human stress. However, urban dwellers spend most of their time indoors[30] and might have limited access to nature, which encourages bringing nature to interior spaces. The presence of nature indoors can be increased simply by introducing photos of landscapes, potted plants or the scent of fresh flowers. Such interventions can bring nature to nearly any indoor environment, regardless of its pre-existing characteristics. Importantly, similar positive effects on human well-being that are observed in outdoor natural environments are detected when nature is brought into indoor settings.[18]

Wood is of particular interest in bringing nature in interior spaces, because it is a versatile and renewable natural material that can be used structurally, decoratively and for other functional elements in buildings.[31] It is perceived as more natural than other common building materials[32,33]; correspondingly, interiors containing more wood are rated as more natural than the interiors with lower wood coverage.[34–37] As such, wood allows us to embed naturalness in the foundations of the built environment while supporting sustainable construction practices.[38] However, does the presence of wood in indoor spaces lead to favourable physiological, affective and cognitive performance outcomes?

Few experimental studies addressed this question and those that attempted have employed diverse methodological approaches. Our objectives were to review the existing randomized controlled trials in order (a) to assess the effects of visual contact with wooden surfaces in the indoor environment on at least one physiological, affective or cognitive performance outcome (compared to visual contact with any other surface) in the entire population; (b) to identify positive and negative aspects of study designs and (c) to develop recommendations for future robust studies. Compared to the existing reviews,[39,40] this review is the first to address the methodological issues in-depth and use the resulting insights to critically evaluate the reviewed research. In addition, this article examines several recent studies that were not included in the previous reviews.

Method

The process of conducting and reporting this review followed the general principles recommended by the Cochrane guidelines for systematic reviews of interventions[41] and the PRISMA statement for reporting systematic reviews.[42] Cochrane guidelines were developed to provide a consistent and reliable framework for systematic, informed and explicit reviews. The guidelines advise all stages of review preparation, from preparing questions and designing the initial search strategy to collecting and analysing data and drawing conclusions. The PRISMA statement encourages the process of review preparation to be fully and transparently reported, allowing readers to assess the strengths and weaknesses of the investigation. It provides reporting guidelines concerning the entire article, starting with the manuscript title and ending with conclusions.

We searched for published randomized controlled trials assessing at least one physiological, affective or cognitive performance outcome in response to visual (real or virtual, of any duration) wood exposure in indoor environments (to both real wood and wood imitations). Eligible studies had to include at least one control intervention, that is visual exposure to a non-wood material. Studies with visual wood exposure interventions that allowed participants tactile or olfactory contact with materials were *not* excluded. Eligible primary outcomes were any indicator of autonomic nervous system functioning for 'physiological outcomes'; any measure capturing either core affect (i.e. simplest consciously accessible feelings, such as pleasantness), emotions or mood of participants for 'affective outcomes', and any measure capturing any facet of executive functions for 'cognitive performance outcomes'. Secondary outcomes included measures of central nervous system functioning and non-affective self-report measures (e.g. fatigue, vigilance) that might provide additional insight into human responses in wooden indoor environments. Only full texts reported in English were included. We did not impose any additional restrictions related to the year of publication, publication type, study design, intervention duration, type of implemented wood or characteristics of participants.

Studies were identified by searching electronic databases (on 6 August 2019) and scanning reference lists of articles. Specifically, we searched in Scopus, PubMed, Web of Science, Cochrane Central and Google Scholar for all article titles containing the word 'wood' or 'wooden' along with any of the following expressions or their derivatives: psychology, emotion, affect, mood, physiology, arousal, human stress, stress response, attention, cognition. The search was developed and conducted by the first author and checked by the second author; a detailed search strategy is available in Table S1. The same search phrases were used in all databases. Screening and eligibility assessments were performed independently by both reviewers and disagreements were planned to be resolved by consensus. Additional articles were identified by scanning reference lists and manual searching.

To ascertain the risk for bias in individual studies, both authors screened each study with the assistance of the revised Cochrane risk of bias tool for randomized trials. The tool includes questions that capture several domains of potential bias (e.g. different aspects of trial design) and algorithms that aid in judging the risk of bias according to the answers on these questions.[43] To extract data, the lead author developed a data extraction form based on the Cochrane Consumers and Communication Review Group's data extraction template, which is designed to help authors capture all relevant information about the included studies.[44] The author then extracted the data from the studies that were later checked by the second author. When a single study was reported in multiple reports, the data from all reports were extracted directly into one data collection form. Any disagreements were resolved by discussion between the authors. From each study, the information was extracted on (1) study design; (2) location; (3) participants (number, age, gender, sociodemographic information, inclusion and exclusion criteria); (4) intervention setting(s); (5) control setting; (6) duration of the exposure and (7) physiological, affective and cognitive performance outcomes. The primary outcome measure was the difference in any physiological, affective or cognitive performance outcome between the intervention (i.e. wooden) and control (i.e. non-wooden) for both within- and between-subject studies. Meta-analyses (or other forms of quantitative synthesis) were not conducted due to incomplete reporting of results and considerable methodological diversity across studies, including differences in measured outcomes and certain studies not controlling for olfactory stimulation. Results were summarized and synthesized narratively. Methods of the analysis and inclusion criteria were not documented in a registered protocol.

Results

Study selection

The search produced 3267 unique articles which were individually examined by title, and, when needed, by abstract and full text. A considerable number of studies was excluded due to their focus on biological (e.g. investigating physiology of wood) or mechanical wood properties (e.g. mechanical stress in wood), while some studies were excluded due to assessing responses to wood that were not relevant for this review (e.g. tactile perception of wood). The full texts of 11 articles (reporting nine studies) were assessed against eligibility criteria, and of those, all were included in the review. The detailed study selection procedure is presented in Figure 1. There were no disagreements on inclusion between the reviewers.

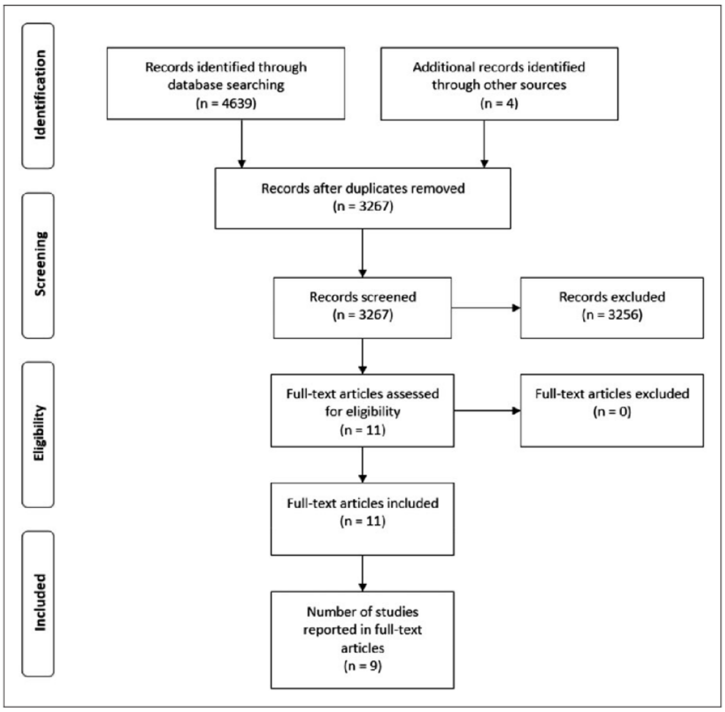

Figure 1. Flowchart of the study selection process.

Characteristics of included studies

Characteristics of included studies are summarized in Table 1 and presented in more detail in Table S2. With the exception of Fell's between-subject experiment,[36] all studies employed a within-subject design. Four experiments are characterized by short exposure times to wood (90 s) and low numbers of participants (between 14 and 28),[34,47–50] while the other five studies employed longer exposure times (10–75 min) and typically larger number of participants (between 12 and 119).[35,36,45,46,51,52] Five studies created wooden settings of only light colour wood,[35,36,45,47,48] two studies used only dark wood,[34,49,50] and two studies employed both light and dark wood, either separately in different settings or combined in the same room.[46,51,52] Five studies included solid wood,[35,48–52] three used wood composites[34,36,46] and one used images of wood.[47]

Four of the reviewed studies investigated both physiological and affective responses,[34,47,48,50] two studies examined a combination of physiological and cognitive performance outcomes,[36,46] one study investigated physiological outcomes,[45] one study assessed affective states[35] and one study inspected all three domains – physiological arousal, affective states and cognitive performance (although the results of cognitive performance tasks will not be reviewed here, since they have not yet been reported in a peer-reviewed article).[51,52]

Risk of bias within studies

Risk of bias assessment based on the Cochrane revised risk of bias tool is summarized in Figure 2 and presented in detail in Table S3. Overall risk of bias was low in four studies,[35,45–47] high in three studies (due to the insufficient randomization process[36] or due to reporting only a selection of results[48,51,52]) and presents some concerns in two studies (due to missing outcome data[34,49,50]).

Table 1. Summary of the characteristics of the reviewed studies.

Author(s) (year)	Study design	Location	Sample characteristics	Experimental setting	Intervention condition(s)	Control condition	Outcome measures
Bamba and Azuma[45] (2015)	RCT (ws)	Japan, Osaka, Kinky University	n: 12 (6 women) students Age: 23.3 ± 4.0 (between 20 and 35);	Set-up: Room with a chair and a desk Visual and olfactory exposure (10 min) Stress induced with a 30 min cognitive task	1. A solid wood panel (Japanese cedar) on one wall with cut slits to increase odour, and 2. Room filled with wood odour but no visible solid wood panel	1. Room with no visible wood or wood odour	Physiological arousal (PA): blood pressure, heart rate, heart rate variability and salivary alpha-amylase (measured continuously) Other: self-reported fatigue levels, room perception
Burnard and Kutnar[46] (2020)	RCT (ws)	Slovenia, Izola, University of Primorska	n: 61 (47 women); Age: 27.7 ± 9.3 (between 18 and 52);	Set-up: Room with a desk, a chair, a filing cabinet and bookshelves above the desk; Visual exposure (75 min); Stress-inducing activity: 6 min video;	1.Wood (oak) veneered light colour furniture, or 2. Wood (walnut) veneered dark colour furniture	1. White colour furniture	PA: Cortisol (measured 7×), heart rate (measured continuously) Executive functions (EF): Proofreading task (administered 1×) Other: Well-Being Index (WHO-5)
Demattè et al.[35] (2018)	RCT (ws)	Italy, Padova, University of Padova	n: 102 (55 women) Mean age: 37.34 (between 20 and 77)	Room set-up: Two desks with chairs, a couch, a coffee table, two floor lamps and a dark carpet; Visual and olfactory exposure (15 min)	1. Floors and all four walls covered with solid wood of light colour (Norway spruce and silver fir)	1. White floors and four plastered walls painted in beige	Affective states (AS): Positive and Negative Affect Schedule (administrated 2×) Other: Nature Relatedness Scale, room perception
Fell[36] (2010)	RCT (bs)	Canada, Vancouver, University of British Columbia	n: 119 (74 women); Age: 21.3 ± 2.48 (between 18 and 30);	Room set-up: one large desk, one small desk, two bookshelves, two chairs, a large window with blinds; Visual exposure (35.5–38 min) Stress-inducing activity: Paced Auditory Serial-Addition Task (PASAT)	1. Light colour wood (birch) furniture, or 2. Light colour wood (birch) furniture + plants	1. White furniture. 2. White furniture + plants	PA: Electrodermal activity, heart rate, heart rate variability (measured continuously) EF: PASAT (administrated 1×) Other: room perception
Nakamura et al.[47] (2019)	RCT (ws)	Japan, Chiba, University of Chiba	n: 28 (all women) Age: 22.3 ± 2.1	Set-up: An image (1.053 m × 1.053 m) projected on a wall in a dark room with participants sitting 1.1 m from the display; Exposure type: Visual (image) (90 s)	1. An image of light colour wood (Japanese cedar) rotated to portray vertical grain pattern, and 2. An image of light colour wood (Japanese cedar) rotated to portray horizontal grain pattern	1. A grey image	PA: Near−infrared time−resolved spectroscopy, heart rate, heart rate variability (measured continuously); AS: Profile of Mood States (POMS) 2nd ed.; (administered 1×); Other: room perception

(continued)

Table 1. Continued.

Author(s) (year)	Study design	Location	Sample characteristics	Experimental setting	Intervention condition(s)	Control condition	Outcome measures
Sakuragawa et al.[48] (2005)	RCT (ws)	Japan	n: 14 (all men); Sociodemographic information: Healthy college students	Set-up: An empty room with one wall covered by a large panel and the surrounding two walls covered with white drapes; Exposure type: Visual and olfactory (90 s);	1. Solid wood (hinoki) panel covering one entire wall surface, and 2. White steel panel covering one entire wall surface	1. A white curtain covering one entire wall surface	PA: Heart rate, blood pressure (measured throughout the entire exposure) AS: POMS (administered 1×) Other: room perception
Tsunetsugu et al.[49,50] (2002, 2005)	RCT (ws)	Japan	n: 15 (all men); Age: 19 25 years;	Set-up: Room with a white couch, a large plant, dark wood flooring and a dark wood coffee table; Visual exposure (90 s)	1. Exposed dark wooden elements on the walls and ceiling	1. Without exposed wooden elements on the walls and ceiling	PA: Heart rate, blood pressure (measured continuously) AS: POMS (administered 1×) Other: blood flow in prefrontal cortex (left and right side), room perception
Tsunetsugu et al.[34] (2007)	RCT (ws)	Japan	n: 15 (all men); Age: 19–28 years Sociodemographic information: Students	Set-up: Room with a white couch, a large plant and a coffee table; Visual exposure (90 s)	1. 45% wood room: dark wood (oak veneer) in flooring, coffee table and in parts of the wall, and 2. 90% wood room: The same as 45% room, except the majority of the wall is covered with wood	1.0% wood room: grey flooring and table, white walls	PA: Heart rate, blood pressure (measured continuously) AS: POMS (administered 1×) Other: blood flow in prefrontal cortex (right side), room perception
Zhang et al.[51,52] (2016, 2017)	RCT (ws)	China	n: 20 (10 women); Age: 26 ± 3	Set-up: A small desk and a chair in an otherwise empty room; Visual and olfactory (60 + 30 min in the preparation room)	1.All walls completely covered in dark solid wood, and 2. All walls completely covered in light solid wood, and 3. Half of each wall covered in light solid wood and the other half painted white	1. All walls painted white	PA: Electrodermal activity, skin temperature, peripheral oxygen saturation (SpO_2) (all measured continuously), heart rate, heart rate variability, blood pressure (measured 4×) AS: POMS (administered 2×) Other: eyesight, questionnaire on fatigue, room perception

bs: between-subject design; RCT: randomized controlled trial; RH: relative humidity; ws: within-subject design.

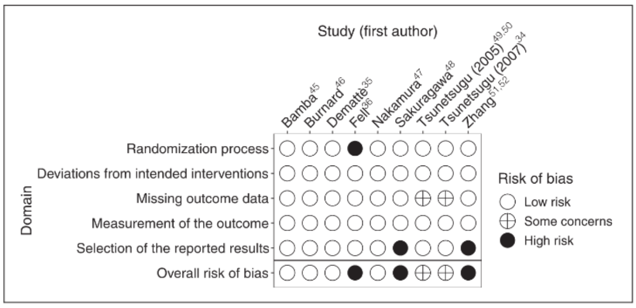

Figure 2. Risk of bias in the reviewed studies.

Methodological issues in the reviewed studies

Several methodological issues were identified in measuring physiological arousal, affective states and cognitive performance. Below we discuss methodological issues separately for each group of these measures.

Assessing physiological arousal. With the exception of the study conducted by Demattè et al.,[35] all reviewed studies included at least one physiological measure. Although such measures seemingly provide robust and objective results, they are often difficult to interpret if not accompanied by a suitable study design. The aspects of the reviewed studies that make interpreting physiological outcomes difficult are discussed below.

Physiological measures not sufficiently corroborated. Physiological response cannot be easily interpreted on its own, especially if the physiological data are derived from few sources. It may be tempting to conclude that lower arousal levels denote lower stress response and thus a favourable outcome (and vice versa), but this is not necessarily the case. First, according to SRT, exposure to pleasant natural environments can either increase, decrease or not influence arousal, depending on the initial arousal level.[21] Second, autonomic nervous system activation corresponds to a variety of functions, including homeostasis, attention, effort and digestion.[53] Third, both positive (e.g. excitement, relaxation) and negative outcomes (e.g. nervousness, sadness) can be reflected in either increased or decreased physiological activation, depending on the context and the specific physiological measure used.[54,55]

Short assessment period. Three of the reviewed studies[34,48–50] measured autonomic activation in each tested environment for 90 s. By offering only a short glimpse into physiological responses, such an approach further complicates the differentiation between positive and negative (affective) outcomes, which are often manifested in overlapping patterns.[54,55] Additionally, a certain stimulus can produce fleeting states that may dissipate soon after the initial stimulation[54] and thus the subsequent effects, that might be a better target when assessing restoration, are not captured.

Including few physiological measures. Most of the reviewed studies included few physiological measures, which are likely to provide inconclusive results. Different autonomic arousal measures can function independently or even in opposition to each other in response to affective states.[54,56] For these reasons, only one or few measures of physiological activation can fail to detect important changes in arousal. Alternatively, they may detect only a subset of differences (e.g. an increase in heart rate) while failing to detect others (e.g. an accompanying decrease in blood pressure), which may, in turn, lead to misleading results. Including a wider array of physiological measures (e.g. heart rate, heart rate variability, blood pressure, electrodermal variability, skin temperature, salivary cortisol) is essential to strengthen the study design. However, incorporating too many measures may prove intrusive and obstruct the potential restorative effects of an environment.

Not including a stress-inducing activity. Five out of nine reviewed studies did not incorporate a stress-inducing activity[34,35,47–50] that can help interpret changes in arousal levels. Researchers can presume that heightened arousal levels after certain stressors (e.g. giving a public presentation) are likelier accompanied by an unpleasant (e.g. fear) rather than a pleasant (e.g. excitement) state.[57]

Another important reason to include a stressor is that it provides the possibility of assessing physiological (stress) *recovery*. Increased physiological activation is not necessarily a detrimental outcome; large stress-induced increases in arousal are associated with several favourable outcomes, including improved cognitive performance, lower day-to-day stress levels and lower levels of psychosomatic symptoms.[58] Thus, a healthy reaction can be associated with a rapid physiological response to a stressor; however, it is also associated with a quick dissipation of the physiological arousal once the stressor is removed.[8,59]

In contrast, the unhealthy response pattern is characterized by physiological arousal that either persists long after the stressor is removed or is repeatedly activated.[10,60,61] To be able to capture this response pattern, studies should include a stressor and increase the length of the assessment period. When selecting stressors, advantage should be given to those that can reliably elicit intense stress responses.[62] Note that the mentioned considerations are compatible with SRT, which does not predict unequivocal changes in arousal without first considering other factors.[21]

Despite the importance of including a stress-inducing activity for experimental purposes, the experience of stress should not be viewed as a dichotomous event, either fully expressed or not existing at all. Instead, stress can be considered as existing on a continuum with relaxation on the opposite end, where one side is characterized by extreme feelings of distress together with high physiological arousal and the other by considerable feelings of calm and low levels of physiological arousal.[63–65] In the absence of a distinct stress-inducing occurrence, one should not be presumed completely relaxed. Accordingly, even studies not including a stress-activity can bring useful findings, because we cannot assume that in such studies a person is already in an optimal state and that environmental interventions cannot further improve it. In such situations, however, it is important to be especially careful in interpreting physiological data before drawing conclusions, as the data can reflect states other than stress or relaxation (e.g. specific affective states, such as feelings of interest).

Assessing affective states. Six out of nine reviewed studies included a measure of affective states.[34,35,47–51] While the incorporation of such a measure is valuable, choosing the one most fitting to the study design is important.

Not including a measure of affective states. Measuring affective states is critical when investigating responses to stress in indoor environments, as this both clarifies and complements physiological measures.

On top of illuminating often ambiguous physiological data, assessing affective states enables capturing changes that are too subtle to be detected by physiological measures alone. Subjects may experience changes in their feelings without the concomitant changes in autonomic arousal[66] and these changes are important in the aetiology of stress. For example, pleasant affective states are thought to both restore coping resources and sustain coping with stressful situations.[67,68]

Selecting an unsuitable measure of affective states. Five out of six reviewed studies[34,47–51] that used a measure of affective states employed the Profile of Mood States (POMS; e.g. Yokoyama et al.[69]), but none of the studies provided a rationale for using this questionnaire. POMS, originally named the Psychiatric Outpatients Mood Scale, measures six specific states which were deemed important by psychiatrists assessing the effects of various drugs on patients, particularly on war veterans showing symptoms of post-traumatic stress disorder. 'POMS' primary targets were depression and anxiety (reflected in the scales 'depression' and 'tension'), while the scales 'anger', 'vigour' and 'fatigue' were of interest due to being related to common side effects of medication. 'Confusion' scale was added to assess potential disruptive effects of drugs on mental functioning.[70] Why these specific affective phenomena are expected to vary in indoor environments is not clear. Consequently, the relevance of POMS in restoration studies is unclear, despite its popularity. The reviewed studies using POMS may have missed changes in affective states by failing to measure more relevant constructs (or they measured relevant affective states that were then diluted by the presence of irrelevant ones).

Another issue with using POMS in such contexts is related to its length and its repeated administrations. The questionnaire consists of many items (65 in its original form), which are often responded to multiple times in a short period of time. Multiple mood ratings in quick succession may lead to misleading similarities in results between measurements.[71]

To select more appropriate measures, researchers should first decide which affective phenomena to study (i.e. core affect, emotion or mood), then select the most relevant theoretical framework conceptualizing the chosen phenomena, and finally select the psychometrically most robust measure that is based on the chosen theoretical framework.[70] Moods (e.g. irritability) are an appropriate target for studies seeking to examine longer-lasting affective changes, for example when investigating long-term effects of exposure to indoor environments. Other studies might be interested in assessing a specific emotion, such as social anxiety following a public speech task. When a specific affective response cannot be anticipated in advance, as is the case in many restoration studies, it is reasonable to capture core affect[70,72] (e.g. with the Affect Grid that targets the broad states of pleasure and arousal[73]).

Assessing cognitive performance. Only two out of nine reviewed studies incorporated a measure of executive functions.[36,46] Considering the lack of studies including a cognitive task, we would like to emphasize the importance of examining cognitive performance, while at the same time taking into account the roles of affective states and physiological arousal.

Necessity of assessing cognitive performance. Assessing cognitive performance is important for at least two reasons. First, directed (voluntary) attention, an important facet of cognitive performance,[74] may play an important role in the aetiology of human stress.[6]

Second, directed attention may be a common resource in executive functioning and self-regulation.[75] Recent findings show, for example, that exposure to nature delays gratification,[14] inhibits aggressive urges[15] and boosts persistence and results on logical reasoning tasks.[13] Thus, a natural environment could not only enhance performance on a variety of cognitive tasks, but also lead to other health-related improvements that are associated with higher self-regulation ability, such as improved coping with stress and healthier food choices.

As natural environments may influence executive functioning without significantly changing affective or physiological states, important discoveries can be overlooked if cognitive tasks are not incorporated (see Parsons,[27] for a brief overview).

Considering methodological caveats when assessing cognitive performance. There are many methodological caveats when investigating changes in cognitive performance in response to natural environments. Some of the important considerations include (1) measuring cognitive performance both before and after exposure to natural stimuli, (2) employing a cognitive task (before the exposure) that is demanding enough to sufficiently deplete cognitive capabilities and (3) selecting the duration of the rest period that will be long enough to allow restorative qualities of an environment to take effect but short enough that cognitive capabilities will not recover regardless of the environment.[76] Specific properties of cognitive tasks should also be considered, as some tasks may be better suited to capture potential restorative qualities of the environment.[26,29] Due to the scope and significance of important considerations, we refer the reader to the work of Neilson et al.,[25] Ohly et al.,[26] Stevenson et al.[29] and Hartig and Jahncke[76] for an in-depth discussion on these issues.

Considering affective states and physiological arousal when assessing cognitive performance. Additionally, we would like to emphasize that affective and physiological states have an important role in executive functions[77,78] that has been widely debated.[75,79–81] In restoration studies, it is not clear if improvements in cognitive performance are observed due to recovered cognitive capabilities or instead result from changes in affective states and physiological arousal.[27,28] To ascertain the mechanisms behind potential improvements in cognitive performance, affective and physiological states must be considered.

Results of individual studies and discussion

After addressing general methodological issues uncovered in the reviewed studies, we will now separately examine the findings of each study. Results of individual studies are summarized in Table 2 and presented in more detail in Table S4.

We will first address four studies that employed shorter contact times with wood (90 s to each condition),[34,48–50] before continuing with an overview of studies with longer exposure durations.

In the study from Tsunetsugu et al.[49,50] 15 subjects first spent time in a practice room, which consisted of intermediate amounts of wood. After that, they were exposed for 90 s to both a 'standard' and a 'designed' room, in random order. The standard room was prepared to resemble a typical Japanese living room, where wood was applied mainly in flooring; the designed room was identical but also included exposed wooden elements on the walls and ceiling. In each room, heart rate, blood pressure and blood flow in the prefrontal cortex were measured; in addition, subjects completed a self-report of affective states (i.e. POMS). The results showed that the heart rate tended to increase in the designed room and decrease in the standard room. Diastolic and systolic blood pressure tended to slightly decrease in both rooms, while blood flow in prefrontal cortex increased in both rooms. Differences in POMS among these rooms were not observed.[49,50]

The interpretation of these results is challenging. First, because of the short assessment time and absence of a stress-inducing activity, what the physiological data represents is unclear. In this case, the detected increase in heart rate may have reflected either pleasant or unpleasant changes in affective states[54] that could go undetected by POMS. SRT cannot illuminate the

Table 2. Summary of the results of the reviewed studies.

Author(s) (year)	Outcomes	Intervention setting	Comparator (control) setting	Results
Bamba and Azuma[45] (2015)	a) Cardiovascular activity: - heart rate (beats per minute) - heart rate variability (HF – ms^2) and (LF/HF ratio) b) Salivary alpha-amylase activity (kIU/l) c) Self-reported fatigue (Visual Analog Scale; 0–100) (mm)	1. Room with visual and olfactory wood exposure 2. Room with only olfactory wood exposure	1. Room without visual or olfactory wood exposure	No significant differences in heart rate, heart rate variability and salivary alpha-amylase activity between the intervention and control settings. At the end of exposure to the rooms, self-reported fatigue levels were lower in the room with visual and olfactory wood exposure (43) compared to the room with only olfactory wood exposure (57) and the control room (58) ($p < 0.05$).
Burnard and Kutnar[46] (2020)	a) Cortisol (nmol/l): - mean concentration - response magnitude after stress induction - recovery magnitude after stress induction b) Heart rate c) Proofreading task	1. Light colour wood (oak) office 2. Dark colour wood (walnut) office	1. White office	No significant differences in cortisol response magnitude and cortisol recovery magnitude between the intervention and control settings. Heart rate and proofreading task results not reported. Lower mean cortisol concentration in light wood office than in the control setting (median difference: 1.33, 95% CI (one-sided): 0.25 to ∞, $p = 0.015$) (differences also detected when pre-stressor and post-stressor periods were compared separately) No significant differences in cortisol mean concentration between dark wood office and the control setting.
Demattè et al.[35] (2018)	Positive and Negative Affect Schedule (PANAS)	Wooden room	Non-wooden room	No significant differences in PANAS scores between the beginning and end of the exposure to either the intervention or the control setting. The overall score on the Positive Affect subscale was higher in the wooden room ($M = 30.19$) than in the non-wooden room ($M = 26.96$; $p < 0.001$); score on the Negative Affect subscale was lower in the wooden room ($M = 10.93$) than in the non-wooden room ($M = 11.91$; $p = 0.005$)
Fell[36] (2010)	a) Electrodemal activity: - mean skin conductance level (μS), - frequency of non-specific skin conductance responses (responses per minute) - amplitude of skin conductance responses (μS) b) Cardiovascular activity: - heart rate (number of seconds between adjacent beats) - heart rate variability (high frequency power (nu)); c) Paced Auditory Serial Addition Test (PASAT) (square root of number of errors)	Wooden room	Non-wooden (white) room	Mean skin conductance level was lower in the wooden room: $M = 8.474$ ($SD = 4.480$) than in the non-wooden room $M = 10.502$ ($SD = 5.924$) at baseline ($p = 0.039$); no significant differences in the test or recovery period. Frequency of non-specific skin conductance responses was lower in the wooden room compared to the non-wooden room at baseline, test and recovery period: - Baseline: Wooden room: $M = 0.817$ ($SD = 1.208$), non-wooden room: $M = 1.607$ ($SD = 1.816$); $p < 0.006$ - Test: Wooden room: $M = 7.525$ ($SD = 3.960$), non-wooden room: $M = 9.055$ ($SD = 4.139$); $p < 0.043$ - Recovery: Wooden room: $M = 0.453$ ($SD = 0.578$), non-wooden room: $M = 0.8226$ ($SD = 0.907$); $p < 0.010$ No significant differences in the amplitude of skin responses, heart rate or heart rate variability between the intervention and control setting in any of the test periods.

(continued)

Table 2. Continued.

Author(s) (year)	Outcomes	Intervention setting	Comparator (control) setting	Results	
Nakamura et al.[47] (2019)	a) Cardiovascular activity: - heart rate (beats per minute), - heart rate variability (HF: ln ms^2) and (HF/LF ratio) b) Blood oxygenation (oxyhaemoglobin concentrations) in the left and right prefrontal cortex (PFC) (μM) c) Profile of Mood States (POMS)	Wood image with vertical grain pattern	Grey image	In conditions with both wood images, Oxy-Hb concentrations were lower in both cortices compared to the condition with the grey image ($p < 0.05$): - vertical wood image: 0.16 ± 0.09 (left PFC) and -0.14 ± 0.09 (right PFC) - horizontal wood image: 0.04 ± 0.10 (left PFC) and -0.03 ± 0.09 (right PFC) - grey image: 0.46 ± 0.14 (left PFC) and 0.35 ± 0.11 (right PFC) No significant differences in heart rate and heart rate variability between intervention and control settings. In conditions with both wood images, Total Mood Disturbance score (POMS outcome) was lower compared to the condition with the grey image ($p < 0.05$); additionally, Total Mood Disturbance was lower in the wood image condition with the vertical grain pattern compared to the condition with the horizontal grain pattern ($p < 0.05$)	
Wood image with horizontal grain pattern					
Sakuragawa et al.[48] (2005)	a) Cardiovascular activity: - blood pressure, - heart rate b) Profile of Mood States (POMS)	Wooden wall panel	Wall covered with a white curtain	Heart rate and diastolic blood pressure results not reported.	Increase in systolic blood pressure in all participants ($p < 0.05$), decrease in the subgroup who liked the wooden panels ($n = 5$, $p < .05$).

(continued)

Table 2. Continued.

Author(s) (year)	Outcomes	Intervention setting	Comparator (control) setting	Results	
					Decrease in Depression subscale (p < 0.05) in the wooden setting, no change in the other subscales
		White steel wall panel			No change in blood pressure in all participants (p < 0.05), increase in the subgroup who disliked the white steel panels (p < 0.05). Increase in Depression scale (p < 0.1) and decrease in Vigor-Activity scale (p < 0.1) in the white steel setting, no change in other subscales
Tsunetsugu et al.[49,50] (2002, 2005)	a) Cardiovascular activity - blood pressure - heart rate b) prefrontal cortex blood flow (left side) – total haemoglobin concentration (µM) c) POMS	Room with wooden elements	Physiological data: The average value in the 10 s before stimulation/ POMS: rooms compared to each other	No changes in systolic blood pressure in either room from before the stimulation. ncrease in prefrontal cortex blood flow in both rooms (p < 0.05). No differences between rooms in POMS total score or any of the POMS subscales.	Increased heart rate (p < 0.05) and no change in diastolic blood pressure.
		Room without wooden elements			Decreased heart rate and diastolic blood pressure (p < 0.05)
Tsunetsugu et al.[34] (2007)	a) Cardiovascular activity blood pressure - heart rate b) prefrontal cortex blood flow (right side) – total haemoglobin concentration (µM) c) POMS	0% wood room	The average value in the 10 s before stimulation	Decrease in systolic and diastolic blood pressure in all rooms (p < 0.05). No differences in POMS total score or any of the POMS subscales.	No changes in heart rate; Increase in prefrontal cortex blood blow (p < 0.05)
		45% wood room			Increased heart rate (p < 0.05); Slight decrease (p < 0.05) at the beginning, then tendency towards increasing
		90% wood room			Increased heart rate (p < 0.05); Increase in prefrontal cortex blood blow (p < 0.05)
Zhang et al.[51,52] (2016, 2017)	a) Cardiovascular activity: - blood pressure (mmHg) - heart rate (beats per minute) - heart rate variability (LF/HF) b) Skin conductance level (µS) c) Peripheral blood oxygenation (%SpO_2) d) Skin temperature (°C) e) POMS f) Self-reported fatigue (score from −125 to 125)	100% dark wood room	Non-wooden room	No differences in skin temperature between the experimental and control settings. Lower systolic blood pressure in at least one measurement period in all three wooden rooms (p < 0.05); diastolic blood pressure results not reported. In all three wooden rooms the	No differences in heart rate or heart rate variability. Higher skin conductance level in two out of three measurement phases. No differences in peripheral blood oxygenation.
		50% dark/50% painted white room			Lower heart rate and higher heart rate variability in the wooden room on one of the two measurement periods in the wooden

(continued)

Table 2. Continued.

Author(s) (year)	Outcomes	Intervention setting	Comparator (control) setting	Results
		100% light wood room		total mood disturbance (POMS overall score) was lower than in the control setting at both periods of measurement ($p < 0.05$) Compared to the control room, fatigue score was lower in the 100% dark wood room ($p < 0.005$), 50% dark/50% painted white room ($p < 0.05$) and 100% light wood room ($p < 0.05$). room ($p < 0.05$). No differences in skin conductance level or peripheral blood oxygenation. Lower heart rate and higher heart rate variability in the wooden room on at least one of the two measurement periods in the wooden room ($p < 0.05$). No differences in skin conductance levels. Higher peripheral blood oxygenation in two out of three measurement phases.

detected pattern of physiological responses, since the theory predicts *regulation* of arousal; depending on the initial arousal level, both decrease and increase could be considered a positive outcome. However, even if the data would be more revealing, attributing physiological changes to any particular aspect of the tested environments would be difficult, as the test settings did not differ only by the quantity of wood, but also by the degree of room novelty and specific design features.

The same authors later conducted a similar study using the same physiological and psychological measures.[34] This time, they created three test rooms with clearer differences in the amount of wood; these rooms were treated with either 0%, 45% or 90% wood coverage. After spending time in the practice room, 15 subjects were exposed for 90 s to each of the three rooms in random order. In all rooms, diastolic blood pressure decreased significantly, while systolic blood pressure followed a similar pattern. Subjects in all rooms also exhibited a tendency towards increased blood flow to the prefrontal cortex. Heart rate tended to increase in the two rooms with the largest amount of wood coverage, while it did not change in the non-wood room. The two wooden rooms were also rated as more natural than the room without wood. There were no differences in reported affective states on POMS among rooms.

As in the previous study, the meaning of the physiological data is unclear. Perhaps the observation that the two wooden rooms showed both an increase in heart rate and a higher rating of naturalness hints to the possibility that an increase in heart rate reflected a certain pleasant affective state, which has been shown to occur in natural environments.[18] However, this is just one possible explanation; the implication of the observed outcomes is uncertain. Tsunetsugu et al.[34,50] are appropriately modest in interpreting physiological data, which they see as an indication that changes among the environments occurred, but their explanation does not go beyond that.

Another similar study conducted by Sakuragawa et al.[48] compared the effects of being exposed to a wall panel made of either wood or steel. Fourteen subjects were exposed for 90 s to each of the following three conditions in random order: facing either a wooden wall panel, a white steel wall panel or a white curtain (control). Their blood pressure was monitored constantly throughout this process. In each condition, subjects also completed a semantic differential scale and POMS.

Yet again the results are inconclusive. Systolic blood pressure slightly increased in the first seconds of exposure to hinoki wood panels and then quickly returned to pre-exposure levels. In contrast, no significant changes in systolic blood pressure were detected when participants were exposed to the white steel panel. The results were then separated into three groups based on participants' preference of the respective wall panels ('like', 'neither like nor dislike' and 'dislike' group; based on the answers provided on one item) and blood pressure data were analysed for each group separately. The analysis showed that the subjects' blood pressure tended to be lower when they spent time in the settings they liked, and vice versa, suggesting the decreases in blood pressure reflected a positive outcome, but the evidence behind this explanation is weak. The authors equate increased blood pressure with 'stress', but we argue that this proposed relationship is not strongly supported by the observed data.

POMS results speak in favour of the wooden setting. Compared to the control setting, participants who were exposed to wood panels had lower scores on the Depression scale (with items such as 'unhappy' and 'discouraged'). In contrast, when exposed to white steel panels, subjects tended to have higher scores on the Depression scale in addition to lower scores on the Vigour scale (with items such as 'energetic' and 'active'). Taken together, results from the study suggest that even a brief exposure to a wooden wall panel may be enough to produce favourable physiological and affective changes. This response pattern, noted by decreased physiological arousal accompanied with improved affective states, could be consistent with certain aspects of SRT, which predict that decreased arousal is linked with mild and moderate levels of interest accompanied by preference of an environment and feelings of calm. However, the results should be interpreted cautiously. Subjects' brief exposures to different wall panels were followed by relatively long self-reports of affective states. This might have inadvertently created conditions encouraging the good-subject effect, where participants are able to discern the hypothesis of a study and start to behave in ways that will confirm the hypothesis.[82]

In Nakamura et al.'s study,[47] 28 participants viewed three image projections (1 m $\times$ 1 m; 1 m away from the subject) for 90 s (in random order). The images consisted of grey colour (control), vertical wood grain and horizontal wood grain. Heart rate, heart rate variability and prefrontal cortex oxygenation were measured throughout, while affective states were captured with the POMS (2nd edition) following each exposure.

Differences in heart rate or heart rate variability between the image viewings were not detected. In contrast, blood oxygenation in subjects' prefrontal cortices was lower when they observed the two wood images (compared to the grey image viewing). The authors interpret this observation as 'physiological relaxation' but we argue that the interpretation is not that straightforward, as the left and right prefrontal cortices and even specific regions within each of these cortices can respond differently to the same stimulus.[83,84] This is further complicated due to the variety of cognitive and affective processes prefrontal cortex is implicated in.[85,86] The overall activity in the prefrontal cortex should not be equated with arousal or relaxation.

Compared to the control image, participants reported their affective states as more favourable after viewing the wood images; these ratings were even more favourable for vertical wood grain image compared to the horizontal wood grain image. This finding suggests that the rotation of the grain pattern may have an important role and should be considered. Explaining this observation with SRT is especially difficult, as the theory discusses human response to the natural environment as a whole. Such findings demonstrate the need for theories to delve deeper in explaining human response to natural stimuli (e.g. Joye et al.[87]). As in the study from Sakuragawa et al.,[48] the results on affective states should be interpreted cautiously, as they may suffer from the good-subject effect, with participants acting in ways to confirm the experiment's hypothesis.

The interpretability of the results reviewed so far is limited due to several methodological approaches: short exposure time to wood, no stress-reducing activity, few physiological measures, unsuitable measurement of affective states, conditions possibly encouraging the good-subject effect and small sample sizes. In contrast, the following five studies are characterized by longer exposure times to wood and typically include a stress-inducing activity and larger sample sizes.

One of these studies was conducted by Fell,[36] where each quarter of the total 119 subjects spent approximately 40 min in one of the four settings – a room with a wooden interior with plants, a room with a wooden interior without plants, a room with a non-wooden interior with plants or a room with a non-wooden interior without plants. After spending 10 min in the room (baseline period), subjects performed a cognitive task (Paced Auditory Serial Addition Test (PASAT)[88]) for approximately 15–20 min which was primarily employed to induce stress. After completing the task, subjects spent additional 10 min in the room (recovery period). Their electrodermal activity and heart rate were constantly monitored.

Physiological outcomes did not differ between the conditions with and without plants, while differences between the wooden and non-wooden settings were detected. Specifically, exposure to wood was associated with lower skin conductance levels and frequency of non-specific skin conductance responses. As the 'anticipation and performance of practically any task will increase both skin conductance levels and the frequency of NS-SCRs [non-specific skin conductance responses]',[89] we have a reason to presume that the exposure to wood and the decreased physiological response are linked. However, as discussed in the previous sections, it is not certain that such an outcome must be considered positive. Importantly, even though the tested settings differed in the average arousal levels, they did not differ in the degree of recovery following stress induction. This observation is not in line with SRT, which suggests that, when the initial arousal level is high, exposure to natural stimuli will be more effective in decreasing it compared to non-natural environments. One possibility is that the wooden environment led to a decrease in arousal already at the beginning of exposure and that the arousal remained lower throughout the entire experimental session. Overall, the findings of the study provide some evidence that visual exposure to wood leads to lower levels of physiological arousal, but the difference between these environments was found only in average arousal levels, not in the degree of recovery after stress was induced. Additional information would be valuable to corroborate these results (e.g. self-reports of affective states).

The study did not find any differences in cognitive performance among subjects. By taking a strict ART perspective, we could argue that there were no differences because no stress-inducing or attention-depleting activity took place prior to the cognitive task, so it is reasonable to expect that subjects were able to perform near their best regardless of the environment. Put differently, even if wooden environments possessed attention *restoring* qualities, they were not given the opportunity to demonstrate them. It is far from clear, however, if the improved attentional capabilities in natural environments indeed result from restoration of attentional resources or if other mechanisms are central.[27] For instance, if enhanced attention capacity is mediated by affective states, differences in PASAT scores had the opportunity to emerge between tested environments.

We would like to draw attention to additional reservations about the results of this study. First, since only one room was available for the experiment, all non-wood sessions were completed before moving on to wood sessions, which might have influenced the results (as the author recognized). The second issue is that the study did not follow a proper randomization process which might have brought on baseline differences between participants that were not accounted for. A proper randomization process and taking baseline measures of participants before they were exposed to the experimental setting would have strengthened the study's findings.

In Bamba and Azuma's study,[45] 12 subjects started each of the three experimental sessions in the baseline room, where they spent approximately 45 min while completing a 30 min long cognitive task used as a stressor. After this, they spent 10 min in one of the three test rooms; a different test room was used every session (the order was randomized). In the first experimental room, one wall was almost entirely covered by a solid wood panel in which slits were cut to increase the room odour (volatile organic compounds). The odour also reached the adjacent second experimental room that did not include a wood panel. The control room did not include either the wood panel or the wood odour. Measures of heart rate, heart rate variability and salivary alpha-amylase activity (higher levels of salivary alpha-amylase activity indicate activation of the sympathetic nervous system)[90] were taken both in the baseline room and in the test settings.

There were no detected differences in any of the physiological outcomes between the three test rooms, even though the subjects reported a more pleasant odour and lower levels of fatigue in the room with the wood panel, compared to the other two rooms. The results do not match the findings from Sakuragawa et al.,[46] who observed differences in physiological responding in similar experimental circumstances. The findings also go against several studies observing decreases in the same physiological indicators following stimulation with wood odour[91–94]; however, the olfactory stimulation in these studies was likely more intense. While the intervention employed by Nakamura and colleagues might not enhance recovery after stress induction, confident conclusions cannot be drawn mainly due to the small sample size of the study.

In Zhang et al. study,[51,52] 20 subjects were exposed to four rooms in random order. One of the rooms was painted white (control); the other three rooms consisted of either 100% of dark wood coverage, 100% of light wood coverage, or 50% of light wood coverage and 50% of walls painted white. Before entering each room, subjects spent 30 min in the preparation room and then another 60 min in each of the experimental rooms. Several physiological measures were taken throughout the whole procedure, together with the measures of cognitive performance, affective states (POMS) and fatigue.

Physiological responses during exposure to wooden environments were conflicting. Some markers were associated with increased levels of autonomic arousal (i.e. skin conductance level, peripheral oxygen saturation), while others corresponded to decreased autonomic activation (i.e. heart rate, heart rate variability, blood pressure), or did not differ between settings (i.e. skin temperature).[56] The most prominent physiological changes were observed in systolic blood pressure, which was generally lower in the wooden environments. Due to diverging findings, the authors' claim that 'the participants were in a more relaxed and comfortable state in a wooden indoor environment' is not sufficiently grounded in the data.[52]

POMS produced clearer results. After spending time in the preparation room, subjects exhibited higher mood improvement in all three wooden rooms compared to the room without wood. However, as the (wood) odour differed between the test rooms, it is not clear if the improved affective states resulted from visual or olfactory stimulation. SRT notes that certain natural smells (and sounds) can influence humans positively but future studies are needed to distinguish between the respective effects of visual and olfactory exposure to wood.

In a study from Demattè et al.,[35] 102 participants spent 15 min in each of these two test rooms in random order. Both rooms featured one wooden and one non-wooden desk. Floor and walls were heavily treated with wood in one room, while they remained untreated (i.e. white) in the other. In each setting, subjects completed a Positive and Negative Affect Schedule (PANAS)[95] once when they entered and once directly before they left the room.

There were no differences between the first and second PANAS administration *within* the two settings; a brief experience of either of the two indoor environments did not significantly influence affective states tapped by PANAS. In contrast, when the PANAS scores were compared *between* the rooms, the results indicated that the participants experienced higher levels of pleasant and lower levels of unpleasant affective states in the wooden environment. However, due to solid wood use, the odour differed between the two test settings and it is not clear whether visual or olfactory stimulation is responsible for the observed effects. However, the authors were not concerned with differentiating between the effects of visual and olfactory stimulation, as they intended to test the effects of wood in 'immersive everyday life conditions'.

In Burnard and Kutnar's study,[46] 61 subjects spent 75 min in each of the two office-like rooms in random order. All subjects spent time in a control room with white furniture, and a room with either oak veneered or walnut veneered furniture. In each setting, participants were exposed to a stress-inducing video and completed a cognitive task, while their salivary cortisol and heart rate were monitored (neither heart rate nor cognitive task results were reported). Cortisol responses in the walnut room did not significantly differ from the control room responses, while the subjects in the oak room exhibited lower average cortisol levels. However, the study did not find any differences in the magnitude of cortisol response and recovery after stress induction. As was the case in the study from Fell,[36] this finding is not consistent with SRT that predicts more effective recovery in natural environments when the initial arousal levels are high. Assuming that the wood office affected stress response and recovery, the differences in magnitude could have been missed due to non-continuous cortisol measurement or because peak cortisol concentrations may have occurred between the cortisol readings. Along similar lines, the experiment may not have lasted long enough to allow the cortisol levels to return to the baseline. Although cortisol responses typically return to baseline after 60 min following the stress induction,[62] the last stage of the experiment consisted of a cognitive task that might have delayed the recovery.

As cortisol is generally a more reliable indicator of *distress* than typically deployed physiological measures (e.g. electrodermal activity),[58] lower average cortisol readings in the oak office represent a promising finding. Still, cortisol concentrations can be expected to only moderately correlate with perceived stress.[96,97] In addition, the cortisol readings in the oak office were lower than in the control room even when compared only for the period before the stress induction. Because peak cortisol concentrations appear in blood and saliva between approximately 21 and 30 min after stress induction,[62] the first three readings were likely affected by the time before the experiment, suggesting a possible difference in baseline cortisol levels of participants. Alternatively, and similar to the study by Fell,[36] participants could have been influenced by wood exposure immediately upon arriving in the test office and remained in a more relaxed state throughout the entire experiment.

In summary, from the eight studies assessing physiological arousal, four studies provide inconclusive results,[34,47–50] two studies offer some evidence that physiological arousal is decreased in wooden environments,[36,46] one study presents mixed findings[51,52] and one study reports no detected differences in physiological responding between the tested environments.[45] From the six studies examining affective states, two studies observed no differences in response to higher amount of wood coverage,[34,49,50] while the other four studies found evidence that affective states are improved in wooden environments[35,47,48,51,52]; however, in the two out of four studies, olfactory stimulation could have been the main cause of improved affective states. From the two studies investigating cognitive performance, one study did not report the results[46] and the other did not observe any differences between wooden and non-wooden settings.[36]

Summary of evidence

We reviewed nine studies assessing either affective, physiological or cognitive performance outcomes to visual wood exposure. The results of four studies with shorter exposure durations to wood provide relatively little information regarding the influence of wood exposure on indicators of stress.[34,47–50] Four out of five studies with longer exposure durations detected at least some favourable (or seemingly favourable) outcomes in wooden environments.[35,36,46,51,52] The results from Fell[36] and Burnard and Kutnar[46] are promising since both studies found that the physiological arousal of participants is lower in the wooden environments. However, neither study detected any differences between the settings regarding the degree of stress recovery, and in both cases the findings were not corroborated by additional measures of affective states, physiological arousal or cognitive performance. Studies from Zhang et al.[51,52] and Demattè et al.[35] observed more favourable affective states in the wooden environment, but in neither case it is clear if this was influenced by visual or olfactory properties of the experimental room(s). Only Fell's[36] study reported cognitive performance outcome and it did not find any differences between the wooden and non-wooden environments. Overall, current research suggests that visual wood exposure may lead to certain favourable outcomes, but the evidence is limited. Future studies are needed to clarify and confirm the current findings before confident conclusions can be drawn.

Limitations

The present review has several limitations. It includes only nine studies and in those the overall risk of bias is high in three experiments, concerning in two investigations and low in only four studies. Additional limitations are found in specific methodological approaches observed in the reviewed studies. Most studies measured only one or few outcomes, which is generally not sufficient to arrive at robust conclusions when examining the effects of indoor environments on humans. On top of that, it is not clear if several positive findings of the reviewed studies should be attributed to olfactory or visual stimulation of wood (or both). More generally, methodology in restoration studies may suffer from demand characteristics,[25] where participants anticipate what researchers are predicting and (unconsciously) respond in a way that fits the research hypothesis.[82] Additional limitations of the review result from the small number of included studies; even few additional studies could have influenced the conclusions of the review. Along similar lines, publication bias might have had a major effect on the review's findings. The number of studies may be limited due to including only studies reported in English and using a search strategy that restricts the topic to human response to wood in indoor environments. A review of the stress-related outcomes following exposure to wood in outdoor environments may be warranted as well.

Conclusions

Our review addresses how using wood in indoor environments influences affective states, physiological arousal and cognitive performance of the room occupants. We reviewed nine studies reported in 10 scientific articles and one doctoral dissertation. Our inspection assessed the methodology and the results through the lens of the multi-dimensional examination of human stress. Current research suggests that visual wood exposure could lead to beneficial outcomes, but the evidence is limited. In general, studies are limited by not examining multiple dimensions of stress indicators simultaneously, which limits the interpretability of their findings. Taken together, the studies reveal a potential for the benefits of wood use in buildings, but it is critical that future studies confirm and expand current findings to ensure any recommendations for building design can be supported by evidence.

Recommendations for future studies

When examining the effects of wood exposure in built environments, future studies should simultaneously investigate affective, physiological and cognitive performance outcomes. By considering the interplay among these concepts, we can better understand human responses to different indoor settings. In addition, each of the incorporated measures should be chosen carefully to fit with each other as well as with the general study design. In general, studies should (1) incorporate a variety of physiological measures to better encompass variable changes in physiological arousal levels; (2) include a suitable measure of affective states (e.g. a measure of core affect) that will both help explain physiological data and provide additional information about the subjects' response to environments and (3) incorporate an appropriate task assessing executive functions, ideally combined with an intervention that will lead to attention fatigue in participants. Researchers should primarily focus on assessing stress *recovery*, that is capturing subjects' physiological, affective and cognitive performance outcomes following the induction of stress. Studies aiming to test the effects of visual wood exposure should be designed carefully in order to control for the effects of tactile and olfactory contact with wood.

The findings of this review reflect a field in its infancy. However, with (1) the minimal risk of side effects, (2) relative affordability, (3) high potential for large scale and long-term implementation and (4) minimal demands on human effort, visual wood exposure is a potential environmental intervention against stress that remains worthy of future investigation.

Authors' contribution

All authors contributed equally in the preparation of this manuscript.

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Supplemental material

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2.2 Article 2

Title: Perception and evaluation of (modified) wood by older adults from Slovenia and Norway

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PERCEPTION AND EVALUATION OF (MODIFIED) WOOD BY OLDER ADULTS FROM SLOVENIA AND NORWAY[1]

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Abstract. Many building users prefer wood over other building materials, but it is unclear how modified wood is perceived compared with unmodified wood. Additionally, it is unclear which material properties play a role in the general preference for wood, how tactile and tactile–visual perceptions of materials affect user preference for wood, and whether human preference for wood is consistent across countries and cultures with different wood use practices. One hundred older adults from Slovenia and Norway rated and ranked wooden materials (ie handrails) made of either unmodified or modified wood and a stainless steel control sample. The materials were rated on a semantic differential scale (capturing sensory and affective attributes) by each participant twice: first, while only touching the materials and then while simultaneously touching and seeing the materials. Finally, each participant ranked the handrails in order of preference. Wooden handrails were generally more preferred than the steel sample. Preference ratings and rankings of modified wood were comparable to those of unmodified wood. Results were relatively consistent across both countries. Materials rated as liked were perceived as somewhat less cold, less damp, more usual, less artificial, more expensive, and less unpleasant. The ratings were fairly consistent between the tactile and tactile–visual tasks. In some indoor applications, certain types of modified wood could be used in place of unmodified wood while meeting human aesthetical preferences. Specific visual and tactile properties can predict material preference and could be considered in the material design phase. The tactile experience is important in overall material perception and should not be overlooked. These findings seem to be stable across countries with different wood use practices.

Keywords: Material preference, wood modification, elderly, handrails.

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INTRODUCTION

People spend most of their time indoors, and indoor environments can affect their health (Redlich et al 1997; Evans 2003). Focus in interior design has shifted beyond approaches minimizing harm, such as reducing outdoor noise, to creating restorative environments that can induce positive changes in well-being (Mcsweeney et al 2015; Markevych et al 2017). In recent years, research on restorative environments has begun to focus on older adults. An overview of the topic by Roe and Roe (2018) concludes that more attention should be paid, among other things, to restoration in residential (rather than natural) environments and to sensory stimuli. According to the authors, the residential environment, where older adults spend much of their time, "arguably offers the most important context for restoration," whereas "sensory stimulation in the living environment triggers curiosity and, in turn, our motivation to move around and explore" (490).

One of the main restorative design practices is to bring elements of nature into indoor spaces, as this can improve psychological and physiological indicators of human well-being (Mcsweeney et al 2015). Comparable outcomes have been observed when people were exposed to indoor wood (Sakuragawa et al 2005; Fell 2010; Nyrud and Bringslimark 2010; Burnard and Kutnar 2015; Zhang et al 2016; Zhang et al 2017; Demattè et al 2018; Nakamura et al 2019; Burnard and Kutnar 2020; Lipovac and Burnard 2020; Lipovac et al 2020; Shen et al 2020).

According to stress reduction theory, the observed positive response to nature is mediated by human aesthetic preferences that are predominantly innate (Ulrich 1983). The theory states that the initial response to a natural setting is affective (eg appreciation, interest), and that it precedes cognitive appraisal of the scene. This response is elicited quickly by different features of the natural environment, including water and vegetation, and many such (nonthreatening) features trigger a positive response. The initial affective response, along with one's experience and culture, influences cognitive appraisal of the scene, which can alter the initial affective state. The interplay between affect and cognition culminates in motivating (adaptive) behavior or functioning. The main predictions of the stress reduction theory are supported by findings showing that people from different cultures prefer natural environments over built environments (see Ulrich 1983, for a brief overview), and the environmental preference is positively associated with restoration (van den Berg et al 2003) and perceived restorativeness of the environment (Purcell et al 2001; Han 2010). Similarly, spaces furnished with wooden materials are perceived as more natural and preferred than environments without wood (Sakuragawa et al 2005; Nyrud et al 2014; Strobel et al 2017; Demattè et al 2018). Improved indicators of well-being and higher preference ratings have also been observed when wood was experienced only through touch (Bhatta et al 2017; Ikei et al 2017a, 2017b). These findings suggest that preference ratings of environments and materials could be used as an indicator of their potential restorativeness: investigating the perception of wood may help create materials that are not only useful in construction but may also contribute to restorative environments.

Modified Wood and Human Preference

Wood is generally perceived as more natural and liked than other common building materials (Rice et al 2006; Burnard et al 2017; Ikei et al 2017b). Recently, however, a lot of attention has been given to modified wood: wood that has undergone modification process that enhances its construction-related properties (Sandberg et al 2017). As a side effect, modification processes change material properties directly available to human senses, such as color, dryness, or roughness (Esteves and Pereira 2009; Bakar et al 2013). Due to its enhancements, modified wood can be expected to become more widely used in the future, but few studies have examined how people perceive it. Existing studies reported promising results: professionals and lay users liked certain thermally and chemically modified wood samples similarly to other types of wood in multiple settings (Gamache and Espinoza 2017;

Lipovac et al 2019). However, more evidence is needed to confirm these findings in other settings and determine whether modified wood is suitable for use in restorative environments.

Wood Properties and Human Preference

To determine whether materials can be used in restorative environments, we need to explore human preferences for materials and material properties that affect these preferences, including visual and tactile qualities of wooden materials, such as color, grain patterns, and surface treatments. People evaluate materials differently when these properties change (Waka et al 2015; Kidoma et al 2017). Studying these variations could help us develop materials that are more attractive to building users.

Human preference ratings (eg "like") can be viewed as the culmination of lower-level affective attributes (eg "interesting") and physical surface perceptions (eg "rough") (Okamoto et al 2016; Kidoma et al 2017). Existing studies have identified certain properties of wood that are associated with greater preference. When people sense wood by touch, they prefer untreated wood surfaces (compared with coated surfaces) (Bhatta et al 2017; Ikei et al 2017a), and their physiological indicators of well-being tend to improve (Ikei et al 2017a). People generally prefer wood surfaces they perceive as smoother (Jonsson et al 2008; Waka et al 2015; Bhatta et al 2017), and some evidence suggests this is also true for surfaces perceived as a denser, warmer, damper, softer, and more natural (Jonsson et al 2008; Waka et al 2015). In a study in which wood samples of outdoor tabletops were visually and tactilely inspected and ranked according to preference, greater preference was associated with perceived surface dampness and with material colors that were darker and closer to red on the green–red color component (Lipovac et al 2019). Other factors additionally influence visual preference for wood: people appear to prefer shinier and less knotty surfaces as well as surfaces with homogeneous color (Nyrud et al 2008; Sande and Nyrud 2008; Høibø and Nyrud 2010; Manuel et al 2015; Waka et al 2015). As relatively few materials have been studied in few contexts, how material properties influence preferences for wooden materials remains unclear.

The Relationship between Tactile and Visual Domain in Material Evaluation

Wood treatments are usually used to improve the performance of mechanical properties or to inhibit degradation of wood, but they often also change tactile properties, such as dampness. Moreover, coatings are frequently used to improve the longevity of the wood and reduce surface roughness. Such treatments might inadvertently negatively impact the tactile experience of materials: when touching materials, people rate unmodified as more liked than coated wood (Bhatta et al 2017), and their physiological state indicates greater relaxation (Ikei et al 2017a). The importance of focusing on surface texture to enhance the tactile experience of materials has been highlighted by Bhatta et al (2017). They argued that surfaces should have qualities that are perceived as natural. The significance of tactile material properties has been further explored in studies examining the consistency of perception between tactile and visual modalities. In a study in which participants rated naturalness of materials, ratings were consistent between tactile, visual, and tactile–visual experience of wood, suggesting that the tactile experience of materials is a rich source of information that is not substantially altered by the visual information (Overvliet and Soto-Faraco 2011). The authors of the study concluded that vision and touch are equally good at predicting naturalness. It seems that the tactile domain plays an important role in general material perception and should be further explored in different contexts of wood use.

Potential Cultural Effect on Wood Perception and Evaluation

Human affinity for natural elements may be widespread, but the role of culture should not be overlooked. When people observe wood, they can struggle in separating natural from artificial materials (Overvliet and Soto-Faraco 2011), and their knowledge about wood treatments can influence their perception of material naturalness (Rozin 2005, 2006). Perception of naturalness, in turn, can affect preference (Jonsson et al 2008). When participants from Slovenia, Norway, and Finland rated several materials on perceived naturalness, their ratings were generally consistent. However, the ratings between participants from Slovenia and the two Nordic countries diverged in certain instances where processed wood samples were rated: Nordic participants perceived these samples as less natural than Slovenian respondents (Burnard et al 2017). This divergence could stem from differences in the knowledge and familiarity with wood and wood processing between the country populations, which, in turn, could result from different practices of wood use in these countries. Wooden buildings have a rich tradition in the Nordic countries (Mayo 2015), whereas in Slovenia, relatively little wood is used for structural components of houses (Statistical Office of the Republic of Slovenia [SURS]). If perceived naturalness and general preference of materials may vary between countries, studying wood perception and evaluation in countries with different wood use practices may help us reach stronger conclusions about the (potentially) universal appeal of wooden materials.

Objectives

The objectives of this study were to investigate 1) general preference for modified wood compared with unmodified wooden materials (and a non-wood control sample), 2) the association between perceived wood properties and wood preference, and 3) the relationship between the tactile and tactile–visual domain of material perception. To extend the work of existing studies, wood samples used were brought closer to real-life context by using handrail samples instead of often used small rectangular blocks of wood. The study was conducted across two countries (Slovenia and Norway) with different practices of wood use, to explore possible cultural influences on perception and evaluation of wood. The sample of participants consisted of older adults, as they may physically interact with interior materials more often than other age groups (eg using assistive railings for walking), and, consequently, contact with pleasant materials may affect them more profoundly.

MATERIALS AND METHODS

Participants

One hundred older adults aged 60 yr or more (M = 68.46 yr, SD = 7.23; 41 women) from Slovenia and Norway participated in the study. Participants were eligible to participate if they had no health impairments that could interfere with the study protocol, such as severely impaired vision or significant cognitive impairment. Subjects were not compensated for participation. Before the testing, subjects signed an informed consent form explaining the study purpose and protocol, participants' rights, and data management practice.

Slovenia. Fifty participants (M = 71.14 yr, SD = 7.19; 27 women) were from Slovenia. Thirty-four of them were recruited and tested in an activity center for older adults (city of Koper), which is visited predominantly by retired people. The remaining 16 participants, who were tested at their homes, were recruited through the social network of the first author and through snowball sampling.

Norway. Fifty participants (M = 65.78 yr, SD = 6.27; 14 women) were from Norway. Eight of them were recruited and tested in various places (eg coffee shop, mall, library) in the city of

Figure 1. Handrail samples (from left to right: unmodified spruce, unmodified pine, acetylated radiata pine, thermally modified pine, thermally modified spruce, stainless steel).

Kristiansund. The other 42 participants, who were part of the still-active faculty staff, were recruited and tested at Norwegian University of Life Sciences (city of Ås).

Handrail Samples

Six cylindrical handrail samples were prepared (Fig 1); one was made of stainless steel and five of modified or unmodified wood. Specifically, we included handrails made of unmodified spruce, unmodified pine, acetylated radiata pine, thermally modified spruce, and thermally modified pine. The thermal modification was performed using the commercial ThermoD process at 212°C and superheated steam at the Heatwood company (Hudiksvall, Sweden). The handrail samples were 42 mm in diameter and 30 cm long. Each sample was mounted on a wooden base measuring approximately 30 cm × 15 cm × 5 cm, which was covered with white foil.

Semantic Differential Scale

Based on the previous work examining material perception in general (Guest et al 2011; Baumgartner et al 2013; Datta 2016; Okamoto et al 2016; Kidoma et al 2017) and wood perception in particular (Overvliet and Soto-Faraco 2011; Waka et al 2015; Kanaya et al 2016; Bhatta et al 2017), we selected sensory and affective descriptors that we considered relevant in the assessment of the materials used in this study. To each selected descriptor, we added a polar opposite descriptor. Altogether, we ended up with 11-word pairs, which captured tactile sensory properties (ie rough—smooth, warm—cold, dry—damp, soft—hard), affective attributes (ie unusual—usual, natural—artificial, cheap—expensive, pleasant—unpleasant, dislike—like), and visual sensory properties (ie dark—light, shiny—matte). The latter two-word pairs were used only in the part of the study in which participants could visually inspect the materials. Subjects responded to each word pair based on a five-point scale that consisted of the adverbs "considerably (eg rough)," "somewhat (eg rough)," "in the middle," "somewhat (eg smooth)," and "considerably (eg smooth)." The order *between* the presented word pairs was kept constant throughout the study; the word pairs followed each other in the same order as presented in this section. The order of descriptors *within each* word pair was also constant and followed the order presented in this paragraph. Note that to minimize possible effects of order within word pairs, the position of descriptors (ie left or right in the word pair) with positive and negative valence alternates among word pairs (eg the first word pair contains "rough" with negative valence on the left, the second word pair contains "cold" with negative valence on the right, etc.). The resulting scale was translated into Slovenian (Table S1) and Norwegian (Table S2). For simplicity, the remainder of this article presents only the item from the right-hand side of the scale (eg smooth) instead of the entire word pair (eg rough—smooth) when referring to the scale items.

Testing Procedure

The study consisted of three tasks. In the first task, participants could touch (but not see) the materials: they were instructed to keep their eyes closed during the test. Based on their tactile experience of materials, participants provided a response on a five-point semantic differential scale that was read to them. Responses were immediately entered into a computerized version of the scale. After completing the tactile task, participants proceeded to the second part of the study: tactile–visual task. This task was identical to the tactile task, except that the subjects could both touch and see the materials. Materials were presented to each participant in randomized order; however, for each participant, the order from the tactile task was repeated in the tactile–visual task, to allow for a better comparison of results on the two tasks. The third part of the study consisted of the ranking task. Participants were presented with all the materials at once to inspect them tactilely and visually. They were asked to rank the materials from most to least preferred by placing cards with numbers from one (most preferred) to six (least preferred). In total, the study session lasted approximately 30 min per participant. All sessions were conducted first in Slovenia and later in Norway.

Statistical Analysis

The data were processed and analyzed in R 4.0.2 (Team R Core 2021) using R Studio 1.3.959 (R Studio Team 2021) with the packages dplyr (Wickham et al 2020), ggplot2 (Wickham et al 2019), rstatix (Kassambara 2020), and rcompanion (Mangiafico 2019). Data from the entire sample of 100 participants were available and analyzed in all results presented below. There were no missing values, as the responses from subjects were entered directly into a computerized tool, which did not allow progressing without receiving a response.

We begin the analysis by examining the general preference of materials. We first calculate means and 95% confidence intervals (CI) for the scores on the item "like" for each material, separately for the tactile and tactile–visual tasks. We then test for differences between these scores with pairwise t-tests. The ranking task results present median ranks and bootstrapped percentile CI, and we test for differences between the ranks with pairwise Wilcoxon tests. For all tasks (tactile task, tactile–visual task, and ranking task), we first analyze results from the entire group of participants, continue with the analysis of results within each country, and conclude with the comparison of results between the countries. Note that in between-country comparisons, scores for each material are only compared with the scores of the same material, in contrast with overall and within-country comparisons, where scores for each material are compared with scores of all other materials.

The second section examines the association between the scores on the "like" item and the remaining items from the semantic differential scale. We calculate Kendall rank correlation coefficients between scores on the item "like" and scores on the other rating items, separately for the tactile and tactile–visual tasks.

The third and final section examines the relationship between the tactile and tactile–visual task scores: we first compare the scores between the tactile and tactile–visual tasks on all rating items (except "matte" and "light," which were not included in both tasks) across all materials and continue with computing Kendall rank correlation coefficients between the scores of both tasks.

In cases where multiple significance tests were used in the analysis (ie pairwise comparisons and significance tests of correlation coefficients), p values were adjusted with the Holm–Bonferroni method.

Data, data analysis R code, and supplementary tables are available in an open-access repository (Lipovac et al 2021).

RESULTS

In the following sections, we first present results on the preference of materials: scores on the item "like" from the semantic differential scale (for both tactile and tactile–visual tasks) and the ranks from the ranking task. We continue by presenting the association between scores on the item "like" and the remaining rating items. Finally, we present the relationship between the item scores on the tactile task and the tactile–visual task.

Preference of Materials

The scores on the item "like" from the tactile and tactile–visual tasks and the ranks from the ranking task are presented in Table 1. In both the tactile and tactile–visual tasks, all five wooden materials were on average rated similarly, as somewhat or considerably liked, whereas the stainless steel sample was on average rated as "in the middle" of the dislike–like item. Pairwise comparisons of scores between materials are presented in Tables S3 and S4. In both tasks, all wooden materials were rated statistically significantly higher than the stainless steel (median differences from 0.90 to 1.27, in all cases $p < 0.001$). In contrast, we did not detect statistically significant differences between ratings of wooden materials.

The results (Fig 2 and Tables S5 and S6) and pairwise comparisons (Tables S7 and S8) *within* each country show that the ungrouped scores mirror the overall results. In each country, wooden materials tend to be similarly liked and more liked than the steel sample in both the tactile and tactile–visual tasks. Some exceptions

Table 1. Mean scores on the item "like" from the tactile and tactile–visual tasks with 95% confidence intervals and median ranks from the ranking task with bootstrapped percentile 95% confidence intervals.

Material	Tactile task ("like" mean score)	Tactile–visual task ("like" mean score)	Ranking task (median rank)
Steel	3.01 [2.74, 3.28]	3.03 [2.75, 3.31]	6.0 [5.0, 6.0]
Spruce (thermally modified)	4.28 [4.10, 4.46]	4.02 [3.82, 4.21]	2.5 [2.0, 3.0]
Spruce (unmodified)	4.03 [3.81, 4.25]	3.93 [3.70, 4.17]	4.0 [4.0, 5.0]
Pine (thermally modified)	4.26 [4.08, 4.44]	3.97 [3.76, 4.18]	3.0 [3.0, 4.0]
Pine (acetylated)	4.20 [4.03, 4.37]	3.97 [3.76, 4.18]	3.0 [3.0, 3.5]
Pine (unmodified)	4.25 [4.06, 4.44]	4.12 [3.93, 4.31]	3.0 [3.0, 4.0]

were observed in the Slovenian sample. In the tactile task, Slovenian participants gave lower preference ratings to unmodified spruce compared with acetylated pine (mean difference = 0.52 [95% CI 0.19, 0.85], $p = 0.026$) and thermally modified pine (mean difference = 0.48 [95% CI 0.18, 0.79], $p = 0.027$). In the visual–tactile task, only unmodified pine (mean difference = 0.84 [95% CI 0.37, 1.31], $p = 0.012$) and acetylated pine (mean difference = 0.80 [95% CI 0.30, 1.30], $p = 0.035$) had statistically significantly higher preference scores than the steel sample.

Some differences were observed when the scores on the "like" item were compared *between* the countries (Fig 2 and Tables S9 and S10). In both tasks, Slovenian respondents gave acetylated pine (tactile task: mean difference = 0.48 [95% CI 0.14, 0.82], $p = 0.006$; tactile–visual task: mean difference = 0.78 [95% CI 0.39, 1.17], $p < 0.001$) and steel (tactile task: mean difference = 0.94 [95% CI 0.43, 1.46], $p < 0.001$; tactile–visual task: mean difference = 1.06 [95% CI 0.53, 1.59], $p < 0.001$) somewhat higher preference ratings than their Norwegian counterparts. Additionally, unmodified pine (mean difference = 0.56 [95% CI 0.19, 0.93], $p = 0.003$) and thermally treated spruce (mean difference = 0.40 [95% CI 0.02, 0.79], $p = 0.042$) received higher preference ratings in the tactile–visual task by Slovenian participants.

In the ranking task, thermally modified spruce was on average ranked the highest, followed by the three pine samples with the same median rank and the unmodified spruce with the lowest median rank among the wooden samples. Stainless steel was on average ranked the lowest among all materials. Pairwise comparisons (Table S11) show that all wooden materials except unmodified spruce were ranked statistically significantly higher than the steel sample (median differences

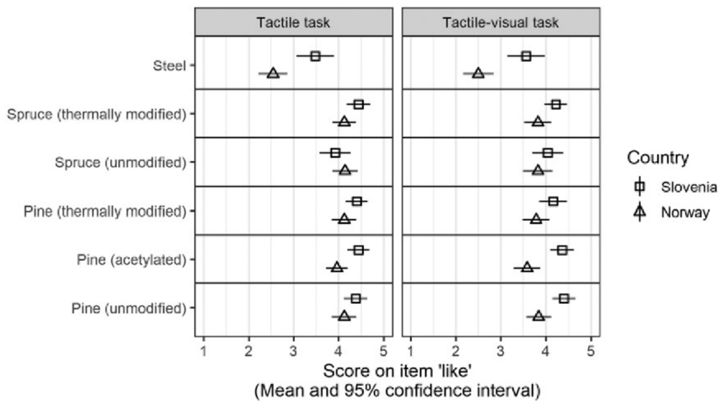

Figure 2. Scores on the item "like" split by countries.

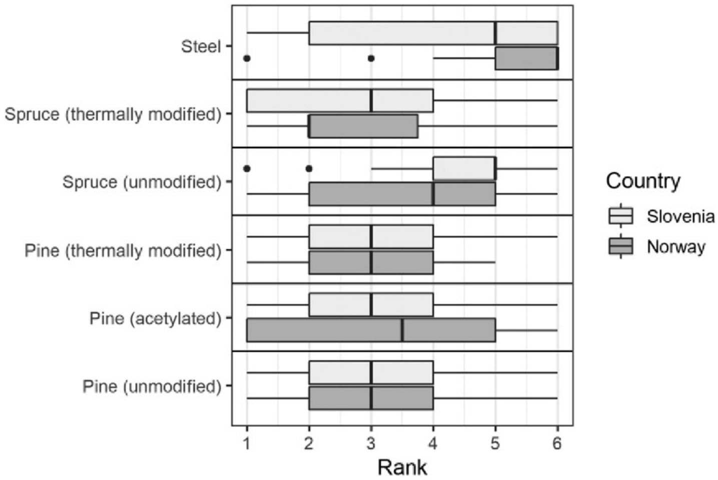

Figure 3. Ranks of materials split by countries.

from 1.5 to 2.0, in all cases $p < 0.001$). Specific differences were also detected between wooden samples: unmodified spruce was on average ranked lower than the other four wooden materials (median differences from 1.0 to 1.5, in all cases $p < 0.05$).

In general, similar results were observed in the ranks *within* each country (Fig 3, Table 2, Tables S12 and S13), with some exceptions: Slovenian participants gave unmodified spruce lower ranks compared with all wooden materials except thermally modified pine (median differences from 1.5 to 2.0, in all cases $p < 0.01$), and only thermally modified spruce received higher ranks than the steel sample (median difference = 1.5 [95% CI 0.5, 2.5], = p = 0.029). Comparisons *between* the countries (Fig 3) revealed differences in the ranking of two materials: compared with Norwegian respondents, Slovenian participants on average assigned higher ranks to steel (median difference = 0.0 [95% CI 0.0, 1.0]; $p = 0.014$) and lower ranks to spruce (median difference = 1 [95% CI 0.0, 2.0]; $p = 0.003$).

Rating Items Associated with the Preference of Materials

Table 3 presents Kendall rank correlation coefficients between the scores on the item "like" and the remaining items for the tactile and visual–tactile task. Correlation coefficients are similar across both

Table 2. Ranks of mean and median ranks of each material for both countries.

Material	Rank of mean rank—Slovenia	Rank of median rank—Slovenia	Rank of mean rank—Norway	Rank of median rank—Norway
Steel	5	5.5	6	6.0
Spruce (thermally modified)	1	2.5	1	1.0
Spruce (unmodified)	6	5.5	5	5.0
Pine (thermally modified)	4	2.5	2	2.5
Pine (acetylated)	2	2.5	4	4.0
Pine (unmodified)	3	2.5	3	2.5

The values in the table were obtained by first computing mean and median ranks for each material (separately for each country) and then assigning ranks to these mean and median ranks.

Table 3. The association between the scores on the item "like" and the remaining rating items for the tactile and tactile–visual tasks—Kendall rank correlation coefficients.

Item	Tactile task	Tactile–visual task
Smooth	−0.02	0.03
Cold	−0.37***	−0.36***
Damp	−0.24***	−0.25***
Hard	−0.04	0.00
Usual	0.33***	0.27***
Artificial	−0.43***	−0.36***
Expensive	0.07	0.11**
Unpleasant	−0.73***	−0.61***
Light	—	0.03
Matte	—	0.24***

** $p < 0.01$, *** $p < 0.001$. p-values are adjusted with the Holm–Bonferroni method.

tasks. In both tasks, materials rated as liked were perceived as somewhat less cold, less damp, more usual, less artificial, more expensive, and less unpleasant. The statistically significant positive correlation between scores on the items "like" and "hard" was found only in the tactile task. We did not detect statistically significant associations between the "like" item scores and the scores from the two items included only in the visual–tactile task (ie "light" and "matte"). The correlation coefficients are generally small to medium; the only exception is the negative correlation coefficient between the scores on the items "like" and "unpleasant," which is larger.

The Relationship between Tactile and Tactile–Visual Task Scores

The comparison of scores between the tactile and tactile–visual tasks on all items (except "matte" and "light" that were included only in one task) for all materials is presented in Fig 4 and Table S14. In general, the ratings are fairly consistent between the two tasks. Some discrepancies are noticeable for the items "usual" and "expensive."

Kendall rank correlation coefficients were calculated for scores on each item between the tactile and tactile–visual tasks (Table 4). Correlation coefficients are moderately high for the items "artificial," "unpleasant," "damp," and "like," and the three items capturing tactile sensory properties (ie "cold," "smooth," "hard"), and somewhat lower for the items "usual" and "expensive."

DISCUSSION

Preference of Materials

The results on the preference of materials show that wooden materials were generally similarly liked and more liked than the steel sample in both the tactile and tactile–visual tasks. This observation is mirrored in the results of the ranking task, in which wooden materials were on average ranked higher than the steel sample. These results are in line with existing studies, which have observed that wood is generally favored over other common building materials (Rice et al 2006; Ikei et al 2017b). The results of this study thus extend previous findings by showing that wood may be preferred over at least some other everyday materials, even when materials are presented in a form that more closely resembles the real-world context (ie presented as handrail samples instead of typically used small rectangular blocks of wood).

Preference ratings and rankings were fairly similar across the participants from Slovenia and Norway. The results *within* each country reflected the overall pattern: the wooden materials were generally rated and ranked similarly, while they were preferred over the steel sample. This pattern was clearly reflected in the results of the Norwegian participants, whereas some deviations occurred in the results of the Slovenian subjects. The Slovenians preferred unmodified spruce somewhat less than some other wooden materials. Although they still generally preferred the steel sample the least, their preference scores varied more than the Norwegian scores. This discrepancy between the countries could stem from cultural differences: clearer distinction in preference between the wooden materials and the steel sample observed among the Norwegians could have resulted from different general attitudes toward wood or steel. Nevertheless, even though the results from Slovenia and Norway varied, it should be highlighted that they are generally very similar.

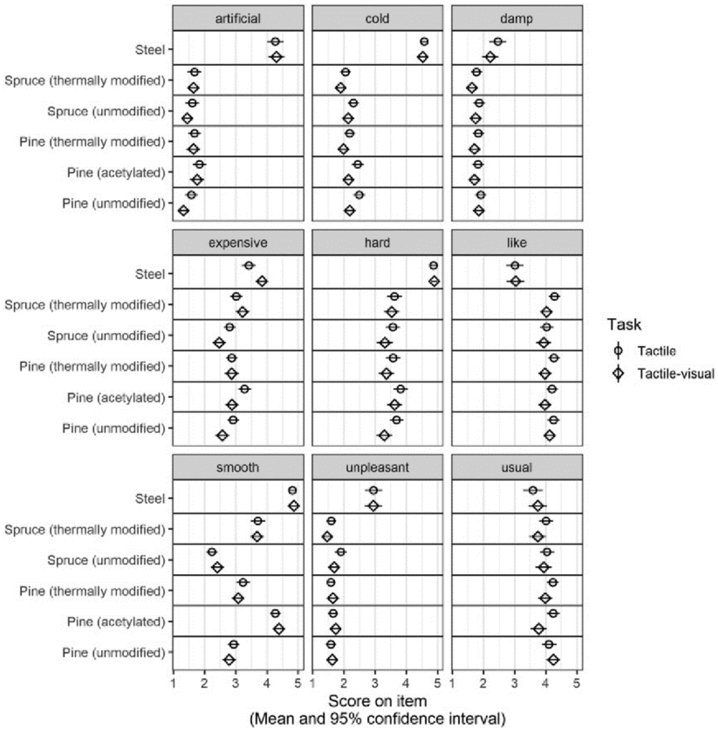

Figure 4. Scores on scale items split by tasks.

Comparison of the results *between* the countries showed that Slovenians, compared with Norwegians, gave higher absolute preference ratings (item "like") to the steel sample and certain wooden samples in both the tactile and tactile–visual tasks. This observation, however, is probably less informative than comparing the within-country results between countries. First, subtle language differences in the scales used in the two countries could have influenced absolute values of the preference scores. Second, lower absolute scores sometimes observed among the Norwegians could have resulted from the slight damage that the materials sustained in the second part of the study conducted in Norway. Comparing the countries on the ranking task, which is not influenced by the abovementioned issues, reveals the same pattern observed in the within-country analysis: Slovenians generally preferred steel more and unmodified spruce less than the Norwegians.

Analysis of the preference scores within wooden materials revealed that modified wood samples

Table 4. The association between the rating item scores on the tactile and tactile–visual tasks—Kendall rank correlation coefficients.

Item	Like	Smooth	Cold	Damp	Hard	Usual	Artificial	Expensive	Unpleasant
Kendall rank correlation coefficients	0.50***	0.60***	0.60***	0.52***	0.62***	0.33***	0.55***	0.37***	0.56***

*** $p < 0.001$. p-values are adjusted with the Holm–Bonferroni method.

were rated and ranked comparably to unmodified wood. The only wooden sample that was ranked somewhat lower than the others was unmodified (ie unmodified spruce). These observations contrast with the observations that treated materials are less preferred than the original, unmodified samples (Ikei et al 2017a). This suggests that modified wood exhibits tactile and visual properties that are, in terms of human preference, comparable to those of unmodified wood and different to those of wood that has been treated otherwise (eg with coating). Splitting these results by country showed similar results: wooden samples, regardless of their treatment, generally received similar preference scores within each country, suggesting that potential cultural influences might not influence the perception and evaluation of modified wood samples.

Association between Material Properties and Preference

Many perceived material properties were associated with a preference for wooden materials in both the tactile and tactile–visual tasks. Materials rated as liked were also rated as somewhat less cold, less damp, more usual, less artificial, less unpleasant, and, only in the tactile–visual task, more expensive and more matte. The observed associations between material properties and preference tend to be minor, which suggests that additional visual and tactile properties, beyond those examined in this study, are important in predicting material preference. Perceived material smoothness, hardness, and color lightness were not associated with preference scores.

The observed results are partially consistent with findings from existing studies. In line with the observations of Waka et al (2015), we observed that materials with higher preference ratings had been perceived as warmer. This suggests that perceived warmth might be associated with preference relatively independently of the context in which the wood samples are presented. In contrast to the findings of Waka et al (2015), who observed that preferred materials were perceived as a damper, we observed they were perceived as dryer. This discrepancy could have resulted from the way the materials had been presented: in handrails, dampness could be associated with (unwanted) slipperiness.

The perceived color lightness of materials was not associated with their preference scores. This observation contrasts with the study that found darker wooden materials had been preferred for an outdoor tabletop (Lipovac et al 2019), suggesting that the relationship between wood lightness and human preference may depend on the context of wood use. Similarly, our results contrast with the observations of Waka et al (2015), who found shinier samples were more preferred, whereas we observed that participants preferred matte materials. This discrepancy could be explained by differences in materials tested in the two studies. Waka et al (2015) examined only samples of wood, many of which likely varied in surface shininess. Our study, on the other hand, included wood samples with relatively uniform shininess levels, so the observed association—shinier materials being less preferred—might have been driven primarily by the presence of the (shiny) steel sample, which was generally the least preferred material. This could also explain why we have not detected the association between perceived smoothness and material preference, which is typically observed in other studies (Jonsson et al 2008; Waka et al 2015; Bhatta et al 2017): the ratings of the stainless steel sample, which was perceived as smooth but less liked, might have steered the association between perceived smoothness and preference toward the opposite direction than typically observed within wood samples. We found no relationship between perceived material hardness and material preference, possibly because the scores on the item "hard" did not vary sufficiently among the tested materials.

We observed that materials perceived as more natural tended to be preferred, similar to what has been observed in other studies (Rice et al 2006; Jonsson et al 2008; Ikei et al 2017b). Such studies, however, typically compared different types of materials instead of mostly different *wooden* materials. Our study thus extends these findings and shows that perception of naturalness may be an important predictor of preference even within the same material (ie wood). Two other items that predicted preference in our study and that we had not identified in other studies assessing the perception of wood, were "usual" and "expensive." Materials perceived as more expensive and more usual were generally rated as more liked. Possibly, perceived expensiveness can reflect the perception of overall material quality, which in turn may be inferred from the pleasantness of the tactile and visual material properties. However, the steel sample was generally perceived as the most expensive material, although it was generally less liked than the wooden samples. This suggests there is a more complex mechanism behind the association between perceived expensiveness and preference of materials.

We observed that people preferred materials with which they were more familiar (ie materials rated higher on the item "usual"). It is possible that preferred materials are more widespread in everyday life, increasing the chances that people will become familiar with them. The association between perceived usualness and preference is particularly interesting in this study, which includes several samples of modified wood that are currently rarely used in real life; so, the participants have probably had few opportunities to come into contact with them. This suggests that modified wood samples exhibit certain visual and tactile properties that are perceived similarly to properties of more common wooden materials.

Association between Tactile and Tactile–Visual Task Scores

Comparison of the results between the tactile and tactile–visual tasks showed that the scores of the two tasks correlate with each other. The highest correlation coefficients between the two tasks were observed in the rating items predominantly assessed by touch: "smooth," "cold," "damp," and "hard." This is unsurprising as the visual modality is not expected to substantially influence the perception of these properties. Somewhat weaker correlations were observed in the affective attributes "usual" and "expensive," suggesting that the perception of these properties changes to a greater extent when people can inspect materials visually. Interestingly, the correlations on the items "artificial," "unpleasant," and "like" were relatively high, comparable to the correlations observed in the items assessing tactile sensory properties, suggesting that the tactile experience importantly influences the perception of naturalness and preference of materials. This finding is consistent with the results of previous studies that reached similar conclusions: tactile domain is important in overall material perception (Overvliet and Soto-Faraco 2011; Waka et al 2015; Bhatta et al 2017). The results of this study extend previous findings by demonstrating the importance of the tactile domain even when assessed materials are brought closer to a real-world context.

LIMITATIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

Due to transportation, the handrail samples were slightly damaged in the tests conducted in Norway, which might have led to some differences in scores that occurred between the countries. Other differences between the countries could have resulted from the demographic characteristics of the participants: most Slovenian subjects were retired individuals with different backgrounds. In contrast, most Norwegian subjects were still-active academic staff. The samples of the two countries additionally differed on gender: women represented 54% of the Slovenian sample but only 28% of the Norwegian participants. For these reasons, it should not be assumed that identified differences between the countries in material perception are due to differences in culture, until the findings are confirmed by future studies. Another limitation stems from the limited variety of selected wooden samples: we used only two types of modification processes despite using three modified wood samples. The findings of this study could be extended by testing additional materials treated with different modification processes and including additional rating items that could further identify and clarify the role of material properties influencing the perception of materials. Testing materials that are similar in all but one property (eg varying only on roughness) would better reveal the role of specific material properties in overall material preference. Future studies could also explore the perception of wooden materials in different furnishings, such as chairs and desks. More generally, the field of study would benefit from a theory explaining how and why specific material properties relate to preference of materials.

CONCLUSIONS

The results of this study confirm and extend previous findings showing that wooden materials tend to be more liked than other common materials—in our case, more than steel. The results also suggest that older adults prefer modified wood samples similarly to unmodified wooden materials. The findings are consistent across Slovenia and Norway, suggesting that different practices of wood use in these two countries do not significantly influence the perception of wooden materials. Preference of materials is associated with certain perceived material properties, and tactile experience has a significant role in the overall perception of materials. Altogether, the results suggest that wood, either unmodified or modified, may be a promising addition to restorative indoor environments for older adults.

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2.3 Article 3

Title: Human preference for visual appearance of desks: examining the role of (wooden) materials and desk designs

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Human Preference for Visual Appearance of Desks: Examining the Role of (Wooden) Materials and Desk Designs

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Abstract

Visually pleasing materials and furnishings may be an important component of pleasant, restorative indoor spaces, where people can rest, relax, and recover from stress. We conducted two studies to examine human preference for different wooden desk materials and designs. In Study 1, 77 participants evaluated the visual appearance of 20 wooden materials and 18 desk designs, in which desk elements and their arrangements were systematically varied. The three highest rated wooden materials and desk designs from Study 1 were combined in 18 new desks evaluated by 80 participants in terms of visual appearance in Study 2, where we systematically varied the type of material, amount of material, and desk design. The results show that preference for different materials and desks varies greatly from person to person, but several evaluated items are on average preferred to others. Study 1 shows that certain materials, desk elements, and the arrangements of those elements received higher preference ratings than others. Study 2 indicates that the type of material, amount of material, and desk design all have a significant role in human preference for the visual appearance of desks. Researchers and designers can build on these findings to create aesthetically appealing indoor environments that have the potential to positively impact human wellbeing.

Keywords

Furniture, preferences, occupant comfort, restorative environments, interior design, wellbeing

1. Introduction

A large body of evidence suggests that building occupants feel and function better when exposed to nature in indoor spaces [1,2]. After being in contact with elements of nature, such as potted plants and photos of landscapes, occupants tend to exhibit improved affective states, lowered physiological arousal, and enhanced cognitive performance. Due to these effects, environments that contain elements of nature are thought to be restorative, as they restore human functioning and wellbeing after it has been diminished by stress and effort [2,3]. Bringing nature indoors is an intervention that can be particularly useful for office workers, as they can be at a heightened risk of experiencing stress [4] and may spend most of their working hours in indoor spaces. Indeed, a recent review reported that implementing nature into the office environment improves worker wellbeing and productivity [5].

The positive effects that people experience when in contact with (elements of) nature are reflected in human environmental preferences: people consistently prefer natural over built environments, especially individuals who are in higher need of restoration due to stress [6,7]. This suggests that environmental preference can be used as a proxy indicator of environmental restorativeness: settings that occupants find attractive may be more likely to provide restorative effects.

Compared to other approaches of bringing nature to indoor spaces, current literature has largely overlooked that wood—a natural material—could positively impact building users. Wood can complement other elements of nature used indoors by bringing naturalness to structural and functional elements of the building, such as furniture, flooring, stairs, and handrails. Many studies suggest that contact with wood could impact building occupants positively: people perceive wood as natural [8], tend to prefer wood over other common materials [9], and, after being exposed to wood, may experience less stress and perform better on tests of cognitive functioning [10–14]. Applying wood indoors could be particularly promising for office workers, who spend much of their time in contact with desks.

However, not all studies have found positive effects of wooden furnishings [15,16]. This could in part result from studies testing different types of wood, applied in various colours, patterns, amounts, and layouts [10]. For example, previously studied materials include birch-, oak-, and walnut- veneered furniture as well as spruce and fir solid wood; and wood coverage in studies ranges from a small wooden desk top [16] to wood applied to most of the room [17]. Identifying the most effective wooden materials and their applications is further complicated by other unique characteristics of previously studied wooden settings: wood emitted noticeable scents in some studies [15,17] but not in others [12,16]; and participants were exposed to wooden environments for different amounts of time, from 90 seconds [18,19] to 75 minutes [12]. So far, studies on human response to interior spaces furnished with wood have not clarified which wooden materials to select and how to apply them in indoor settings to increase the likelihood of providing positive effects for building occupants.

Due to the apparent connection between preference and restorative effects, studies investigating human preference for wooden materials could provide clarity and guidance for researchers, architects, designers, and other stakeholders that want to create restorative indoor spaces. However, most existing research examined how people perceive one or few types of wood compared to other everyday materials [20–23], whereas fewer studies compared human perception between different types of wood. The few existing studies that did compare different wooden materials in terms of human preference either observed no difference between the evaluated wooden materials [23] or found that people prefer wooden surfaces perceived as more homogenous [24,25] and closer to red on the green-red colour component [26]. The preference for specific wooden qualities, however, may greatly depend on the intended wood application. For example, people might prefer lighter and glossier wooden materials for no particular application [27] but favour darker wood for an outdoor table top [26] and wood with matte surface for handrails [28]. Due to the many and diverse wooden materials and possibilities for their indoor application, human preference for wood applied in indoor spaces remains under-explored.

The ambition to create office desks that could be part of restorative environments is further complicated by numerous possibilities of designing a desk but few evidence-based design guidelines that could positively impact human wellbeing. Existing desk-design guidelines focus on ergonomic aspects, which suggest creating desks with adjustable height, sufficient width, adequate knee space, and rounded edges [29]. However, desks that follow these recommendations can still vary in many aspects, such as type of desk legs and presence or absence of drawers and shelves. The design possibilities can lead to desks with diverse aesthetic and functional qualities, and the more visually appealing designs are in principle more likely to lead to restorative effects. Currently, however, it is not clear how the visual appearance of desks is related to preferences of people. To the best of our knowledge, human preference for different desk designs has not yet been examined and reported in a peer-reviewed article. It is also not known to what extent to incorporate wooden materials in desk designs to make desks more visually appealing to users. People seem to prefer a medium amount of wood coverage in a room [30] but it is unclear if the desired wood coverage is similar in a single piece of furniture, such as desk.

In summary, from the existing studies it cannot be determined which wooden materials and desk designs are preferred in terms of visual appearance and in turn more likely to provide restorative effects to office workers. However, as office employees may spend most of their working hours at a desk, having such knowledge may lead to an effective, efficient, and scalable passive intervention that could increase worker wellbeing and productivity. The first steps of developing such an intervention are the objectives of this study, which aims to investigate which wooden materials and desk designs are the most visually appealing to people, and how the preferred wooden materials and desk designs can be best integrated to produce aesthetically pleasing desks.

The present research consists of two studies. In Study 1, we examined preferences of people for selected images of wooden materials and desk designs. The most preferred materials and designs from Study 1 were used to create a new set of (images of) desks that combined different desk designs, wooden materials, and amounts of wooden materials. Preferences of people for these new desks were examined in Study 2.

2. Study 1

2.1 *Materials and methods*

2.1.1 *Wooden materials*

The selection of wooden materials tested in this study was based on existing studies investigating human preference for and response to wooden materials and settings. We identified 17 relevant articles [13,16,32–37,19–22,24–26,31] and extracted a list of 22 unique wood species that had been reported. Our goal was to present each unique wood species as one untreated wooden material, regardless of whether the original study had tested the wooden material that had been untreated, treated, or both. From the list of identified wooden materials we excluded 1) Silver fir, due to its considerable resemblance to the more commonly reported Norway spruce, and 2) Hinoki (Japanese) cypress, due to the unavailability of the image in the online database from which the images were later collected. The images of the resulting 20 wooden materials (Figure S1) were extracted from the website https://www.wood-database.com (with permission from the website owner).

2.1.2 *Desk designs*

We identified 12 vendors of office desks with the online store available in Slovenia. Of those 12 vendors, the online stores of four offered the possibility to sort products by popularity. At each of those four websites, we visited the section with desks and sorted them by popularity.

We extracted five desk designs from each of the four vendors, resulting in 20 desk designs in total. From these 20 desk designs, we identified common design components that fell into three categories: 1) type of desk legs, 2) type of storage, and 3) arrangement of desk legs and storage. In the first category, we identified three types of desk legs: poles (round legs), board, and (square support). In the second category, we identified three types of storage: drawers, single-door cabinet (“cabinet”), and single-door cabinet with a shelf at the top (“shelf”). In the third category, we identified three distinct arrangements of desk legs and storage: the same type of legs were used at both sides of the desk (“both-stand desks”), one side of the desk had some type of legs and the other side of the desk had some type of storage (“one-stand-one-storage desks”), or both sides of the desk had some type of storage (“both-storage desks”).

Based on these identified patterns, we first created digital models of the three types of legs and three types of storage, and then created desk designs with all possible arrangements of these elements, with the following exceptions: 1) if only desk legs were used in the desk, both sides of the desk must have had the same type of legs, and 2) different elements (types of legs or storage) were combined only once, without repeating that same combination in the mirror image of the desk design (e.g., if we prepared a desk design with poles on the left and drawers on the right, we did not prepare a desk design with poles on the right and drawers on the left). This process resulted in 18 distinct desk designs (Figure S2). The models of desks were designed in SketchUp Make 2017 [38] and rendered with the SketchUp extension Raylectron 4 [39]. The dimensions of each digital desk model were in the approximate ratio of 2 (length) x 1 (width) x 1 (height) (i.e., 160 cm x 80 cm x 70 cm). The desk models were given a light wood texture (instead of a neutral white) due to the resulting higher quality of rendered images. Two types of legs—poles and square legs—were coloured with light metal silver colour.

2.1.3 *Survey*

In Study 1, participants first provided preference ratings for 20 wooden materials and later for 18 desk designs. When presented with each image of the wooden material, participants responded to the question “How do you like the appearance of the material in the image as a material for visible surfaces of an office desk?”; and when presented with the image of each desk design, subjects responded to the question “How do you like the appearance of the desk design in the image?”. Each question was responded to on a 7-point rating scale (1—dislike a lot, 2—dislike, 3—somewhat dislike, 4—in between, 5—somewhat like, 6—like, 7—like a lot). The instructions emphasized that participants should focus on stating their preference for the appearance (and not functionality) of the rated items. Before rating each wooden material and desk design, participants were able to first see all images of wooden materials and later desk designs in one large grid of images, to get more familiar with the rating task ahead of them. In the survey, the images of the wooden materials did not contain names of wood species. All images were presented in the same (random) order to all participants.

The survey was implemented in the 1KA survey platform [40] and ran in August of 2021. Participants typically needed between 5-10 minutes to complete the survey, which was administered both in Slovenian (Supplementary material 1) and English language (Supplementary material 2). For the purposes of the survey, images of wooden materials and desk designs were processed (i.e., cropped and arranged to a grid) with the R package magick [41].

2.1.4 *Participants*

Participants were invited to the online survey through the internal and external (social media) communication channels of the InnoRenew CoE research institute (conducting research on renewable materials and healthy environments) and through personal social media accounts of the first author. At the beginning of the survey, subjects provided an informed consent to participate in the study, after they had been informed about the study purpose and procedure, rights of participants, and data management practices.

In total, 83 people responded to the Study 1 survey. All 83 respondents completed the first part of the survey (on preference for wooden materials), whereas 77 of those also completed the second survey part (on preference for desk designs). Of the 77 respondents who completed the entire survey (and for whom the demographic data is available), six were below 25 (8%), 55 (71%) were between the ages of 25-44, 15 were above 44 (20%), and one person (1%) did not wish to disclose their age. Forty-two participants identified as female (55%), 34 identified as male (44%), and one respondent (1%) did not wish to disclose their gender. Education or work were unrelated to wood or design in 47 respondents (61%), related to wood in 25 respondents (32%), and related to design in 5 respondents (7%).

2.1.5 *Statistical analysis*

The data were processed, analysed, and visualized in R 4.0.2 (R Core Team, 2021) using RStudio 1.4.1106 [43] with the packages *rstatix* [44], *ordinal* [45], *emmeans* [46], *imager* [47], *colordistance* [48], *spacesXYZ* [49], *flextable* [50], *ggtext* [51], *gridextra* [52], and the *tidyverse* [53] collection of packages. Descriptive statistics are reported as means and standard deviations (SD).

Images of wooden materials were processed with the R package *colordistance* [48] to express the colours of materials in the three parameters of the CIELAB colour space: L* (lightness), a* (red-green component), and b* (yellow-blue component).

To quantify the colour variability *within* images, each image was first separated into 900 non-overlapping segments, each 200 pixels in size. For each segment, the average colour was computed by selecting 20 random pixels, identifying their L*a*b values, and calculating means of those values. Using these means, we calculated Delta E—a measure of colour difference in CIELAB space [49,54,55]—between all unique pairs of the 900 segments (900 × 899 / 2; 404550 total comparisons). The mean of these Delta E values was then calculated for each image, representing the degree of colour variability within the image (the higher the mean Delta E, the higher the colour variability). The relationship between these Delta E means and the preference ratings was then examined visually and using the Spearman's rank correlation coefficient.

We also quantified colour differences *between* the images of wood, using the approach described in the *colordistance* R package documentation [48,56]. The approach bins pixels of an image into a select number of bins, each with specific colour and size. Colours of each image can thus be represented on a histogram. The difference in colour between images can be calculated with several metrics that compare the colour histograms of images. We used the (recommended) Earth mover's distance, which calculates the minimum cost of transforming one colour distribution into another. Higher Earth mover's distance values denote higher colour difference [57]. The mean Earth mover's distance was then calculated for each material (i.e., material's average colour distance to all other materials), and the association between these mean distances and preference ratings was examined visually and using the Spearman's rank correlation coefficient.

Cumulative link mixed models (fitted with the function clmm [58] from the R ordinal [45] package) [45,59,60] were used to examine how specific wooden materials, desk designs, desk elements, and the arrangements of desk elements affect preference ratings of people. The models aim to explain the latent continuous variable (degree of preference) that underlies the ordinal variable (discrete preference ratings) based on a set of predictor variables treated as fixed effects (i.e., specific desk designs) and subjects treated as random effects. The main models (those fitted on all data instead of subsets of data) at first included demographic variables as predictors (i.e., age, gender, and a variable indicating if respondent's education was related to wood or design). These models were then compared with the versions of models that excluded the demographic variables. As there were no significant differences between the models with and without demographic variables (as tested with analysis of variance), we report the simpler models with fewer predictors.

If the model detected a statistically significant effect of a predictor variable, post-hoc comparisons were conducted with the R package *emmeans* [46]. Due to the exploratory nature of the study, the *p* values were not adjusted for multiple comparisons, as we aimed to decrease the possibility for the Type II error (i.e., false negative). This means that the possibility of a Type I error (i.e., false positive) was increased, so the results should be interpreted with caution. The results of post-hoc comparisons are reported as exceedance probability (EP): the probability of the item (e.g., specific desk design) being rated as liked (i.e., the probability of having a rating of at least 5—"somewhat like"—on the scale of 1 to 7). For models with more than one factor as predictor, the EPs are averaged over the levels of other factors.

We first fitted the model and calculated EPs separately for all 20 wooden materials and 18 desk designs as predictors, which showed us how individual wooden materials and desk designs compare to each other in terms of preference of people. We continued with the model examining the role of the arrangement of desk elements, where desks were grouped according to three distinct arrangements: 1) both-storage desks, where both sides of the desk contained an element intended for storage, 2) both-stand desks, where both sides of the desk contained a leg element, or 3) one-stand-one-storage desks, where one side of the desk contained a storage element and the other a leg element. Finally, we fitted models that explored the role of specific desk elements (e.g., drawers, poles) in human preference. The latter models were fitted on specific subsets of data because some desk elements (e.g., cabinet) were not present in some subsets of data (e.g., desks with both elements used as a stand). A separate model with specific desk elements as predictors was thus fitted for each group of desks based on the arrangement of their desk elements (i.e., both-storage, both-stand, one-stand-one-storage desks), resulting in three separate models examining the role of desk elements in preference.

2.2 *Results*

2.2.1 *Wooden materials*

2.2.1.1 *Preference for wooden materials*

Most of the rated materials received a similar mean preference rating, which was typically between approximately 4 ("in between") and 4.5 (between "in between" and "somewhat like"). Oak, maple, and guibourtia were the highest rated materials with the mean preference ratings of 4.87 (SD = 1.48), 4.63 (SD = 1.41), and 4.53 (SD = 1.39), respectively (Figure 1, Table S1).

The preference ratings of the remaining materials decreased gradually; their mean preference ratings were between 4.47 and 3.81 (SD between 1.40–2.04), except for the three lowest rated materials (aspen, pine, and spruce), which had mean preference ratings between 3.39 and 3.10 (SD between 1.51–1.67).

The variability of individual preference ratings within the materials was high: for all materials, the ratings ranged across most or all of the seven possible ratings (from 1—“dislike a lot” to 7— “like a lot”). All materials, except birch, received at least one rating of “like a lot” while only three materials did not receive a rating of “dislike a lot”: maple, guibourtia, and Japanese cedar. The variability of ratings was especially high for ebony and relatively low for lauan, but still spanning the entire range of possible ratings in both materials.

The model with the individual wooden materials as predictors and preference rating as the outcome is available in Table S2. Statistically significant differences of pairs of materials (with the total of 190 paired comparisons) most often occurred in pairs with one of the four lowest rated materials (i.e., aspen, pine, spruce, and chestnut) or the highest rated material (i.e., oak) (in 72 of 80 pairs with statistically significant difference) with the remaining (eight) pairs including birch, guibourtia, maple, radiata pine, teak, and lauan (Table S3).

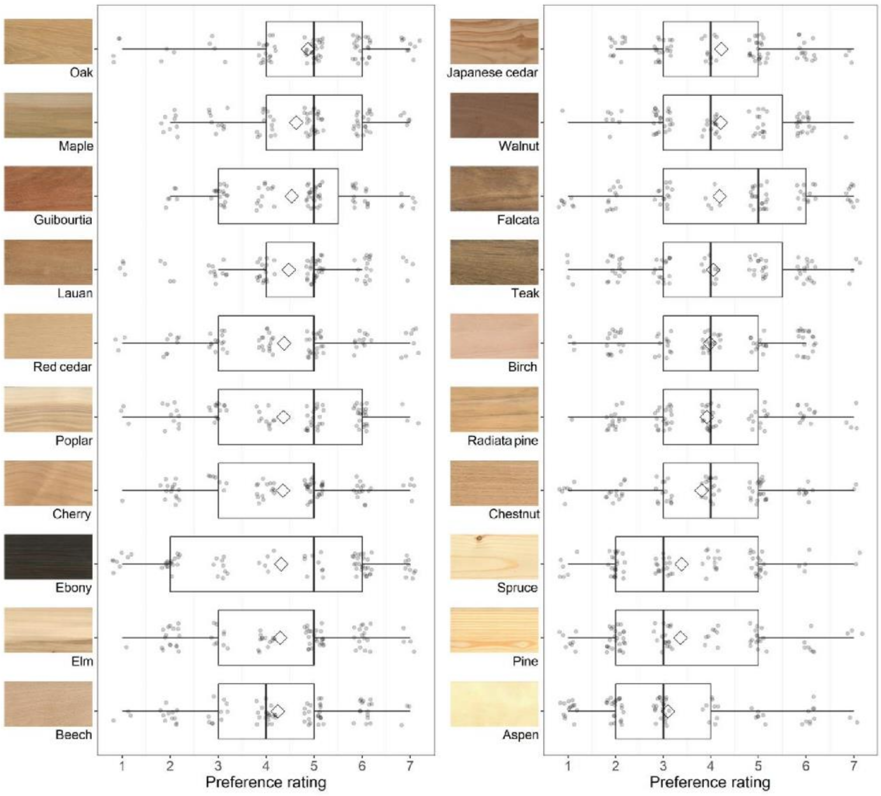

Figure 1: Preference ratings for wooden materials (ordered from the highest to lowest mean preference rating, represented with the diamond shape)

2.2.1.2 *The role of wood colour in preference for wooden materials*

The analysis of colour distances between materials (i.e., Earth mover's distances) shows that ebony stands out from the rest with relatively large colour distances to most other materials in the study. Other materials with somewhat large colour distances to remaining materials include aspen, walnut, spruce, pine, and guibourtia, with the (mean) colour distances gradually decreasing for other materials (Figure 2, Table S4).

There is no noticeable overall relationship between the mean colour distances of materials (in reference to all other materials) and their preference ratings (Figure S3), and the Spearman's rank correlation coefficient between the two variables is not statistically significant ($r_s = 0.30$, *p* = 0.225). The only notable exceptions are the three lowest rated materials (aspen, pine, and spruce), which have a relatively high colour distance to colours of other materials.

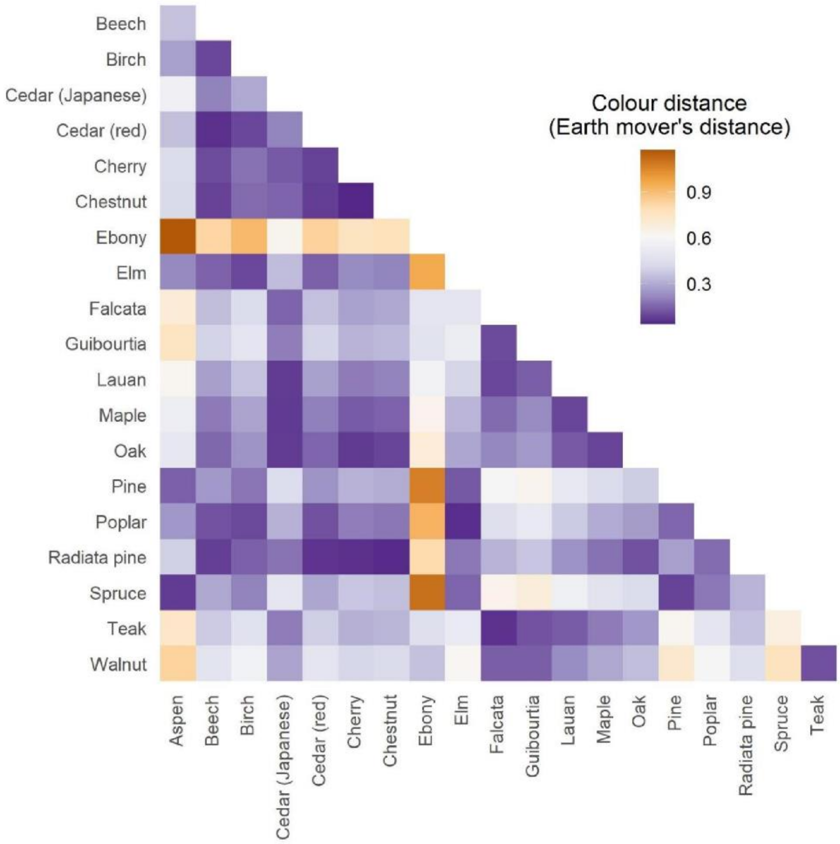

Figure 2: Colour distance between wooden materials (higher number/browner colour indicate larger distance between colours)

The analysis of colour variability *within* materials, as examined with the mean Delta E values, indicates that colour varied the most within poplar, elm, and pine, and the least within red cedar, birch, and walnut (Table S5). There was no obvious association between preference ratings and colour variability within materials ($r_s = 0.01$, $p = 0.962$, Figure S4).

2.2.2 *Preference for desk designs*

Most desks received the mean preference ratings between slightly below 4 (“in between”) and slightly above 4.5 (between “in between” and “somewhat like”). Desks that received the highest preference ratings were board-cabinet, board-drawers, square-drawers, and board-board, with the mean preference ratings of 4.70 (SD = 1.51), 4.68 (SD = 1.51), 4.56 (SD = 1.54), and 4.56 (SD = 1.74), respectively (Figure 3, Table S6). The mean preference ratings of other materials gradually decreased and were between 4.52 and 3.31 (SD between 1.36–1.81), with aspen, pine, and spruce being the lowest rated materials.

The variability of individual preference ratings within the desk designs was generally high, spanning throughout the entire range of possible ratings for all designs, although in many cases only one or few ratings were in the extreme parts of the scale. The board-shelf desk design had a somewhat lower variability of preference ratings compared to other designs.

Within the six highest rated desks, five are in the group of one-stand-one-storage desks, and four contain the board element. All six desks from the both-storage desk group are among the seven lowest rated desks.

The model with desk designs as predictors and preference rating as the outcome is available in Table S7. Post-hoc analysis shows that 79 out of the total of 153 comparisons between desk designs are statistically significant. Many of the significant differences predictably appeared within pairs that included the highest and lowest rated desk designs, but they occurred also within pairs with other desk designs (Table S8).

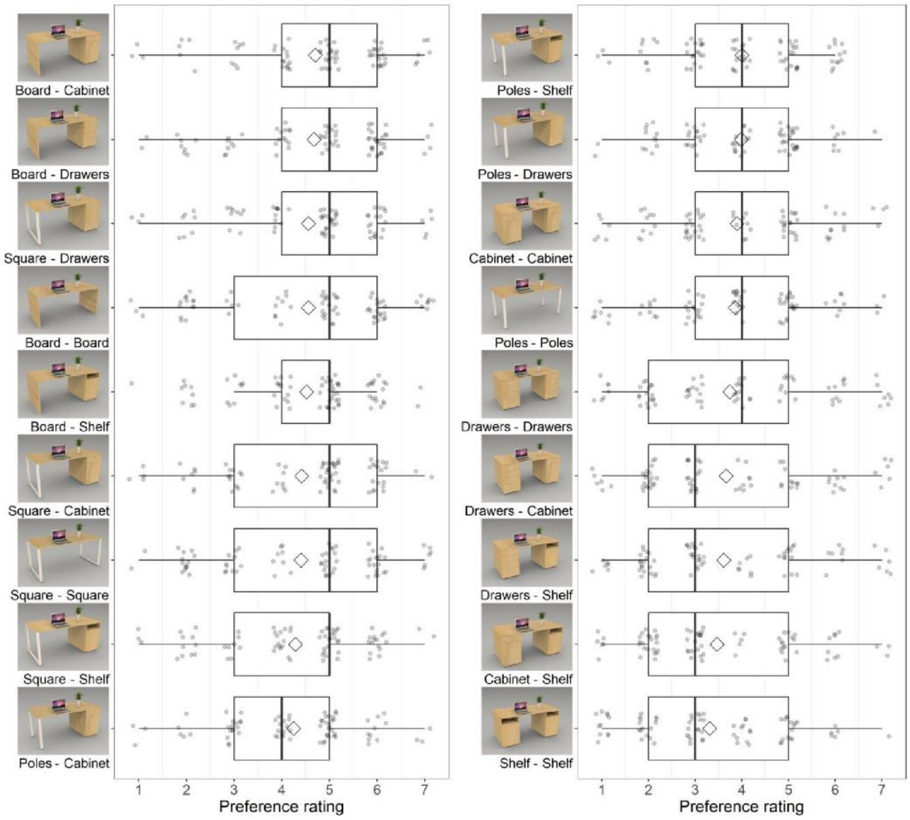

Figure 3: Preference ratings of desk designs (ordered from the highest to lowest mean preference rating, represented with the diamond shape)

2.2.3 *The role of arrangement of desk elements in preference for desk designs*

The model examining the role of the arrangement of desk elements (i.e., both-stand, both-storage, one-stand-one-storage) in preference is available in Table S9. Post-hoc analysis shows that both-stand desks (EP = 0.51, 95% CI [0.44, 0.59]) and one-stand-one-storage desks (EP = 0.53, 95% CI [0.47, 0.59]) were similarly likely to be rated as liked (both-stand desks − one-stand-one-storage desks = −0.02, 95% CI [−0.08, 0.04], $p = 0.51$). Both-storage desks (EP = 0.34, 95% CI [0.28, 0.39]) were significantly less likely to be rated as liked than both-stand desks (both-stand desks − both-storage desks = 0.18, 95% CI [0.11, 0.24], $p < 0.001$) and one-stand-one-storage desks (both-storage desks − one-stand-one-storage desks = −0.20, 95% CI [−0.25, −0.15], $p < 0.001$).

2.2.4 *The role of individual desk elements in preference for desk designs*

The role of specific desk elements in preference is analysed separately for both-storage desks, both-stand desks, and one-stand-one-storage desks.

2.2.4.1 *The role of desk elements within both-storage desks*

The model examining the role of specific desk elements in preference within both-storage desks is available in Table S10. Post-hoc analysis shows that a both-storage desk was significantly more likely to be rated as liked if the shelf element was *not* present (shelf not present: EP = 0.21, 95% CI [0.06, 0.36]; shelf present: EP = 0.12, 95% CI [0.01, 0.23]; difference = 0.09, 95% CI [0.01, 0.17], $p = 0.020$). The preference ratings of both-storage desks did not significantly differ based on the presence or absence of the remaining two elements: cabinet (cabinet not present: EP = 0.16, 95% CI [0.03, 0.28]; cabinet present: EP = 0.18, 95% CI [0.04, 0.31]; difference = −0.02, 95% CI [−0.08, 0.04], $p = 0.501$) and drawers (drawers not present: EP = 0.16, 95% CI [0.03, 0.28]; drawers present: EP = 0.18, 95% CI [0.04, 0.31]; difference = −0.02, 95% CI [−0.08, 0.04], $p = 0.553$).

2.2.4.2 *The role of desk elements within both-stand desks*

The model examining the role of specific desk elements in preference within both-stand desks is available in Table S11. Post-hoc analysis indicates that the desks containing the board element (EP = 0.62, 95% CI [0.48, 0.75]) were similarly likely to be rated as liked as desks containing the square element (EP = 0.57, 95% CI [0.43, 0.70]; board − square = 0.05, 95% CI [−0.08, 0.18], $p = 0.462$). The desks containing board or square elements were more likely to be rated as liked than the desks containing poles (EP = 0.37, 95% CI [0.24, 0.50]; board − poles = 0.25, 95% CI [0.12, 0.38], $p < 0.001$; poles − square = −0.20, 95% CI [−0.33, −0.07], $p = 0.003$).

2.2.4.3 *The role of desk elements within one-stand-one-storage desks*

The model examining the role of specific desk elements in preference within one-stand-one-storage desks is available in Table S12. Post-hoc analysis reveals that the desks containing the board element (EP = 0.66, 95% CI [0.56, 0.75]) were more likely to be rated as liked than the desks containing the square element (EP = 0.57, 95% CI [0.47, 0.67]; board − square = 0.08, 95% CI [0.01, 0.16], $p = 0.030$). The desks containing board or square elements were more likely to be rated as liked than desks containing poles (EP = 0.44, 95% CI [0.34, 0.54]; board − poles = 0.21, 95% CI [0.14, 0.29], $p < 0.001$; poles − square = −0.13, 95% CI [−0.21, −0.06], $p < 0.001$).

The desks containing cabinet (EP = 0.59, 95% CI [0.49, 0.68]) and drawers (EP = 0.57, 95% CI [0.48, 0.67]) were similarly likely to be rated as liked (cabinet − drawers = 0.01, 95% CI [−0.06, 0.08], $p = 0.728$), whereas the desks containing the shelf (EP = 0.51, 95% CI [0.41, 0.61]) were somewhat less likely to be rated as liked but the differences were not statistically significant (cabinet − shelf = 0.07, 95% CI [0.00, 0.13], $p = 0.053$; drawers − shelf = 0.06, 95% CI [−0.01, 0.13], $p = 0.113$).

2.3 *Discussion*

2.3.1 *Preference for wooden materials*

The findings suggest that people's preferences for wooden desk materials vary significantly and that no individual material can satisfy most tastes. However, some materials, especially oak and maple, were favoured more often, and other materials, such as aspen, pine, or spruce, were liked less than others. There were no obvious overall relationships between the colour and preference ratings of materials once the three lowest rated materials were excluded. Interestingly, these three materials were lighter in colour, which partially contrasts with the findings by Fujisaki et al. [27], who observed that people evaluating the aesthetics of wooden materials not intended for any particular use preferred materials with a lighter colour. Perhaps participants in our study associated very light colour with wooden materials commonly used in construction (e.g., spruce), which they did not consider particularly suitable for use in furniture, such as desks. It should be emphasized, however, that outside of the three lowest rated materials, there was no trend indicating that darker materials were generally preferred, as was the case in the study by Lipovac et al. [26], which examined preference for outdoor table top materials.

Interestingly, in the same study by Lipovac et al. [26], materials made of oak—the material among the most preferred in our study—were associated with lower preference, and materials made of pine, radiata pine, and spruce—the materials among the least preferred in our study—tended to be more preferred (although the trend was not statistically significant).

These patterns of results suggest the preferences of people for different wood species and colours importantly depend on the context of wood use. Future studies can build on these results and systematically vary certain aspects of wooden materials (e.g., colour hue, intensity of the grain pattern, etc.) to identify the most important aesthetic qualities of wood in different contexts of use.

2.3.2 *Preference for desk designs*

Both-storage desks were less preferred than both-stand desks and one-stand-one-storage desks, with no significant differences between the latter two. The shelf element was clearly associated with lower preference within both-storage desks and showed a tendency towards being associated with lower preference within one-stand-one-storage desks. The remaining two storage elements—cabinet and drawers—were not significantly associated with preference within either group (i.e., both-storage, one-stand-one-storage) of desks. The poles element was associated with lower preference both within both-stand desks and one-stand-one-storage desks, whereas the board element was associated with higher preference ratings than the square element within the one-stand-one-storage of desks but not within the both-stand desks.

This is the first study we are aware of that examined human preference for the aesthetics of desk designs. The findings suggest that desks with certain desk elements and their arrangements are on average more preferred than others. Future studies should build on these results, to advance our understanding of desk elements and their arrangements that have the potential to appeal to the greatest number of people.

3. Study 2

3.1 *Materials and methods*

3.1.1 *Desks with different designs and types and amounts of wood*

From the results of Study 1, we extracted the three highest rated wooden materials and the three highest rated desk designs (according to the mean preference ratings). The mean preference ratings of square-drawers and board-board desk designs were tied in the 3^{rd} place in Study 1; the tie was resolved by selecting the material with the lower SD for further study in Study 2. Based on the highest rated wooden materials and desk designs, we created new images of desks that combine and systematically vary different wooden materials, desk designs, and amounts of wood coverage. Specifically, each of the three desk designs was prepared in one of three options of wood coverage (i.e., no wood—white, medium amount of wood, all wood) using each of the three highest rated wooden materials. This resulted in 21 new desks (Figure S5).

The details of specific desk designs were based on the desk designs identified in the websites of online vendors (section 2.1.2): 1) the square legs remained non-wooden even in the “all wood” condition, as they are typically made of metal; 2) in the “medium amount of wood” condition, wood was applied to desk parts to which it is normally applied when the desk includes some wood but is not fully wooden (many desks in this condition contain more wood than implied with the term “medium”).

3.1.2 *Survey*

The Study 2 survey was similar to the second part of the Study 1 survey (preference for desk designs; see section 2.1.3 for a detailed description). The respondents were presented with 21 desk designs and asked "How do you like the appearance of the desk in the image?", to which they responded with the 7-point rating scale used in Study 1. The Study 2 survey ran between September and November of 2021, and respondents needed about five minutes to complete the survey. The procedure, languages, online survey platform, and other characteristics of the survey were otherwise the same as in Study 1 survey.

3.1.3 *Participants*

Eighty people completed the Study 2 survey. Eight participants were below the age of 25 (10%), 51 (64%) were between 25-44, 20 were above 44 (25%), and one person (1%) did not wish to disclose their age. Forty-three participants were female (54%), 33 were male (41%), two identified as non-binary (3%), and two (3%) did not wish to disclose their gender. Education or work were unrelated to wood or design in 56 respondents (70%), related to wood in 21 respondents (26%), and related to design in 3 respondents (4%).

3.1.4 *Statistical analysis*

The statistical analysis was similar to the analysis of the second part of the Study 1 results (preference for desk designs; see section 2.1.5 for a detailed description). We first fitted a cumulative link mixed model with all 21 desks as predictors and the preference rating as the outcome, which showed us how the desks compare to each other in terms of preference. We continued with the model that contained desk design and material as predictors of preference. Finally, we fitted a model that in addition to the latter two predictors included the wood amount as predictor. This model was fitted to the subset of data—within desks that have at least some wood (i.e., are not white). The main models (those fitted on all data instead of subsets of data) did not include demographic variables as predictors, as the models with demographic variables did not significantly differ from the simpler models without them. As in Study 1, the results of post-hoc comparisons are reported as EPs, and for models that have more than one factor as predictor, the EPs are averaged over the levels of other factors.

3.2 ***Results***

3.2.1 *Preference for desks*

The desks received a relatively wide range of mean preference ratings – from slightly above 3 ("somewhat dislike") to slightly below 5 ("somewhat like") (Figure 4). The highest rated desks are board-drawers made with oak, board-drawers made with maple, board-cabinet made with oak, and board-cabinet made with maple (all four desks completely made of wood) with the mean preference ratings 4.79 (SD = 1.69), 4.61 (SD = 1.57), 4.41 (SD = 1.70), and 4.40 (SD = 1.71), respectively. The lowest rated desks were square-drawers made of maple (all wood) and three desks made of guibourtia: board-drawers (medium amount of wood), square-drawers (all wood), and board-cabinet (medium amount of wood), with the mean preference ratings of 3.73 (SD = 1.55), 3.49 (SD = 1.48), 3.28 (SD = 1.58), 3.18 (SD = 1.52), respectively.

The variability of individual preference ratings within the desks was typically high and spanned throughout the entire range of possible ratings for all desks, with one desk—board-drawers made entirely of guibourtia—displaying even more variability in preference ratings than other desks.

The four highest rated desks are all made entirely of wood, and they all contain the board element. All three white desks are among the highest rated half of desks (i.e., top 11 desks), whereas all six desks made of guibourtia are among the lowest rated half of desks (i.e., bottom 10 desks).

The model with individual desks as predictors and preference rating as the outcome is presented in Table S13. Ninety-two comparisons of pairs of desks (out of the total of 210 comparisons) were statistically significant, mostly within pairs that included the two highest and five lowest rated desks but also within pairs that included other desks (Table S14).

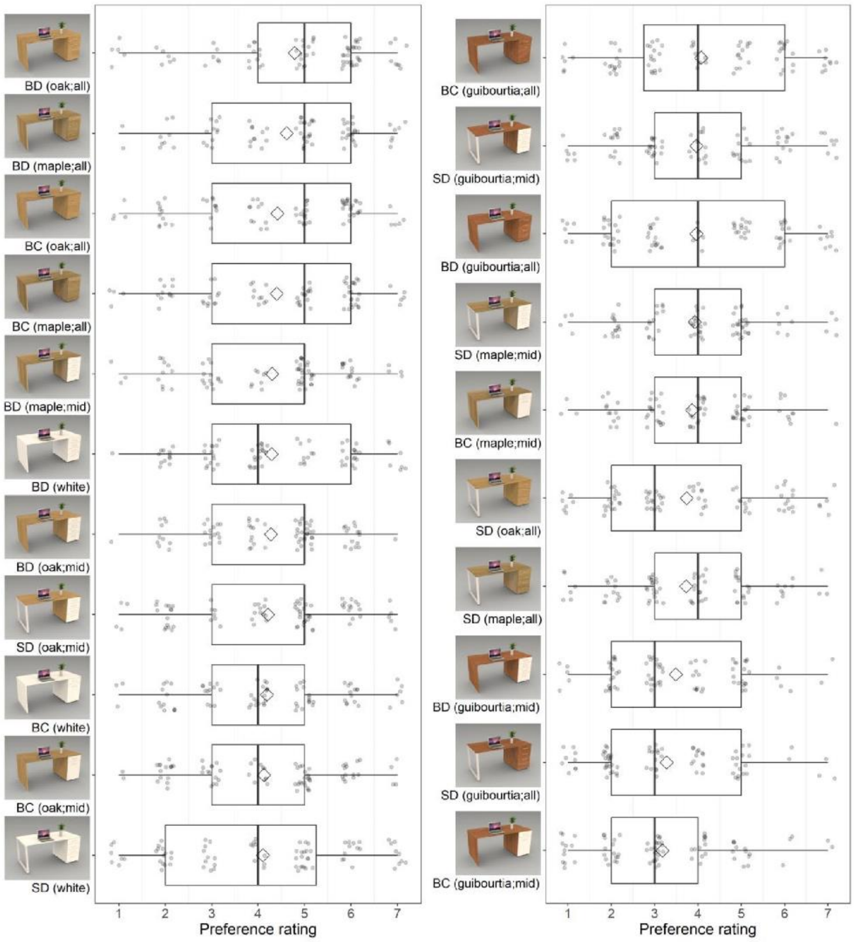

Figure 4: Preference ratings of desks (ordered from the highest to lowest mean preference rating, represented with the diamond shape). "BD" = board-drawers, "BC" = board-cabinet, "SD" = square-drawers; "Mid" = medium amount of wood, "All" = all wood

3.2.2 *The role of material and desk design in preference*

The model examining the role of desk design and material in preference is presented in Table S15. Post-hoc analysis of the role of materials in preference shows that maple (EP = 0.44, 95% CI [0.37, 0.51]), oak (EP = 0.48, 95% CI [0.40, 0.55]), and the white material (EP = 0.47, 95% CI [0.39, 0.55]) were similarly likely to be rated as liked, with no significant differences between them (maple – oak = −0.03, 95% CI [−0.09, 0.02], $p = 0.196$; maple – white = −0.02, 95% CI [−0.09, 0.04], $p = 0.477$; oak – white = 0.01, 95% CI [−0.05, 0.07], $p = 0.732$). Guibourtia (EP = 0.31, 95% CI [0.25, 0.38]) had a significantly lower probability of being rated as liked compared to all three remaining materials (guibourtia – maple = −0.13, 95% CI [−0.18, −0.08]; guibourtia – oak = −0.16, 95% CI [-0.21, -0.11]; guibourtia – white = −0.15, 95% CI [−0.21, −0.09]; all $p < 0.001$).

Post-hoc analysis of the role of desk design in preference shows that the board-drawers desks (EP = 0.48, 95% CI [0.41, 0.55]) were more likely to be rated as liked than the board-cabinet desks (EP = 0.42, 95% CI [0.35, 0.49]; board-cabinet – board-drawers = −0.06, 95% CI [−0.11, −0.01], $p = 0.012$), and both desk designs were more likely to be rated as liked than the square-drawers desks (EP = 0.37, 95% CI [0.30, 0.44]; board-drawers – square-drawers = 0.11, 95% CI [0.07, 0.16], $p < 0.001$; board-cabinet – square-drawers = 0.05, 95% CI [0.01, 0.10], $p = 0.027$).

3.2.3 *The role of wood amount in preference*

Table S16 presents the model examining the role of wood amount in respondent preferences. Post hoc analysis shows that desks made entirely of wood (EP = 0.44, 95% CI [0.37, 0.51]) were rated similarly as desks without any wood (EP = 0.47, 95% CI [0.39, 0.55]; all wood – no wood = −0.03, 95% CI [−0.09, 0.03], $p = 0.351$), and both types of desks had a higher probability of being liked than desks with a medium amount of wood (EP = 0.39, 95% CI [0.32, 0.45]; all wood – medium wood = 0.05, 95% CI [0.01, 0.10], $p = 0.011$; medium wood – no wood = −0.08, 95% CI [−0.14, 0.02], $p = 0.007$).

3.3 ***Discussion***

The highest rated desk design was board-drawers, followed by board-cabinet and square-drawers, with preference for each desk design differing significantly from the next. Maple, oak, and the white material were similarly liked, and they were all liked more than guibourtia. This somewhat contrasts with the results of two other studies which observed that wood tends be more appealing to people than some other common materials when used for desk tops [23] and handrails [28]. In these two studies, participants were able to see and touch the materials, and the tactile experience may have contributed to the generally high preference for wooden materials. This could explain the somewhat diverging findings between these studies and the current study, in which participants could only see the images of the materials. Another explanation may be that preferences for materials are context specific. That is, people may prefer wood in some situations or for some products, but are ambivalent or prefer other materials in different uses.

The desks made entirely of wood were rated similarly as desks without any wood, and both types of desks were preferred to desks with a medium amount of wood (i.e., desks with mixed materials). The preference for wood coverage could thus be different for desks than for rooms, where the opposite trend was observed: a medium amount of wood in a room seem to be preferred to a room furnished without any wood (i.e., white room) and a room made entirely of wood [30]. Alternatively, users may have preferred those desks less due to the specific way the materials were mixed, and not because of the specific amount of the material or the fact that the materials were mixed.

Because the rated desks are perfectly balanced in terms of features—they include all possible combinations of desk designs, wooden materials, and amounts of wood—we can easily compare the roles of the different features in preference of desks. The highest rated desk design (i.e., board-drawers) increased the probability of the desk being liked by about 11% in reference to the lowest rated design (i.e., square-drawers), whereas the presence of guibourtia decreased the probability for the desk being rated as liked by about 13-16% in reference to the three higher rated materials. This suggests that the material may have a slightly more important role in the overall evaluation of a desk than the desk design. It should be noted, however, that the desk designs in Study 2 were very similar; if they had differed substantially, their role may have been greater and more important than the role of materials.

The desks made entirely of wood were about 6% more likely to be rated as liked than desks with medium amount of wood. This suggests that the amount of wood has a noticeable role in preference but not necessarily as important as materials and desk designs. As we are not aware of any studies examining a similar topic, we cannot compare our results with existing findings. Future studies are encouraged to build on our findings by investigating human preference for desks consisting of different combinations of wooden materials and desk designs.

4. General discussion

The two studies reported in this article show that human preference for wooden materials and desks varies widely: any given material or desk tends to be (very) liked by some people and (very) disliked by others. Still, some wooden materials and desks are on average more preferred, and can serve as a starting point for both designers and researchers who wish to understand how interior spaces impact the occupants.

Comparing the results of Study 1 and Study 2 reveals an interesting pattern. The top three wooden materials and desk designs in Study 1 had very similar preference ratings; however, when the same wooden materials and desk designs were tested in Study 2, their preference ratings clearly differed. In Study 2, guibourtia was rated noticeably lower than oak and maple, and the top three rated designs all received ratings that were significantly different from each other.

This pattern of results could be explained by possible differences in the use of the preference rating scale by participants in the two studies. Study 1 included numerous and diverse wooden materials and desk designs, and it is not surprising that the variability of their visual characteristics leads to variability in their preference scores. Because of this wide range of preferences, the rated items in Study 1 that were similar (but not the same) in terms of preference might have received the exact same rating, so the larger differences in preference could be properly captured by the scale. In contrast, Study 2 had fewer unique wooden materials and desk designs, which might have allowed participants to use the rating scale in a way that captured even the smaller differences in preference between the rated items (the differences that could not have surfaced in Study 1).

Another explanation for the pattern of results when comparing Study 1 and Study 2 is related to the presentation of wooden materials and desk designs, which differed between the two studies. In Study 1, participants rated a wooden material that would be used for a desk, whereas in Study 2, they rated a desk that implemented the material. The rated desk designs were all made of the same material in Study 1 but included different materials applied in different amounts in Study 2. The wooden materials and desk designs may interact so that the preference for a specific wooden material or desk design depends significantly on other properties of the desk in which the material or design is applied.

Taken together, the results of both studies suggest that despite the variability of preference ratings, 1) people can discriminate between a variety of (sometimes similar) wooden materials and desks in terms of preference, and 2) preference for a particular desk cannot necessarily be predicted from separate preference assessments of the desk design and wooden material that comprise that desk.

The findings of the two studies can be seen as initial steps towards designing furnishings that are part of restorative indoor environments—pleasant, comfortable spaces that can positively impact human wellbeing. Visually appealing furnishings are likely an important element of restorative indoor environments, and desks are among the furnishings that might be used frequently, especially in offices. Future studies can build on our findings to not only expand our understanding of preference for different desk features, but also to examine preference for other types of furnishings, and how different types of furnishings can be integrated into a coherent whole that occupants will find appealing.

5. Limitations

As we aimed to systematically vary desk elements and their arrangements in tested desks, the number of unique elements had to remain small to keep the total number of desks manageable for the study. As a result, the resulting desks are relatively simple in terms of design. We did not consider many desk design features that might influence human preference, such as material thickness, height-to-width ratio, and type of handles.

Because the appearance of the tested wooden materials varied widely, any notable patterns between wood colour properties and preference were unlikely to emerge (and did not).

Another limitation is related to the presentation of the rated items: the wooden materials and desk designs might have been perceived differently if seen in person rather than in images. This might be especially true for the rendered images of desks made of different wooden materials, where the quality of the rendering (instead of the actual appearance of wood) may have influenced the results.

6. Summary and conclusions

The study examined preferences of people for different wooden desk materials, desk designs, and desks that combine different designs and materials. In general, the results show considerable variability in preference ratings, suggesting that no single material or desk can satisfy all tastes. Still, the results suggest that some wooden materials and desks are more liked than others, and that the material, design, and amount of wood all play an important role in preference. It seems that both-storage desks are less liked than both-stand and one-stand-one-storage desks, and that desks containing the shelf and poles elements are less liked than desks containing other elements (i.e., cabinet, drawers, square, board). Board-cabinet seems to be a particularly liked desk design. Some wooden materials, especially oak and maple, seem to be more liked than others, and some other materials, especially spruce, pine, and aspen, appear to be less liked than others. Desks with the white material were rated similarly to desks with oak and maple and liked more than desks with guibourtia. The preference for the desk seems to be higher when it is made entirely of wood or without any wood than when it is made with a medium amount of wood (i.e., when materials are mixed).

As furniture is a relatively easy way to introduce natural materials to built environments, using wood furniture for this purpose may make sense. Designers can take hints from our results, but they must be cautious to select or design furniture that matches the preferences of users, which we have shown vary considerably. Involving users in selecting their furniture may produce the best outcomes in terms of restorativeness.

We encourage future studies to systematically explore which indoor furnishings and features users prefer, and how the functional and design elements of the built environment are associated with the restorative qualities they can provide.

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2.4 Article 4

Title: Effect of desk materials on affective states and cognitive performance

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Effect of desk materials on affective states and cognitive performance

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Abstract

Visual and tactile properties of materials can influence human emotional and cognitive functioning. Existing studies indicate that exposure to wood may lead to more favourable outcomes than contact with other common materials, but evidence is limited. We measured affective states and cognitive performance in 16 participants before and after each spent 15 min at 10 desks with differing top surfaces. Desk surfaces were made of untreated, oiled, or lacquered spruce or oak solid wood, laminated or oak-veneered particleboard, glass, and mineral-filled thermoplastic composite. The results indicate that cognitive performance and affective states of participants did not differ between the desk surfaces. It appears that exposure to a relatively small wooden surface does not significantly influence affective and cognitive outcomes. Incorporating larger amounts of wood coverage and a more demanding cognitive task would probably increase the chances of capturing the potential effects of wood exposure on human affective states and cognitive performance.

Keywords: Wood, Materials, Emotion, Cognition, Attention

Introduction

An increasing body of evidence demonstrates that when people are exposed to natural environments or elements of nature, such as plants or water, certain indicators of human stress and well-being tend to improve, including affective states, cognitive performance, and physiological arousal [1]. These observations are typically explained through the stress reduction theory [2], emphasizing physiological and affective improvements in response to nature exposure, or/and attention restoration theory, highlighting restoration of cognitive capabilities [3, 4]. The findings in this field urge building designers to provide connection to nature in the built environment, where people spend most of their time [5]. Indeed, indoor nature exposure can be seen as a health-promoting framework [1].

Pleasant flower aromas, lush greenery, and water walls are some of the ways in which nature can be brought indoors. The modern built environment, however, does not only need to be a nature surrogate, but has to offer practical solutions, which cannot be directly constructed from most elements of nature. As a result, most elements of nature have limited capabilities of bringing indoor spaces closer to the natural environment.

In contrast, wood is a material that can be used in most indoor furnishings [6]. It is perceived as more natural than other common building materials and, accordingly, indoor spaces containing more wood are rated as more natural than their counterparts [6–8]. The current research inspects how humans can be affected through visual, tactile, and olfactory wood stimulation [9–11]. Of these, visual and tactile stimulation of wood might be easier to implement on a wider scale, as it seems challenging for indoor wood furnishings to provide long-term olfactory stimulation that is as intense as the one delivered in the experiments observing positive findings [12].

Altogether, not many studies have investigated the effects of tactile and visual exposure to wood. The existing findings demonstrate that touching wood can

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improve certain indicators of stress and well-being when compared to the effects of the tactile experience of other everyday materials, such as aluminium or marble [9, 13, 14]. These studies showed that certain indicators of physiological arousal decrease after a short tactile exposure to wood (typically 90 s). Other studies observed similar physiological outcomes when investigating visual wood exposure [15–17], while certain studies that combined visual and olfactory wood stimulation detected improved affective states in the wooden environment [18–20].

However, overall evidence for positive effects of tactile or visual wood exposure is limited, as it is not clear if the effects of wood exposure can extend beyond the initial brief period being observed in several existing studies. Additionally, it is not known if wood exposure, in the absence of olfactory stimulation, can influence not only (often ambiguous) physiological outcomes [21], but also other indicators of stress and well-being, such as affective states and cognitive performance.

Six studies were found that have investigated the effects of wood exposure on affective states [8, 18–20, 22, 23]. Five of these used the Profile of Mood States (POMS) measurement scale, which was devised to assess psychiatric outcomes and may be less sensitive to changes in affective states in different contexts [24], including in investigations of human responses to natural environments. In addition, due to its length (65 items in its original form), the questionnaire is less appropriate for repeated administrations typical in restoration studies, as it can encourage unvarying responses that can lead to misleading similarities in results between measurements [25]. A carefully chosen measure (fitting to the study context) can increase the chances of capturing potential changes in affective states [24].

We found only two studies that examined cognitive performance following the exposure to wood [16, 17]. One of these did not report the results due to issues with the nature of the employed task [17]. In the other study, which did not detect differences between the tested environments, cognitive performance was not assessed prior to exposure to the experimental settings [16]. This excludes the possibility of detecting baseline differences in performance and it does not induce cognitive fatigue that might be important in finding differences in restoration between environments [26, 27]. In addition, the type of the deployed task and the length and timing of its administration can be decisive in detecting restoration of cognitive performance [26–28]. These observations indicate that greater attention is needed in selecting and administering cognitive tasks in restoration research.

In addition to knowledge gaps related to affective states and cognitive performance, it is not clear if and how different wooden materials influence indicators of well-being. The existing studies incorporated various wood types, colours, and species, from birch wood-veneered furniture [16] to oak and walnut-veneered furniture [17] and spruce and fir solid wood [18]. These studies typically compared the effects of a wooden versus a control material, but not different wooden materials with each other. As visual and tactile properties of wood differ between wood species and treatments as well as between solid and processed wood, different wooden materials might lead to diverse human responses.

The scarcity of research and the specific methodological approaches identified in many existing studies lead to several gaps in knowledge that we investigated in the present study. The objective of the study was to investigate the effects of tactile and visual exposure to (untreated and treated) wood, glass, and mineral-filled thermoplastic composite (MFTC) desk materials on cognitive performance and affective states, while incorporating a fitting measure of affective states and including an assessment of cognitive performance prior to the subjects' exposure to the experimental settings.

We hypothesized that (1) wooden materials compared to the non-wooden materials and (2) untreated wooden materials compared to treated wooden materials will:

a. Influence affective states
    1. Increase the pleasure dimension.
    2. Decrease the arousal dimension.
b. Improve cognitive performance
    3. Increase the proportion of correct answers on the cognitive task.
    4. Decrease the mean response time in correct answers.
    5. Decrease the differences in mean response time between congruent and incongruent task trials (Simon effect).

Materials and methods

Participants

A convenience sample of 16 volunteer subjects (mean = 25.88 years, standard deviation (SD) = 3.98 years; 10 women) participated in the study. Subjects belonged to the social network of the first two authors. They were eligible to participate in the study if they did not present with health issues or other characteristics that would make completing the study tasks difficult (e.g. very poor vision). A large majority of the invited people agreed to participate in the study; the refusals were generally related to the lack of time. In general, participants were not expected to possess in-depth knowledge on materials that could substantially influence the results, even though that the educational background of two participants included wood science. Subjects did not receive any compensations for participating in the study. Before the experiment, participants signed an approved informed consent waiver that provided them information about study purpose and procedure, participant rights, and data management. The study protocol and testing procedures (ClinicalTrials.gov identifier: NCT03733366) were approved by the National Medical Ethics Committee of Slovenia (No. 0120-631/2017/2) and the research was carried out in compliance with the Oviedo convention.

Sample size and power

Statistical power for Friedman tests was computed by calculating the power of repeated measures analysis of variance and transforming the resulting value [29]; the study was underpowered ($1-\beta$ (type II error probability)=0.52, effect size: Cohen's $f=0.8$). Statistical power for Wilcoxon tests was calculated empirically using Monte Carlo simulation [30]. The empirical power of these tests is 0.88 with a large effect size (Cohen's $f=0.8$). The effect size in this power calculation indicates the probability that $X<Y$, where X and Y are random observations from the compared data. When testing a location shift hypothesis, the null hypothesis is an effect size of 0.5 and effect size increases as the probability approaches 0 and 1 [30].

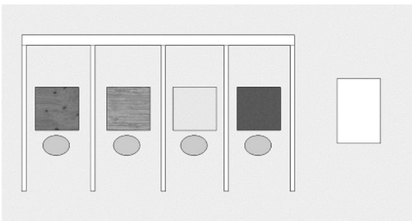

Fig. 1 Layout of the test setting with control (right) and test desks (left)

Test setting

The experiment was performed at the kinesiology and ergonomics laboratory of the University of Primorska in Izola, Slovenia. The layout of the test setting is presented in Fig. 1. Four desk frames were prepared from solid spruce wood and were positioned close to a white wall (participants were seated to face the wall). White drapes were put in between the desk frames, so the subjects participating in the experiment simultaneously could not see each other. Next to them was a control desk (80 × 120 cm) that was covered with a plain white tablecloth and had no chairs (participants were standing). The control desk was not divided in sections and when many simultaneous sessions were running, participants were able to see each other. The indoor temperature and relative humidity were measured several times per day; the mean values were 23.58 °C (SD = 0.69) and 37.40% (SD = 7.05), respectively. The experiment took place in November and December 2018. Most of the testing was conducted in first half of the day during weekdays, but sessions were sometimes executed later in the day and on weekends.

Desk materials

Desk surfaces were prepared from 10 different materials (with dimensions 80 × 80 cm; thickness varied by material), listed in Table 1 and presented in Additional file 1: Figures S1 to S9. Eight surfaces were manufactured from wood; six from solid wood (and were either untreated,

Table 1 Desk materials used in the study

Material	Surface treatment	Material thickness
Spruce	Untreated	2 cm
Spruce	Oil	2 cm
Spruce	Lacquer	2 cm
Oak	Untreated	2 cm
Oak	Oil	2 cm
Oak	Lacquer	2 cm
Oak (veneer)	Untreated	2 cm
Imitation wood laminate	–	2 cm
Glass (on laminate)	–	1.5 cm (glass) + 0.5 cm (laminate)
MFTC	–	0.8 cm (MFTC) + 1.2 cm (particleboard)

oiled, or lacquered) and two were wood composites. The two non-wood materials were glass and a commercially available MFTC (Kerrock®). An example is presented in Fig. 2.

Measures of affective states, cognitive performance, and material assessment

Subjects completed an affective state assessment and a cognitive performance task that were presented with Tatool, an open-source test platform [31]. After an introduction to the experiment, the test procedure was automated, including breaks and instructions.

Pleasure and arousal single-item scales

Affective states were examined with two single-item scales assessing the states of pleasure and arousal [32]. As it is not clear which specific affective states can be induced by wood exposure, including any specific measure increases the chances of not detecting other affective changes [33]. For this reason, we used the scales capturing the broad state of core affect—simplest consciously accessible feelings [33]. In addition, the testing with the single-item scales is brief and thus especially useful when many assessments are carried out in a short period of time [32], as is the case in our protocol. Despite the brevity, these measures have proven to be reliable and valid [32, 34]. The two administered items asked: "How pleasant/activated do you feel at this moment?". Participants provided answers on a 9-point Likert-type scale (1 = especially unpleasant/inactivated, 5 = neutral, 9 = especially pleasant/activated).

Simon task

Cognitive performance was assessed with the Simon task that captures inhibitory control—the ability to override the urge to an internal predisposition or an external lure [35, 36]. We based our task selection on the findings of a recent review demonstrating that exposure to nature has been shown to restore this core executive function [26]. In the task, a circle appeared on either the left or the right side of the screen. Participants were instructed to press the left arrow key when the circle was green and the right arrow key when the circle was red, regardless of the circle location on the screen. In approximately half of the trials, the location of the circle and the correct response key were congruent (e.g. a red circle appeared on the right) and in the other half they were incongruent. Each session consisted of 100 trials, taking about 90–120 s to complete.

Fig. 2 Desks with top surfaces made of MFTC (left) and oak (right)

Subjective assessment of materials

At each desk, subjects completed a short writing task and answered four questions examining their perception of a material. Results of the subjective assessment are not reported in this article.

Arm and material temperature

Arm and material temperatures were measured as part of the protocol using a non-invasive thermal camera. The results of the temperature measurement are not reported here.

Experimental procedure

The experimental (within-subject) procedure is outlined in Fig. 3. Before the first session, the necessary instructions and explanations were given to the subjects. It was explained to them how to rate the affective states (arousal and pleasure) and they completed a short demo of the cognitive task (Simon task). The instructions were also available in the computerized testing during all sessions. In addition, subjects were instructed not to communicate with each other at any stage of the experimental session and to abstain from caffeinated beverages prior to the testing.

The participants started with the baseline period, where they were brought to a control desk. They rested for 1 min in silence before completing the cognitive task and reporting affective states (CTAS; measurement time "Pre"), to minimize any influences of the previous interaction with the researcher(s). Subjects were instructed to keep their gaze at the desk surface during all rest periods throughout the experiment.

After the baseline period, participants began with the experimental part of the study, where they sat at a desk made of one out of 10 desk surface materials (the order was randomized). Before completing CTAS for the second time (measurement time "Start"), they again rested for 1 min, (1) to enable dissipation of any temporary influences resulting from the relocation from the baseline period and (2) to enable subjects to gaze at the desk surface.

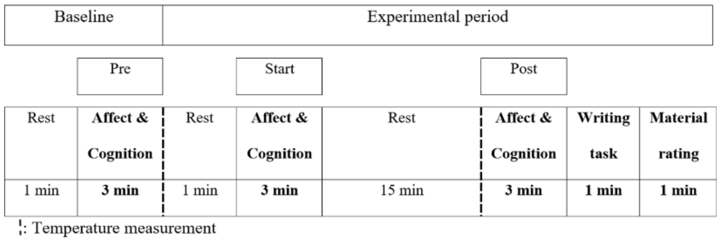

Fig. 3 Experimental procedure

After this, participants rested for 15 min while keeping their bare arms immobile and flat on the desk and their gaze directed to the desk surface. After the rest period, subjects completed CTAS for the third and last time (measurement time "Post"). Participants then completed the short hand writing task and answered the four questions on subjective assessment of the material.

Subjects repeated the entire session 10 times, once for each desk material. They took 15-min breaks between sessions, when more than one was conducted in the same day. Up to five sessions per day were planned.

Statistical analysis

The data were processed and analysed in R 3.6.1 [37] using R Studio 1.2.1335 [38] with the packages dplyr [39], ggplot2 [40], rstatix [41], rcompanion [42], wmwpow [43], and WebPower [44]. Data from the entire sample of 16 participants were available and analysed in all results presented below. There were no missing values, as the computerized testing tool did not allow progressing through tasks without providing a response.

The assumptions of parametric tests were not met for any of the analysed outcomes, so we calculated bootstrapped medians and percentile confidence intervals to report observed values and their spread. We used nonparametric tests throughout the analysis.

To compare subjective assessment ratings between materials and examine differences between materials regarding changes in affective states and cognitive performance, we conducted Friedman tests that test for the difference between paired observations on ranked data. Separate Friedman tests were conducted for each subjective assessment item as a dependent variable and material as an independent variable. Similarly, separate Friedman tests comparing change scores (the difference in scores between two measurement times) between materials were conducted individually for each affective state and cognitive performance outcome, with the change score as the dependent variable and material as the independent variable. p values in Friedman tests were adjusted with the Bonferroni correction.

To investigate changes in affective states and cognitive performance between study parts across all materials, we performed one-sample Wilcoxon signed rank tests that test for the difference between the observed values and a theoretical value, by comparing the ranks of the computed differences. Unless noted otherwise, p values in multiple comparisons were adjusted with the Bonferroni correction. The significance threshold was set at 0.05; reported effect sizes are on the measurement scale.

Results

In most cases more than one subject participated in the study simultaneously (up to four). It generally took four visits (i.e. over a period of 4 days) for each participant to complete the study for all 10 desk materials; typically, less than a week passed between visits.

Affective states

Results on pleasure and arousal dimension across all materials are presented in Fig. 4 and Additional file 1: Table S1. The subjects generally reported feelings that were around the middle (or slightly higher) of the arousal and pleasure continuum.

Change scores (the difference in scores between two study parts) across materials in both affect dimensions were computed with Wilcoxon signed rank test and are presented in Table 2. Neither affective dimension significantly changed from the Pre to the Start period. In contrast, both arousal and pleasure scores decreased in the Post period when compared to either of the first two phases; the scores were approximately one point lower (on the 9-point scale) in the Post measurement time compared to the values taken in the Start and Pre phase.

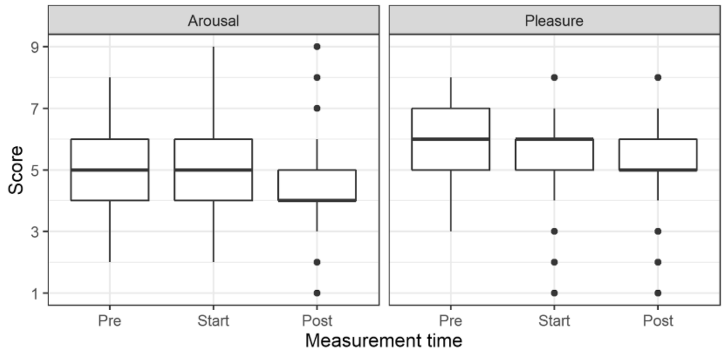

Fig. 4 Arousal and pleasure scores across all materials

Table 2 Changes in arousal and pleasure scores across study parts (all materials combined)—results of the Wilcoxon signed rank test

Affect dimension	Change period	*V*	Pseudomedian	95% CI	*p*
Pleasure	Start–Pre	1057	0.000	− 0.000 to 0.000	1
	Post–Pre	1121	− 1.000	− 1.000 to − 0.000	< 0.001***
	Post–Start	737.5	− 1.000	− 1.000 to − 0.500	< 0.001***
Arousal	Start–Pre	982.0	− 0.000	− 1.000 to 0.000	0.438
	Post–Pre	1238	− 1.000	− 1.500 to − 1.000	< 0.001***
	Post–Start	608.0	− 1.000	− 1.500 to − 1.000	< 0.001***

p-values are adjusted with the Bonferroni correction

V, *V*-statistic; CI, confidence interval. ***$p < 0.001$

The scores on both affective dimensions grouped by materials are displayed in Fig. 5 and Additional file 1: Tables S2 and S3. The results of Friedman tests comparing change scores in arousal and pleasure ratings between materials are presented in Table 3. There were no statistically significant results; neither arousal nor pleasure change scores differed between materials.

Cognitive performance

Three outcomes of the Simon task were analysed: (1) proportion of correct answers, (2) mean response time on correct answers, and (3) Simon effect, the difference in mean response time between correct answers on incongruent trials and correct answers on congruent trials (higher values generally suggest lower cognitive inhibition). The results across all materials are presented in Fig. 6 and Additional file 1: Table S4. Typically, subjects responded correctly to more than 90% of the trials, their mean response time in correct answers was around 400 ms, and the Simon effect was usually between 20 and 30 ms.

Change scores in the three Simon task outcomes computed with Wilcoxon signed rank test (across all materials) are presented in Table 4. The proportion of correct answers in the Simon task was higher in the Start period when compared to the Pre period by approximately one percentage point, while no differences were detected between other study parts. Differences in the other two Simon task outcomes between study parts were not detected.

The scores on the Simon task outcomes grouped by materials are presented in Fig. 7 and Additional file 1: Tables S5–S7. The results of Friedman tests comparing change scores in Simon task outcomes are presented in Table 5. No statistically significant differences were detected; change scores did not differ between materials.

Discussion

The results did not support our first group of hypotheses; affective states did not differ between wooden and non-wooden desks. When pooled data were inspected (combining all materials), neither arousal nor pleasure

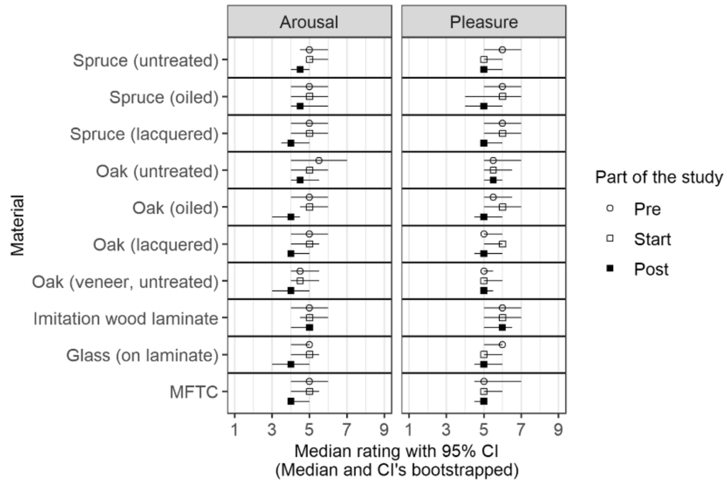

Fig. 5 Arousal and pleasure scores grouped by materials and measurement time

Table 3 Changes in arousal and pleasure across measurement times with material as a dependent variable—results of the Friedman tests

Affect dimension	Change period	df	χ^2	Kendall's *W*	*p*
Pleasure	Start–Pre	9	15.54	0.108	0.232
	Post–Pre	9	5.033	0.035	1
	Post–Start	9	6.899	0.048	1
Arousal	Start–Pre	9	2.322	0.016	1
	Post–Pre	9	5.762	0.040	1
	Post–Start	9	5.163	0.036	1

p-values are adjusted with the Bonferroni correction

df, degrees of freedom, χ^2, Chi-square value

significantly changed from the Pre to the Start period, but ratings on both dimensions were lower in the Post sessions. These scores suggest that participants were experiencing more feelings such as sleepiness, tiredness, or boredom in the last stage of the experiment. It should be pointed out, however, that the differences in affective state scores were small; overall, the arousal and pleasure states of participants were relatively similar in Pre, Start, and Post measurement times. This lack of substantial differences is not surprising, given that participants rested for only a short period of time while being relatively unstimulated. The reason that we were able to detect these small changes might have been related to using two single-item (arousal and pleasure) scales instead of often used longer questionnaires that can be less sensitive in restoration studies (e.g. POMS). For example, a recent study from Demattè and colleagues [18] administered Positive and Negative Affect Schedule (PANAS) before and after the exposure to a wooden setting and did not detect any changes between the measurements, despite the study's large sample (102 participants), relatively large amount of wood coverage, and the presence of olfactory stimulation. While it is possible that the subjects' affective states did not significantly change between the measurements, it could be that PANAS, consisting of many items capturing specific affective phenomena, might have missed broad and subtle changes that could have been detected with measures of core affect, including the one used in this study. Such measures may be more sensitive in detecting changes with small effect sizes that can have large effects in practice, due to small, seemingly insignificant effects compounding over time.

The observed trend of decreasing arousal and pleasure did not differ between materials—wooden materials did not seem to influence the affective states, as we expected. Similar results were observed in the two studies by Tsunetsugu et al. [8, 22], where differences in affective states were not detected between the test settings differing in the amount of incorporated wood. However, certain studies did detect an effect of wood exposure on affective states. Compared to the present

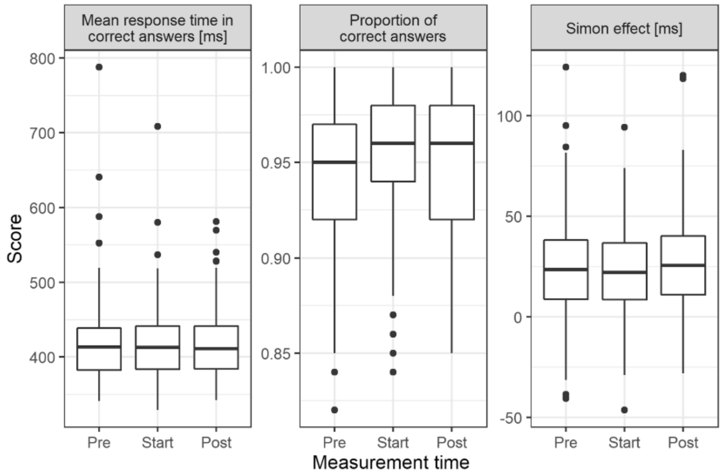

Fig. 6 Simon task outcomes across all materials

Table 4 Changes in Simon task outcomes across study parts (all materials combined)—results of Wilcoxon signed rank test

Simon task	Change period	*V*	Pseudomedian	95% CI	*p*
Proportion of correct answers	Start–Pre	5931	0.010	0.005 to 0.015	< 0.001***
	Post–Pre	5034	0.005	− 0.000 to 0.010	0.141
	Post–Start	3872	− 0.005	− 0.010 to − 0.000	0.107
Mean response time on correct answers (ms)	Start–Pre	6187	− 0.785	− 4.435 to 2.785	1
	Post–Pre	6619	0.667	− 3.140 to 4.470	1
	Post–Start	7126	1.985	− 1.355 to 5.305	0.730
Simon effect (ms)	Start–Pre	5852	− 2.085	− 6.190 to 2.055	0.951
	Post–Pre	7143	2.965	− 1.975 to 7.980	0.693
	Post–Start	7123	2.810	− 1.805 to 7.735	0.736

p-values are adjusted with the Bonferroni correction

V, *V*-statistic; CI, confidence interval, ***$p < 0.001$

study, these incorporated a larger amount of wood in their test environments [20] and those who used solid wood also had detectable levels of wood scents in the air [18, 19]. Other studies that observed lowered physiological arousal in the wooden settings similarly incorporated a relatively large amount of wood in their test settings (without olfactory stimulation). Although these studies did not directly measure affective states, lower physiological arousal (when considered a marker of lower stress levels) would likely be reflected in changes in affective phenomena [21, 45, 46]. Interestingly, in both studies decreased physiological arousal was observed early in the study and it did not seem to depend on the exposure time, nor was it evident only after the stress-inducing activity.

Put together, these results suggest that the amount of wood coverage might be one of the prime suspects for the diverging results of the present study and other findings. Indeed, according to stress reduction theory and attention restoration theory, environments that are generally richer in natural stimuli are more to likely to benefit humans [2, 4]. Perhaps the small desk surface was not stimulating enough to generate these benefits, despite participants being instructed to keep their gaze

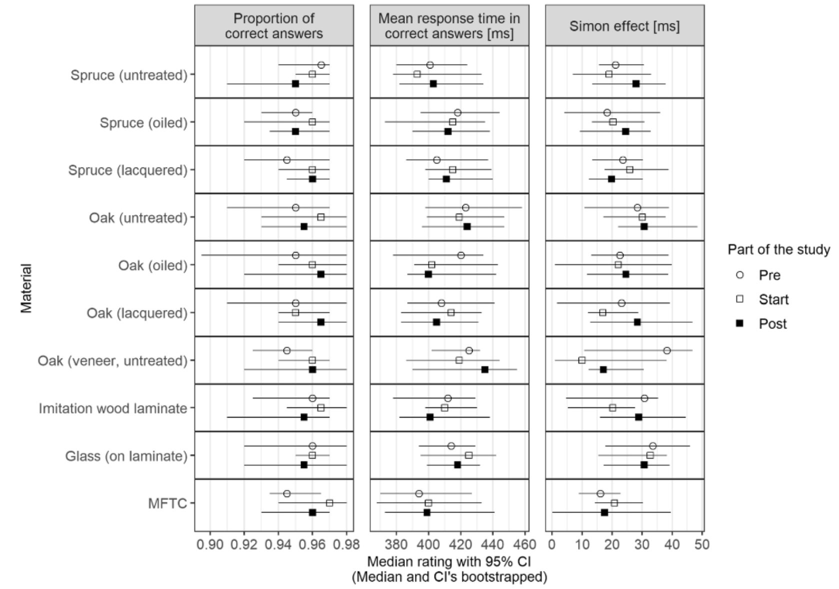

Fig. 7 Simon task outcomes grouped by materials and measurement time

Table 5 Changes in Simon task outcomes across measurement times with material as a dependent variable—results of the Friedman tests

Simon task	Change period	df	χ^2	Kendall's *W*	*p*
Proportion of correct answers	Start–Pre	9	2.929	0.020	1
	Post–Pre	9	9.308	0.065	1
	Post–Start	9	8.912	0.062	1
Mean response time on correct answers	Start–Pre	9	13.39	0.093	0.437
	Post–Pre	9	6.709	0.047	1
	Post–Start	9	7.173	0.050	1
Simon effect	Start–Pre	9	6.600	0.046	1
	Post–Pre	9	9.055	0.063	1
	Post–Start	9	4.486	0.031	1

p-values are adjusted with the Bonferroni correction

df, degrees of freedom, χ^2, Chi-square value

at the material throughout the experiment. It is also possible that such less intense environmental stimulations might benefit people, but that these benefits would become apparent only during the recovery following an induction of stress or fatigue [26]. Exposure to a larger amount of wood coverage combined with a stress- or fatigue-inducing activity would likely increase the chances of detecting potential effects of wood exposure on human affective states.

The results were similarly not in line with our second group of hypotheses; we did not observe differences in cognitive performance between materials. Across all materials, there were no significant differences between the study periods in mean response time in correct answers or in the Simon effect; in contrast, the proportion of correct answers was higher in the Start period than in the Pre phase. Considering that the two cognitive task sessions were conducted with only a few min in between, perhaps the first session served as a training experience that improved the results on the second administration. Alternatively, the results could have improved due to other differences between the first and the second session; for example, due to the participants' change from the standing to the sitting position or due to fewer distractions that the subjects faced in the second session, as they were isolated from each other.

As was the case in the examination of affective states, we did not find any differences in cognitive performance between the tested desk materials. Only two existing studies tested the effects of wood exposure on cognitive performance; one did not report the results [17] and the other did not observe any differences between the wooden and non-wooden environment [16]. Despite our results being in line with the latter finding, they run counter to the findings observed in several other studies with somewhat similar research protocols, which mainly differ by incorporating other elements of nature instead of wood [1]. While wood may not exhibit attention enhancing properties similar to other elements of nature, it is also possible that other factors played a role.

In all wood exposure studies (including the present study) cognitive fatigue might not have been sufficiently induced. Attention restoration theory is specific to predict *restoration* from induced attention fatigue but not improvement in cognitive capabilities, if these are not fatigued prior to the exposure to natural environments. However, several studies found that exposure to nature improved cognitive performance even without prior induction of attention fatigue, suggesting that other mechanisms, such as changes in affective states, may be important [26]. Another reason for the absence of effects on cognitive performance may be related to the cognitive task we deployed. It has been proposed that cognitive tasks with certain properties are more likely to capture the differences in performance in attention restoration studies. Among other qualities, tasks should be high in cognitive demand, which may not have been the case in this study. Namely, the percentage of correct answers in the Simon task was often in the high nineties, with several sessions where all the answers were correct. Furthermore, the results generally improved on the second administration of the task, suggesting that the employed task was not sufficiently difficult to lead to attention fatigue after the first administration. Our findings urge future studies to employ tasks demanding enough to induce attention fatigue and to avoid the ceiling effect, where the range of the scores is restricted and prevents potential differences between the environments to occur.

Limitations

The sample size in the study was relatively small and the statistical power was too low for the study to reliably capture small and moderate effects that could be practically relevant. In addition, the study did not include any physiological measures that could capture important changes that would not necessarily be detected in either the measures of affective states or the tests of cognitive performance. Several confounders could have influenced the results that might not have been sufficiently controlled for, including the frequency of testing sessions, time and day of testing, and the potential effects of being without caffeine before and during the test.

Conclusions

The findings suggest that a brief visual and tactile exposure to a wooden small desk surface might not be enough to significantly improve human affective states and cognitive performance, even though the study tested a variety of materials and included a sensitive measure of affective states. To increase the chances of capturing potential effects, future studies should include a larger number of participants, increase the amount of wood coverage, and incorporate a cognitive task with different properties, including higher cognitive demands. Although the study did not observe positive outcomes following wood exposure, it is important for the research in this field to continue, as even small effects of wood stimulation could contribute to substantial real-life outcomes. Wood furnishings are relatively simple and inexpensive to implement on a wide-scale, while at the same time wood exposure does not depend on human effort and determination, as do many other psychosocial interventions addressing stress and well-being.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s10086-020-01890-3.

Additional file 1: Table S1. Arousal and pleasure scores across all desk materials. **Table S2.** Arousal scores across study parts for each desk material. **Table S3.** Pleasure scores across study parts for each desk material. **Table S4.** Simon task outcomes across all desk materials. **Table S5.** Proportion of correct answers in the Simon task across study parts for each desk material. **Table S6.** Mean response time [ms] on correct answers in the Simon task across study parts for each desk material. **Table S7.** Simon effect [ms] in the Simon task across study parts for each desk material. **Figure S1.** Engineered stone. **Figure S2.** Imitation wood laminate. **Figure S3.** Oak (lacquered). **Figure S4.** Oak (oiled). **Figure S5.** Oak (untreated). **Figure S6.** Oak (veneer, untreated). **Figure S7.** Spruce (lacquered). **Figure S8.** Spruce (oiled). **Figure S9.** Spruce (untreated).

Abbreviations

CTAS: Cognitive task and (reporting) affective states; MFTC: Mineral-filled thermoplastic composite; POMS: Profile of Mood States; SD: Standard deviation.

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Authors' contributions

All authors contributed to preparing the research protocol. DL and NP collected the data; DL and MB analysed the data. DL prepared a large part of the article content with major contributions from MB and significant contributions from NŠ. All authors read and approved the final manuscript.

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Availability of data and materials
All data generated or analysed during this study are included in this published article and its supplementary information files.

Ethics approval and consent to participate
The study protocol and testing procedures (ClinicalTrials.gov identifier: NCT03733366) were approved by the National Medical Ethics Committee of Slovenia (No. 0120-631/2017/2) and the research was carried out in compliance with the Oviedo convention. Participants signed an approved informed consent waiver that provided them information about study purpose and procedure, participant rights, and data management.

Consent for publication
Participants agreed the collected data can be used for research purposes, including publishing.

Competing interests
The authors declare that they have no competing interests.

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Publisher's Note

2.5 Article 5

Title: A pilot study examining the suitability of the Mental Arithmetic Task and single-item measures of affective states to assess affective, physiological, and attention restoration at a wooden desk

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A pilot study examining the suitability of the mental arithmetic task and single-item measures of affective states to assess affective, physiological, and attention restoration at a wooden desk

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Abstract

People seem to function and feel better in indoor natural environments, including spaces furnished with wood. When restorative effects of indoor spaces are not detected, suboptimal methodological approaches may be responsible, including stress-inducing activities and measures of affective states and cognitive performance. Our primary objectives were to test (1) whether the Mental Arithmetic Task (MAT) can reliably induce stress and measure cognitive performance, and (2) whether two single-item measures of pleasure and arousal can detect changes in affective states in restoration research. Our secondary objective was to examine whether stress recovery and cognitive performance differ between indoor settings furnished with or without wood. Twenty-two participants, allocated to a space furnished with either a wooden or a white desktop, completed MAT twice, while their electrodermal and cardiovascular activity and affective states were monitored. Participants on average responded to MAT with increased subjective arousal but unchanged subjective pleasure, and with increased physiological arousal on some but not all parameters, suggesting that MAT was effortful but not necessarily stressful. Scores on MAT improved at the 2nd administration, suggesting that MAT did not induce cognitive fatigue at the 1st administration and that its role as a cognitive task in restoration research may be limited. The items assessing affective states performed well. The measured outcomes did not differ between the wooden and non-wooden setting, suggesting that substantial restorative effects of a wooden desktop are unlikely, and that higher wood coverage is needed to increase the chances of observing restorative effects.

Keywords: Restorative environments, Indoor nature, Human stress, Cognitive performance

Introduction

A large body of evidence suggests that people feel and perform better after spending time in natural, restorative environments [1–4]. These observations are usually explained with the stress reduction theory (SRT) [5], attention restoration theory (ART) [6, 7], or both. SRT claims that the positive outcomes following contact with nature result from the connections humans have developed with nature during the evolution of the species. According to SRT, pleasant, non-threatening natural environments elicit pleasant feelings, hold interest of people and reduce stressful thoughts, and decrease physiological arousal if the initial level is high [5]. ART focuses on the ability of nature to hold human interest: it claims that nature possess qualities that attract effortless attention of people, allowing their directed (effortful) attention to rest and replenish, as fatigued directed

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attention supposedly leads to stress and decreased cognitive performance [6].

In line with predictions of SRT and ART, several recent reviews observed that participants who spend time in a natural environment generally report improved affective states, exhibit lower physiological arousal [1–4], and perform better on cognitive tasks [8, 9]. However, not all studies observe positive effects following exposure to nature. In those cases, it is challenging to discern whether the tested environment does not lead to restoration or whether the restorative effects do exist but are not observed due to the particular study design and outcomes.

This is especially problematic in studies that test for presumably smaller effects of exposure to nature in indoor spaces, where nature is present only indirectly or in smaller quantities, such as in spaces furnished with natural materials, like wood [10–12]. Indeed, while some studies observed promising effects of wooden indoor environments on occupants [13, 14], others detected no positive effects [15], or reported inconclusive results [16]. Future research should clarify whether (and in what contexts) wood impacts people positively, as bringing nature indoors can be a valuable intervention [17] because most people spend most of their time indoors [18].

Future studies examining effects of indoor nature exposure would benefit from clearer guidelines that would minimize the possibility to miss differences in restorative effects between tested environments due to the study protocol and outcomes, and thus maximize the chances to distinguish restorative from non-restorative environments. A typical study in the field measures some combination of affective states, physiological arousal, and cognitive performance before and after exposure to environments [17]. Researchers must select specific affective, physiological, and cognitive measures from numerous options and then decide when in the study protocol to administer those measures. If the selected measures and the timings of their implementation are inappropriate, results can be misleading. Researchers may incorrectly conclude that tested environments do not differ in terms of restorativeness, when, in fact, the particular study protocol and outcomes are responsible for the lack of observed differences.

One issue can arise from the selection of tools that capture affective states in restoration research. Some assessment tools seem to show higher effect sizes than others, in part presumably because natural environments likely elicit specific affective states that different tools capture to different extents [1]. Currently, however, we do not know which affective states are most reliably influenced by the natural environment [1]. Even tools such as Positive and Negative Affect Schedule (PANAS) [19], which show relatively high effect sizes [1], could be far from optimal in restoration research, as they capture specific affective states (such as "guilty" and "proud") that may not be reliably influenced by exposure to nature. PANAS and other commonly used measures also tend to be long (e.g., PANAS contains 20 items), which makes them less suitable for frequent administration and thus more likely to miss changes of affective states in longer exposures to (restorative) environments. Assessment tools based on dimensional approach—an approach describing all affective states on a set of selected dimensions (e.g., pleasure and arousal) [20, 21]—have been underused in restoration research [1]. These assessment tools are recommended in conditions that often characterize restoration studies: (1) when based on the current theory it cannot be anticipated how manipulations will impact affect [22], and (2) when subjects are required to report affective states on several occasions of a study [21].

Another opportunity for misleading results occurs when viewing lower physiological arousal as a positive outcome without additional information [12]. According to SRT, pleasant natural environments can either not influence, decrease, or increase arousal, depending on the initial arousal level [5]. In addition, physiological arousal can reflect states other than stress, including digestion, effort, and attention [23]; and, importantly, both pleasant and unpleasant states can be reflected in either higher or lower physiological arousal [24, 25]; for example, high arousal can indicate vigor [26] and low arousal can signal fatigue [27]. These observations suggest that measures of physiological arousal should be corroborated by measures of affective states, and that a stress-inducing activity should be included so the higher physiological arousal can be more easily attributed to an unpleasant state, such as fear, instead of a pleasant state, such as excitement [28]. Despite the importance of assessing affective states and inducing stress, a recent review of 43 studies reported that only about two-thirds of the studies in the field used a self-report measure and only one in ten studies experimentally induced stress in participants [2].

Including a stressful activity is important, but not all stressors are equally effective. Some approaches, such as exposing people to noise or inducing specific emotions with videos, do not lead to reliable increases in stress (as reflected in cortisol—a commonly used biomarker of stress), while the greatest increases in stress occur with the combination of a cognitive task and public speaking [29]. This combination is present in the commonly used Trier Social Stress Test (TSST) [30, 31], which induces stress relatively reliably even with the variations in the TSST protocol [32]. The downside of TSST is its requirement of three individuals acting as an evaluative audience (i.e., "judges") and its duration: not counting the acclimatation and recovery periods, TSST typically lasts 20 min [30, 31]. Despite the advantages of TSST, at least some restoration studies could benefit from a shorter yet reliable stress-induction method that is simpler to implement.

On top of challenges related to assessing affective states and inducing stress, studies can encounter issues when assessing attention restoration—how people perform cognitively after spending time in nature [8, 9, 12, 33, 34]. Results can depend on the specific cognitive function that is measured and on how fatigued participants are: restoration may be more likely to occur in domains of cognitive flexibility and working memory [8], and in participants who are fatigued, either because of a cognitively fatiguing task within an experiment or because of fatiguing day-to-day occurrences, such as attending lectures [8]. Experimentally inducing fatigue with cognitive tasks can be problematic as it can be lengthy—up to 40 min in studies identified by Stevenson et al. [8], while uncontrolled fatiguing day-to-day occurrences are less likely to lead to uniform levels of fatigue among study participants (e.g., during lectures, some students may exert more mental effort and get more fatigued than others). An approach that could sidestep these limitations is increasing cognitive fatigue by inducing stress—according to ART, attentional resources can decline due to stress and not only task demand [6]. This approach is currently used in few studies [8], although it might provide a briefer standardized method to increase participants' need for attention restoration. This opens an interesting possibility of using the mental arithmetic task (MAT)—a part of the TSST stress-inducing protocol—as a stressor as well as a fatiguing cognitive task and test of cognitive performance. MAT involves subtracting the number 13 or 17 from a 4-digit number and reporting answers aloud [30]. As a stressor, MAT can be effective because it involves a social-evaluative threat—task performance could be negatively judged by others [29]; and as a cognitive task, MAT can be suitable because it taps the working memory domain [35], which can be influenced by natural environments [8].

In summary, current research shows that people benefit from spending time in natural environments, but the effects are less clear when people are exposed to some indoor elements of nature, such as wood, possibly due to suboptimal methodological approaches. It is unclear (1) whether the changes of affective states in restorative environments are detected by the tools based on dimensional approach (e.g., pleasure and arousal dimensions), and (2) whether a cognitive task that acts as a stressor (i.e., MAT) is a viable inducer of stress and cognitive fatigue and a viable measure of cognitive performance in restorative environments.

Objectives

Our study primarily aimed to test the suitability of a selected task and outcomes for restoration research, specifically in the context of people's exposure to indoor wood. We aimed to test whether MAT reliably induces stress, as reflected in cardiovascular and electrodermal activity, and affective states, as captured by two items assessing pleasure and arousal (based on the circumplex model of affect) [20]. We were additionally interested in whether MAT can be a viable cognitive task in restoration research. The secondary aim of our study was to examine whether the inspected physiological, affective, and cognitive outcomes differ between wooden and non-wooden indoor settings.

Methods

Participants

A convenience sample of 22 subjects (18 females) participated in the study, with 19 subjects between the ages of 18 and 34, and three subjects between the ages of 35 and 54. Subjects were eligible to participate in the study if they had no health issues or characteristics that would have interfered with the study tasks (e.g., very poor computer skills). Before the experiment, subjects signed an informed consent form that informed them about the study purpose and procedure, rights of participants, and data management practices. The study protocol was approved by the National Medical Ethics Committee of Slovenia (No. 0120–298/2020/3) and the research was carried out in compliance with the Oviedo convention. As a compensation for participating in the study, subjects received a report of their results (in reference to aggregated results of other participants).

Test setting

The experiment was conducted in spaces of University of Primorska in Koper, Slovenia. The test setting included a preparation desk with a smaller top surface (100 cm × 70 cm) and a test desk with a larger top surface (200 cm × 90 cm). The two desks were placed at the opposite sides of the space. The top surface of the smaller desk was covered with beige melamine, while the top surface of the larger desk was made of oak (*Quercus robur*) veneer—light colored wood with darker streaks and with a clear lacquer finish applied by the vendor. The oak veneer was exposed in the experimental condition and covered with a white tablecloth in the control condition (Fig. 1). Windows in the test setting were covered with white drapes to prevent participants from viewing the outdoor environment. The

Fig. 1 The test desk in the control (left) and experimental condition (right)

experiment took place in August of 2020, and the testing was conducted throughout the entire day.

Measures

Affective states

Affective states were assessed with two single-item measures capturing the states of pleasure and arousal [21]. The scales, based on the circumplex model of affect [20], capture the broad state of core affect—simplest consciously accessible feelings, rather than specific emotions or longer lasting moods [36]. Despite their brevity, the scales have proven to be reliable and valid [21, 37]. The two administered items asked participants: "How pleasant/activated do you feel at this moment?". Participants responded on a 9-point rating scale (1 = especially unpleasant/inactivated, 5 = neutral, 9 = especially pleasant/activated).

Cognitive performance

Cognitive performance was assessed with MAT—a part of the TSST [30]. Participants were instructed to (mentally) sequentially subtract the number 13 from a 4-digit number (1022 and 1059 in the 1st and 2nd task administration, respectively) as fast and as accurately as possible and report their results verbally, while the researcher was monitoring the correctness of their responses. If participants made a subtraction error, they were instructed to start subtracting again from the initial 4-digit number. The subtraction period lasted for 5 min at each task administration.

Physiological arousal

Physiological arousal was examined with measures of cardiovascular activity, which reflects the activity of the heart and blood vessels, and electrodermal activity, which reflects the activity of the sweat glands in the skin. Different measures correspond to different branches of the autonomic nervous system. Electrodermal activity predominantly reflects the sympathetic branch [38], heart rate corresponds to both sympathetic and parasympathetic branches, and heart rate variability largely relates to the parasympathetic branch [39]. As indicators of stress, measures of cardiovascular and electrodermal activity have been frequently used in psychophysiological research in general [38–40] and restoration research in particular [17].

Participants were equipped with wireless sensors that captured cardiovascular and electrodermal activity. Cardiovascular activity was monitored with a chest strap (Equivital Life Monitor EQ02; Hidalgo, Cambridge, UK), and electrodermal activity was assessed with a galvanic skin response sensor (EQ-ACC-34; Hidalgo, Cambridge, UK), which was attached to pre-gelled Ag/AgCl electrodes placed on two fingers (index and middle finger) of participants' left hand. Cardiovascular activity was parametrized as heart rate (beats per minute) and heart rate variability. The root mean square of successive beat-to-beat interval differences (RMSSD) was used as a representative measure of heart rate variability [41]. Electrodermal activity was parametrized as skin conductance level (SCL; i.e., tonic level of electrical conductivity of skin), percentage of skin conductance responses (SCR; i.e., brief increase in conductance following physiologically arousing external or internal stimuli), and SCR amplitude (i.e., the extent of the increase in conductance at the SCR [38]). The physiological arousal data were captured and processed in LabChart 8.1 [42]. Electrodermal activity data were additionally processed with the Python package NeuroKit2 [43]. Electrodermal activity data from one subject were excluded from the analysis, due to unusually high SCL and odd SCL patterns, suggesting a systematic error in the measurement process.

Experimental procedure

Participants were instructed ahead of the study to abstain from caffeinated beverages on the day of the testing, as these might interfere with measurements of physiological arousal [44]. Before the experiment, participants received an overview of the upcoming study protocol and instructions on completing the study tasks. They were then equipped with physiological activity sensors and provided with the opportunity to ask questions related to the study.

Participants were guided through the experimental protocol by a web platform (developed with the R package psychTestR [45]), which delivered instructions, captured self-reported data, and provided timers. The experimental protocol (Fig. 2) started with the baseline period (Baseline), to ensure participants acclimatized to the test testing and that the baseline values of physiological activity were captured. Participants then responded to a measure of affective states, completed MAT (Task (1)), and responded to the measure of affective states again immediately after. Afterwards, they started with the recovery period (Recovery): they relocated to a larger desk at the opposite side of the room, which had its wooden surface either exposed (experimental condition) or covered with a white tablecloth (control condition), where they rested for 10 min (half of the participants were randomly assigned to one of the two conditions). Note that the duration of the resting period should suffice for cardiovascular [46] and electrodermal activity [47, 48] to return to baseline levels after stress induction. Finally, participants responded to a measure of affective states for the third (and final) time and completed MAT for the 2nd (and final) time (Task (2)).

Statistical analysis

The data were processed and analyzed with R 4.0.2 [49] and Python 3.9.2 [50] using RStudio 1.4.1106 [51] with the packages janitor [52], NeuroKit2 [43], broom.mixed [53], rstatix [54], reticulate [55], lme4 [56], lmerTest [57], emmeans [58], DHARMa [59], flextable [60], and the collection of packages tidyverse [61]. Summary statistics were reported as means (M) and confidence intervals (CI), and visualized as boxplots. In the boxplots, the box represents the interquartile range, which spans from the first (lower) quartile at the bottom hinge to the third (upper) quartile at the top hinge. The thicker line passing through the box represents the median (second quartile). The whiskers extend from the hinges to the largest (for the upper whisker) or smallest value (for the lower whisker) that is no further from the hinge than 1.5 × interquartile range—distance between the first and third quartiles. The overlaid dots represent raw data points.

Our data would commonly be analyzed with a mixed analysis of variance (ANOVA), where the desktop condition (i.e., wooden or white desk) would be treated as a between-subject factor and the study phase (i.e., baseline, task, recovery) as a within-subject factor. Instead of using the mixed ANOVA, we based our analysis on (generalized) linear mixed models, which are becoming increasingly more widespread and recommended approach to analyze within-subject data due to their flexibility and robustness [62].

We typically fitted a linear mixed model, where the residual error term is expected to follow a normal distribution. In one instance, we fitted a binomial mixed model, which can handle dependent variables whose residual error does not follow a normal distribution (i.e., a binary dependent variable whose error distribution is binomial) [63]. The (generalized) linear mixed models were fitted with the R packages lme4 [56] and lmerTest [57]. In all models, subjects were treated as random effects and desktop conditions, study phase, and/or task administration were treated as fixed effects. All models tested for interactions between fixed effects. Variables representing electrodermal and cardiovascular activity were included in the model as dependent variables after the mean values were calculated for each participant at each study phase. At Baseline and Recovery, only the 5 min of the lowest physiological activity (according to skin conductance values) for each period were taken for further analysis, to minimize the presence of physiological arousal resulting from the period before the experiment and from the anticipation of the upcoming task

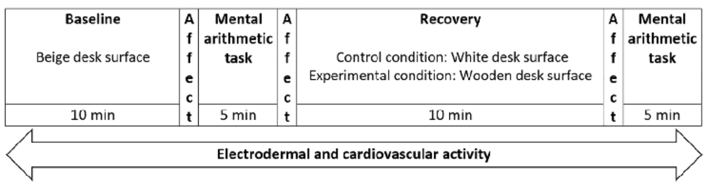

Fig. 2 Experimental procedure

during the experiment. The variables representing affective states and cognitive performance were included as dependent variables in their raw form.

If statistically significant main effects or interaction effects were detected, post hoc comparisons were conducted with the R package emmeans [58], where p values were adjusted with the Tukey method and estimated marginal means (*EMM*) were reported. In one instance of the linear mixed model, the dependent variable (i.e., SCR peaks) underwent square root transformation to improve model fit; however, reported *EMMs* were back-transformed and presented in the original unit of the dependent variable, while the corresponding contrasts (differences between the values of two dependent variables) generally cannot be back-transformed and were reported as differences between two square roots. Model diagnostics were conducted with the R package DHARMa [59], which uses a simulation-based approach to analyze residuals of (generalized) linear mixed models. None of the reported models exhibited issues with fit to the data.

In some cases, we examined the data in more detail after uncovering atypical response patterns in some participants (i.e., atypical responses on the affective state of pleasure). Here, we split the participants into two groups: if the participant's score on the affective state of pleasure increased or stayed the same from Baseline to Task (1) and decreased or stayed the same from Task (1) to Recovery, the participant was classified as an atypical responder; otherwise, the participant was classified as a typical responder. The results (i.e., physiological activity and cognitive task scores) of these two groups were compared with Wilcoxon tests (the Wilcoxon signed-rank test was used as a paired difference test and the Wilcoxon rank-sum test was used as an unpaired two-sample test). By splitting our sample, we created two smaller groups of participants (with unequal sizes), which lowers the statistical power of significance tests [64]. For this reason, the p values were not adjusted for multiple comparisons, to decrease the possibility of the Type II error (i.e., false negative).

Results

Affective states

Participants on average reported values around the middle of the scale for the affective states of arousal ($M = 4.53$, 95% CI [4.09, 4.97]) and pleasure ($M = 5.15$, 95% CI [4.70, 5.60]). The results of the linear mixed model showed that the arousal scores significantly changed throughout the study phases, while the pleasure scores did not (Table 1, Fig. 3). The arousal and pleasure scores did not differ between desktop conditions, and there were no interaction effects between desktop conditions and study phases. Post hoc comparisons showed that arousal scores were higher at Task (1) ($EMM = 5.59$, 95% CI [4.87, 6.31]) than at Baseline ($EMM = 3.73$, 95% CI [3.01, 4.45]; Task (1)—Baseline = 1.86, 95% CI [1.08, 2.64], $p < 0.001$) and Recovery ($EMM = 4.27$, 95% CI [3.55, 4.99]; Task (1)—Recovery = 1.32, 95% CI [0.54,—2.10], $p < 0.001$), while the scores did not significantly differ between Baseline and Recovery (Baseline–Recovery = − 0.55, 95% CI [− 1.33, 0.24], $p = 0.217$).

It should be noted that the pleasure scores, even though they have not (on average) significantly changed in any one direction between study phases, still varied within participants (Fig. 4)—few participants reported

Table 1 Results of the linear mixed models with affective states as dependent variables

Outcome	Predictor	Estimate	SE	95% CI	df	*t*	*p*
Arousal	Intercept	3.82	0.50	2.83 to 4.80	35.17	7.59	< 0.001
	Condition: Wood	− 0.18	0.71	− 1.58 to 1.21	35.17	− 0.26	0.800
	Phase: Task (1)	2.00	0.45	1.11 to 2.89	40.00	4.41	< 0.001
	Phase: Recovery	0.73	0.45	− 0.16 to 1.62	40.00	1.60	0.117
	Wood * Task (1)	− 0.27	0.64	− 1.53 to 0.98	40.00	− 0.43	0.673
	Wood * Recovery	− 0.36	0.64	− 1.62 to 0.89	40.00	− 0.57	0.574
Pleasure	Intercept	5.64	0.56	4.55 to 6.73	44.06	10.12	< 0.001
	Condition: Wood	0.18	0.79	− 1.36 to 1.72	44.06	0.23	0.818
	Phase: Task (1)	− 0.91	0.60	− 2.08 to 0.26	40.00	− 1.52	0.136
	Phase: Recovery	− 0.91	0.60	− 2.08 to 0.26	40.00	− 1.52	0.136
	Wood * Task (1)	0.09	0.84	− 1.56 to 1.75	40.00	0.11	0.915
	Wood * Recovery	0.09	0.84	− 1.56 to 1.75	40.00	0.11	0.915

Significant predictors ($p < 0.05$) are shown in bold

SE: standard error; CI: confidence interval; df: degrees of freedom; *t*: test statistic *t*; *p*: *p*-value

*Interaction between predictors

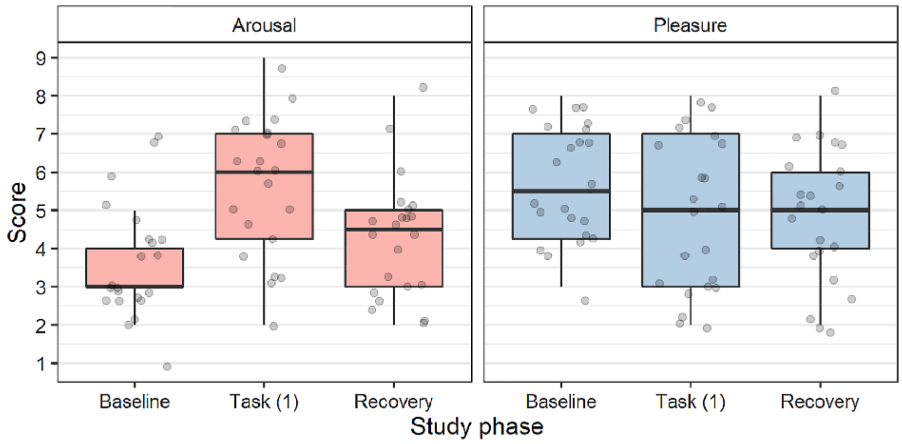

Fig. 3 Affective states throughout study phases

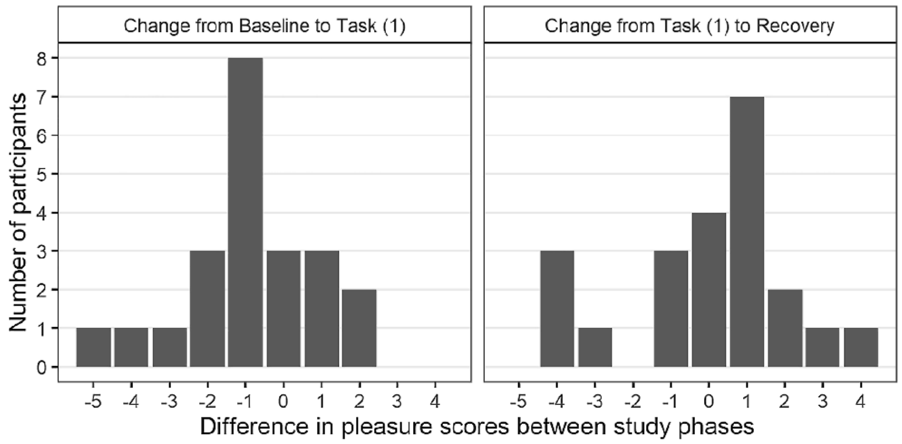

Fig. 4 Changes in pleasure scores within each participant from Baseline to Task (1) (left) and from Task (1) to Recovery (right)

no change in their pleasure scores between study phases, while many reported either decreases or increases in pleasure both from Baseline to Task (1) and from Task (1) to Recovery.

Further examination identified six participants with atypical responses, for whom pleasure seems to have increased or stayed the same from Baseline to Task (1) and decreased or stayed the same from Task (1) to Recovery, in contrast with 16 participants with typical responses, for whom pleasure appears to have decreased from Baseline to Task (1) and increased from Task (1) to Recovery (Fig. 5, Additional file 1: Table S1).

Atypical and typical responders had similar scores on subjective arousal at Task (1) and Recovery (Additional

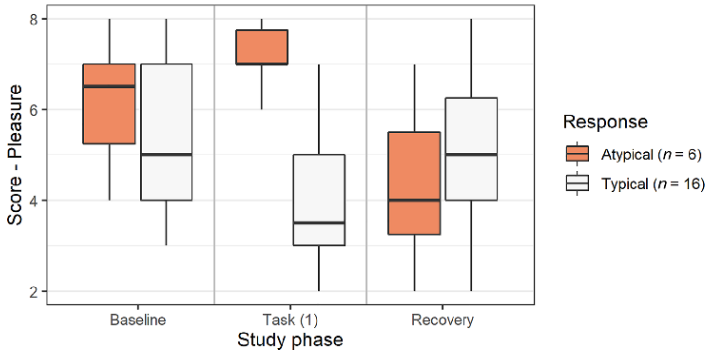

Fig. 5 Pleasure scores across study phases for participants with atypical and typical responses

file 1: Figure S1, Tables S2, 3), but different scores at Baseline, where atypical responders had somewhat lower scores compared to typical responders (difference:—1.00, 95% CI [− 3.00, 0.00], $p = 0.046$).

Physiological arousal

Electrodermal activity

Throughout all study phases, the mean of (means of) exhibited values was 6.35 µS (95% CI [5.46, 7.24]) for SCL, 0.51% (95% CI [0.31, 0.71]) for SCR, and 0.23 µS (95% CI [0.17, 0.29]) for SCR amplitude. The linear mixed models showed that the SCL and SCRs (but not SCR amplitude) changed throughout study phases, while there were no main effects of desktop condition or interactions between desktop condition and study phases (Table 2, Fig. 6).

Post hoc comparisons showed that SCL scores significantly increased from Baseline (*EMM* = 4.36 µS, 95% CI [2.88, 5.84]) to Task (1) (*EMM* = 8.05 µS, 95% CI [6.57, 9.53]; Task (1)—Baseline = 3.69 µS, 95% CI [3.00, 4.38], $p < 0.001$) and then decreased from Task (1) to Recovery (*EMM* = 6.57 µS, 95% CI [5.09, 8.05]; Task (1)—Recovery = 1.48 µS, 95% CI [0.79, 2.18], $p < 0.001$), but remained higher at Recovery than they were at Baseline (Recovery—Baseline = 2.21 µS, 95% CI [1.52, 2.90], $p < 0.001$). A somewhat similar trend was seen in SCRs, which increased from Baseline (*EMM* = 0.13%, 95% CI [0.04, 0.28]) to Task (1) (*EMM* = 0.76%, 95% CI [0.49, 1.10]; Task (1)–Baseline (difference of square roots) = 0.51, 95% CI [0.35, 0.68], $p < 0.001$), and decreased from Task (1) to Recovery (*EMM* = 0.24%, 95% CI [0.10, 0.43]; Task (1)—Recovery (difference of square roots) = 0.39, 95% CI [0.22, 0.55], $p < 0.001$), while they did not significantly differ between Baseline and Recovery (Baseline–Recovery (difference of square roots) = − 0.13, 95% CI [− 0.29, 0.04], $p = 0.155$).

Cardiovascular activity

Throughout all study phases, the mean of (means of) exhibited values were 79.95 beats per minute for heart rate (95% CI [75.47, 84.43]) and 36.41 ms for heart rate variability—RMSSD (95% CI [31.59, 41.23]). The linear mixed models showed that heart rate (but not heart rate variability) changed throughout study phases (Table 3, Fig. 7). There were no main effects of desktop conditions or interaction effects between desktop conditions and study phases. Post hoc comparisons for heart rate showed a similar trend as electrodermal activity results: heart rate values (beats per minute) were comparatively low at Baseline (*EMM* = 74.24, 95% CI [67.13, 81.35]), increased from Baseline to Task (1) (*EMM* = 91.92, 95% CI [84.80, 99.03]; Task (1)–Baseline = 17.68, 95% CI [10.55, 24.81], $p < 0.001$), and decreased from Task (1) to Recovery (*EMM* = 73.69, 95% CI [66.58, 80.80]; Task (1)—Recovery = 18.23, 95% CI [11.10, 25.36], $p < 0.001$), with no significant differences between Baseline and Recovery (Baseline–Recovery = 0.55, 95% CI [− 6.58, 7.68], $p = 0.852$).

Further analysis suggested that participants with atypical pleasure scores (see "Affective states" section) had similar patterns of electrodermal activity but different patterns of cardiovascular activity compared to participants with typical pleasure scores (Fig. 8, Additional file 1: Tables S4, 5). The atypical responders had a relatively stable heart rate across the study phases, while the heart rate of the typical responders increased

Table 2 Results of the linear mixed models with electrodermal activity parameters as dependent variables

Outcome	Predictor	Estimate	SE	95% CI	df	*t*	*p*
SCL [µS]	Intercept	4.66	0.99	2.72 to 6.59	22.2	4.72	< 0.001
	Condition: Wood	− 0.60	1.43	− 3.40 to 2.20	22.2	− 0.42	0.680
	Phase: Recovery	2.60	0.47	1.67 to 3.52	38.0	5.51	< 0.001
	Phase: Task (1)	3.85	0.47	2.93 to 4.78	38.0	8.17	< 0.001
	Wood * Recovery	− 0.78	0.68	− 2.12 to 0.56	38.0	− 1.14	0.262
	Wood * Task (1)	− 0.32	0.68	− 1.66 to 1.02	38.0	− 0.47	0.638
SCR [%] (square root)	Intercept	0.33	0.12	0.10 to 0.55	29.55	2.82	0.008
	Condition: Wood	0.06	0.17	− 0.26 to 0.39	29.55	0.38	0.704
	Phase: Recovery	0.21	0.09	0.03 to 0.40	38.00	2.32	0.026
	Phase: Task (1)	0.59	0.09	0.41 to 0.77	38.00	6.37	< 0.001
	Wood * Recovery	− 0.18	0.13	− 0.44 to 0.09	38.00	− 1.31	0.197
	Wood * Task (1)	− 0.15	0.13	− 0.41 to 0.11	38.00	− 1.12	0.270
SCR amplitude [µS]	Intercept	0.19	0.07	0.06 to 0.33	39.97	2.79	0.008
	Condition: Wood	0.09	0.10	− 0.11 to 0.28	39.97	0.87	0.388
	Phase: Recovery	0.00	0.07	− 0.14 to 0.14	38.00	0.03	0.978
	Phase: Task (1)	0.07	0.07	− 0.07 to 0.21	38.00	0.98	0.332
	Wood * Recovery	− 0.09	0.10	− 0.3 to 0.11	38.00	− 0.90	0.374
	Wood * Task (1)	− 0.06	0.10	− 0.27 to 0.14	38.00	− 0.62	0.540

Significant predictors ($p < 0.05$) are shown in bold

SE: standard error; CI: confidence interval; df: degrees of freedom; *t*: test statistic *t*; *p*: *p*-value

*Interaction between predictors

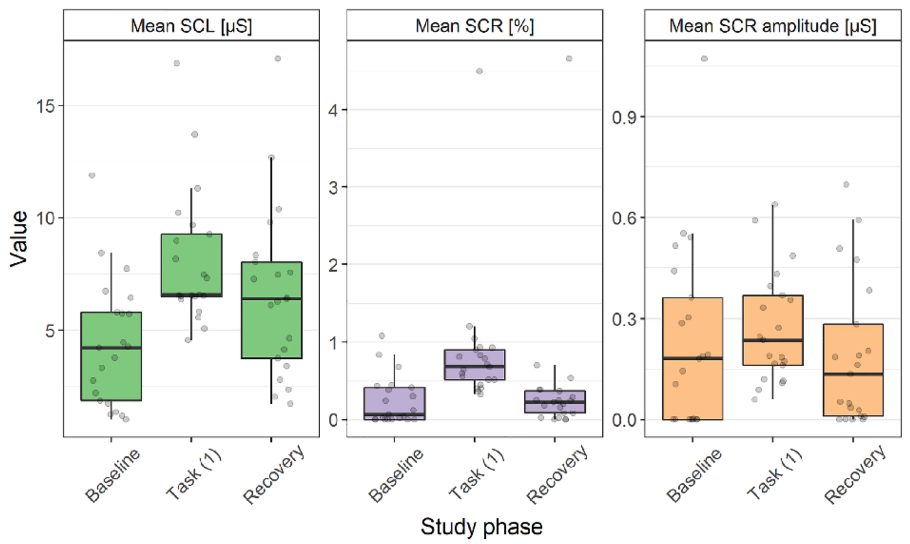

Fig. 6 Electrodermal activity throughout study phases

Table 3 Results of the linear mixed models with heart rate and heart rate variability (RMSSD) as dependent variables

Outcome	Predictor	Estimate	SE	95% CI	df	*t*	*p*
Heart rate [beats per minute]	Intercept	71.51	4.94	61.83 to 81.20	32.57	14.47	< 0.001
	Condition: Wood	5.45	6.99	− 8.25 to 19.15	32.57	0.78	0.441
	Phase: Recovery	16.40	4.14	8.28 to 24.52	40.00	3.96	< 0.001
	Phase: Task (1)	− 0.75	4.14	− 8.87 to 7.36	40.00	− 0.18	0.856
	Wood * Recovery	2.55	5.86	− 8.93 to 14.03	40.00	0.44	0.666
	Wood * Task (1)	0.41	5.86	− 11.07 to 11.89	40.00	0.07	0.945
RMSSD [ms]	Intercept	43.47	5.82	32.07 to 54.88	33.65	7.47	< 0.001
	Condition: Wood	− 12.23	8.23	− 28.36 to 3.90	33.65	− 1.49	0.146
	Phase: Recovery	− 6.20	5.03	− 16.07 to 3.67	40.00	− 1.23	0.225
	Phase: Task (1)	1.90	5.03	− 7.97 to 11.76	40.00	0.38	0.708
	Wood * Recovery	2.98	7.12	− 10.97 to 16.94	40.00	0.42	0.677
	Wood * Task (1)	− 0.08	7.12	− 14.03 to 13.88	40.00	− 0.01	0.992

Significant predictors ($p < 0.05$) are shown in bold

SE: standard error; CI: confidence interval; df: degrees of freedom; *t*: test statistic *t*; *p*: *p*-value

*Interaction between predictors

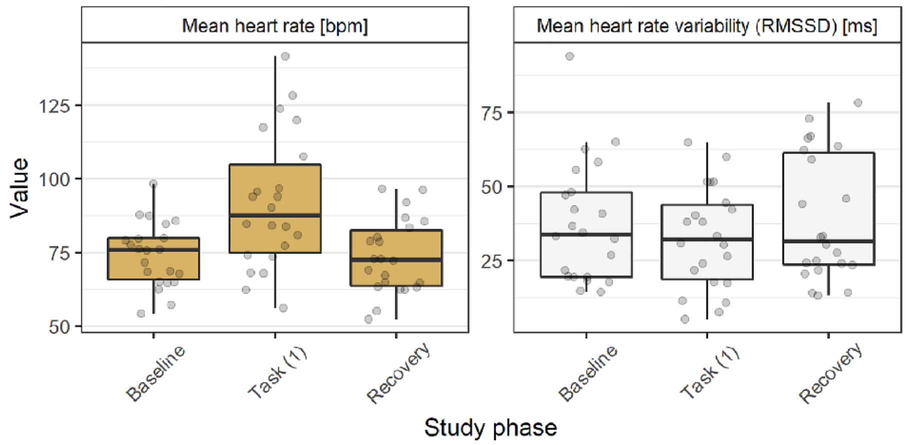

Fig. 7 Cardiovascular activity throughout study phases

markedly at Task (1) (Task (1)—Baseline = 22.61 beats per minute, 95% CI [11.56, 31.70], $p < 0.001$). Similarly, the atypical responders reacted to Task (1) with slightly (but insignificantly) increased heart rate variability (Task (1)—Baseline = 7.62 ms, 95% CI [− 13.48, 28.21], $p = 0.219$), in contrast with the typical responders, for whom the heart rate variability slightly (but insignificantly) decreased at Task (1) (Task (1)—Baseline = − 9.06 ms, 95% CI [− 19.20, 0.18], $p = 0.058$).

Mental arithmetic task

Participants on average generated more than 50 total responses to MAT ($M = 51.41$, 95% CI [45.72, 57.10]) with a very high proportion of correct responses ($M = 0.94$, 95% CI [0.93, 0.95]). The mixed models showed that the proportion of correct responses (Table 4) and the number of responses (Table 5) varied between study phases but not between desktop conditions, and there were no interactions between the desktop

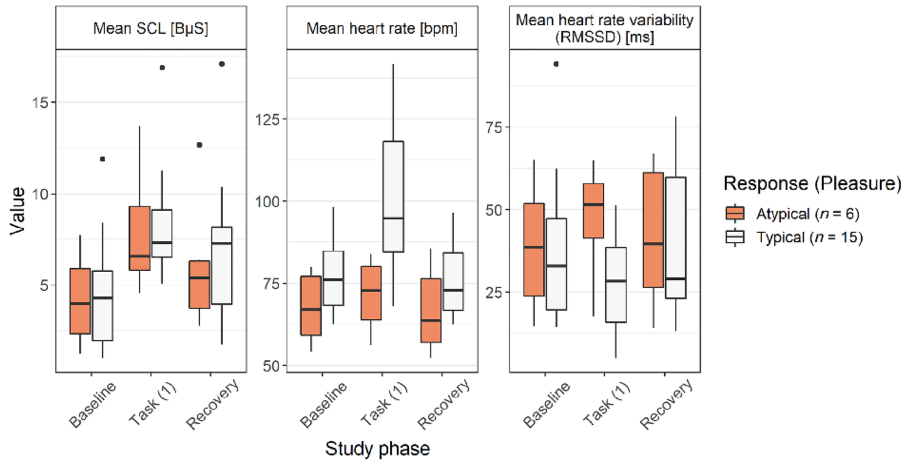

Fig. 8 Physiological activity across study phases, split by participants with atypical and typical pleasure score patterns

Table 4 Results of the binomial mixed model with MAT response correctness as the dependent variable

Outcome	Predictor	Estimate	SE	CI	z	p
Correct responses	Intercept	11.86	3.37	6.79 to 20.71	8.70	< 0.001
	Condition: Wood	1.31	0.55	0.58 to 2.96	0.65	0.513
	Phase: Task (2)	2.21	0.54	1.38 to 3.56	3.28	0.001
	Wood * Task (2)	0.78	0.29	0.37 to 1.63	− 0.66	0.512

The estimates represent odds ratios. Significant predictors ($p < 0.05$) are shown in bold

SE: standard error; CI: confidence interval; *z*: test statistic *z*; *p*: *p*-value

*Interaction between predictors

Table 5 Results of the linear mixed model with MAT total number of responses as the dependent variable

Outcome	Predictor	Estimate	SE	95% CI	df	t	p
Number of responses	Intercept	53.09	5.27	42.76 to 63.42	22.01	10.07	< 0.001
	Condition: Wood	− 12.91	7.46	− 27.52 to 1.7	22.01	− 1.73	0.097
	Phase: Task (2)	9.55	2.31	5.02 to 14.07	20.00	4.13	< 0.001
	Wood * Task (2)	0.00	3.27	− 6.4 to 6.4	20.00	0.00	1.000

Significant predictors ($p < 0.05$) are shown in bold

SE: standard error; CI: confidence interval; df: degrees of freedom; *t*: test statistic *t*; *p*: *p*-value

*Interaction between predictors

condition and task administration. Post hoc comparisons revealed that participants provided fewer responses in Task (1) (*EMM* = 46.64, 95% CI [38.91, 54.37]) than at Task (2) (*EMM* = 56.18, 95% CI [48.45, 63.91]; Task (1)–Task (2) = − 9.55, 95% CI [− 13.00, − 6.14], $p < 0.001$), and they were less likely to respond correctly to MAT at Task (1) (*EMM* = 0.93, 95% CI [0.90, 0.95]) than at Task (2) (*EMM* = 0.96, 95% CI [0.95, 0.98]; Task (1)/Task (2) (odds ratio) = 0.51, 95% CI [0.35, 0.74], $p < 0.001$) (Fig. 9).

A closer examination of participants who responded atypically on the affective state of pleasure (see "Affective states" section) suggests they provided more responses in

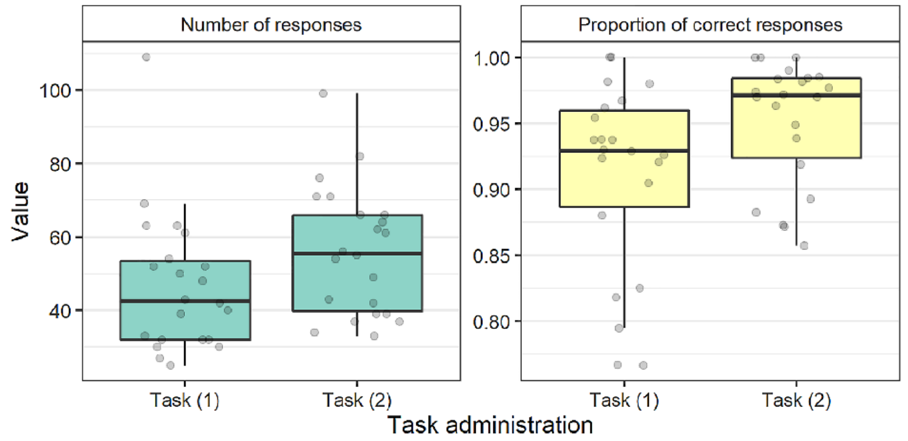

Fig. 9 MAT results on the first and second task administration

Task (1) than the typical responders (Atypical responders–typical responders = 17.00, 95% CI [2.00, 37.00], $p = 0.035$). The difference in number of responses between the two groups was similar in Task (2), although the variability of scores was greater and the difference was not statistically significant (Atypical responders–typical responders = 16.87, 95% CI [−4.00, 33.00], $p = 0.090$) (Fig. 10, Additional file 1: Table S6). In addition, the atypical responders had a larger proportion of correct responses than the typical responders in Task (1) (Atypical responders–typical responders = 0.06, 95% CI [0.03, 0.16], $p = 0.004$) but similar proportion of correct responses in Task (2) (Atypical responders–typical responders = 0.02, 95% CI [−0.01, 0.09], $p = 0.376$).

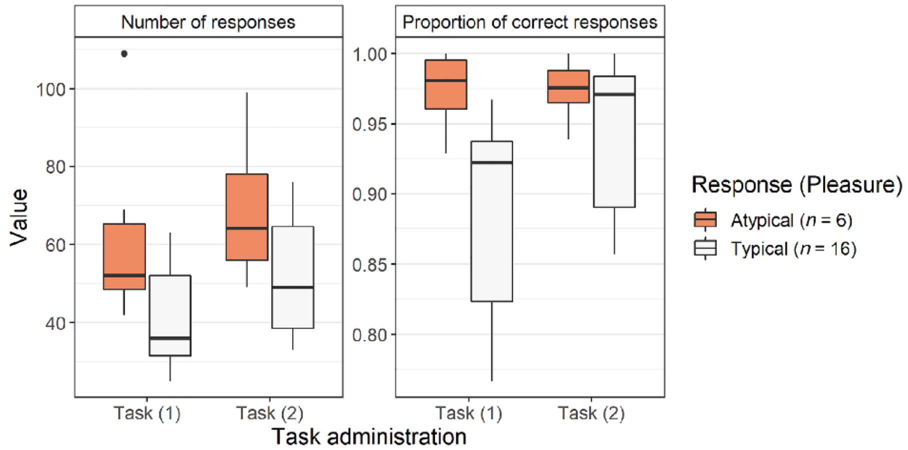

Fig. 10 MAT results on the first and second task administration, split by participants with atypical and typical pleasure score patterns

Discussion

Affective states

Participants generally reacted to MAT with a state of higher arousal accompanied with middle values of pleasure, indicating a highly aroused state close to neutral in terms of valence, such as alertness or tension, but not stress [20]. Had the participants on average experienced a significant amount of stress, the experienced affective states should have been characterized by high arousal and *low* pleasure, such as anxiety [65]. In contrast, some participants reported *increased* subjective pleasure following MAT, suggesting that MAT sometimes induced more pleasurable states, such as excitement [20]. In the absence of low subjective pleasure, high subjective arousal following MAT likely primarily reflects the effort required to accomplish task demands [66]. This suggests that MAT does not lead to a reliable stress response in at least a subgroup of people, and that different or additional stressors are needed. At Recovery, the subjective arousal that MAT induced returned to levels similar to those observed at Baseline, suggesting that a 10-min recovery period is sufficiently long for affective states to return to initial values. The results also suggest that the deployed single-item measures assessing arousal and pleasure are sensitive enough to detect changes in affective states, as evidenced by the variability in scores, indicating that these scales may prove useful in restoration research.

Physiological activity

Electrodermal activity results generally followed the pattern observed in the self-reports of arousal—an increase after MAT followed by a decrease at Recovery. This pattern, however, differed between electrodermal activity parameters. SCL and SCR both increased from Baseline to Task (1), but SCL was higher at Recovery than at Baseline, while SCR returned to levels similar to those observed at Baseline. This indicates that MAT is capable of inducing increases of electrodermal activity, but that the period of 10 min may not be sufficient for the physiological arousal to return to baseline levels, suggesting that a longer recovery period is warranted. Unlike SCL and SCR, SCR amplitude did not significantly change throughout study phases. High SCL usually co-occurs with a high number of SCRs and large SCR amplitudes [38]; however, different electrodermal activity parameters may represent partially independent sources of information that are uniquely related to different psychophysiological processes. While all three electrodermal activity parameters are associated with strain, SCR amplitude is thought to also reflect preparatory activation, signaling increased perceptual and motor readiness for an upcoming task [67, 68]. This suggests one possible explanation of the observed results: participants might have anticipated the upcoming task both at Baseline and Recovery, leading to increased values of SCR amplitude at these periods of rest to the point that these values did not significantly differ from those observed at Task (1). Alternatively, SCR amplitude may be less responsive to the specific type of demands placed on participants by MAT.

The patterns of cardiovascular activity resembled those of electrodermal activity for heart rate but not for heart rate variability. Heart rate increased from Baseline to Task (1) and then decreased at Recovery, to the point of being no different than at Baseline. Heart rate variability showed no such variation and remained similar throughout the study phases. When the heart rate increases following a stressor or an effortful cognitive task, the heart rate variability tends to decrease [69], making the cardiovascular responses observed in this study somewhat atypical. However, heart rate and heart rate variability are thought to provide partially independent information when it comes to stress and mental effort. Heart rate variability seems to be somewhat more sensitive to mental strain than heart rate [68], opening the possibility that participants were at least slightly tense at Baseline and Recovery periods, as they might have been anticipating the upcoming task, which could have been reflected in the heart rate variability not being significantly different than at Task (1). An alternative explanation is similar to the above interpretation related to unchanging SCR amplitudes: heart rate variability may be less responsive to the type of demands that participants faced on MAT. It should be noted, though, that the interaction between cardiovascular responses and arousal following stressors or cognitive tasks is complex, and a number of influences could be responsible for the observed results [67, 68].

MAT

The results of MAT showed that participants generally improved from the 1st to 2nd administration on both MAT outcomes: number of provided responses and the proportion of correct responses. This suggests that the potential cognitive fatigue induced by the 1st administration of the task was offset by learning and practice gained from completing the task. Alternatively, participants might have been more distracted at the 1st task administration, before getting acclimatized to the experimental session ahead of the 2nd administration of the task. Higher scores at the 2nd administration of the task could still show positive effects of restorative environments; indeed, many studies exploring attention restoration in natural environments detect higher scores at the 2nd task administration [8, 33]. However, the attention restoration theory claims that exposure to nature *restores* fatigued cognitive capacities [6]. This suggests that the positive effects of natural environments on cognitive performance will be less likely present if participants are not cognitively fatigued and operate at their peak cognitive capacities, leaving the natural environment no maneuvering space: cognitive capacities cannot be restored if they have not been depleted. It is unclear, though, whether the observed effect of natural environments on cognitive performance is in fact the restoration of a depleted cognitive resource [8, 70, 71]. Still, inducing cognitive fatigue seems more likely to lead to a more reliable restoration effect, at least on some occasions [8], and the 5-min instance of MAT may not be sufficient to induce significant levels of cognitive fatigue.

Atypical versus typical responders on the affective state of pleasure

Some participants reacted to MAT with an increased affective state of pleasure—the opposite of what would be expected if they had experienced stress. In response to MAT, these atypical responders appeared to have similar electrodermal activity but lower cardiovascular activity than the typical responders. Perhaps this discrepancy can be explained by different properties of the two physiological systems: electrodermal activity is a relatively direct measure of sympathetic activity of the autonomic nervous system, while heart rate provides a broader picture of both sympathetic and parasympathetic activity [38]. The atypical responders may have been sufficiently activated for the increased sympathetic activity to be detected on the measure of electrodermal activity but not activated enough for the activation to be evident in heart rate, which also involves parasympathetic activity. Increased parasympathetic activity in the atypical responders could also be indicated by their slight increase in heart rate variability in response to MAT [39].

Interestingly, even though physiological activity was somewhat different between typical and atypical responders in response to MAT, subjective arousal was similar in both groups of participants. This suggests that subjective arousal cannot be fully explained by measures of electrodermal and cardiovascular activity. It is also possible that subjective assessment cannot capture arousal as precisely as physiological measures, due to the subjectivity involved. Based on the identified discrepancies between subjective and physiological arousal, it appears that both types of arousal should be measured to obtain a more complete understanding of arousal in the studied situation.

The affective and physiological response of the atypical responders—higher pleasure and lower physiological activity—might be explained in part by their better performance on MAT. Perhaps these participants reacted to MAT atypically due to their higher ability or affinity for cognitive tasks, suggesting that MAT might not lead to stress especially in people who are more capable or motivated to perform on cognitive tasks.

Outcomes in wooden versus non-wooden desktop conditions

Affective states, electrodermal and cardiovascular activity, and cognitive performance did not differ between desktop conditions (i.e., wooden desktop versus desktop covered with a white cloth). This can be due to the low number of participants, making the study underpowered to detect presumably small effects of the exposure to a wooden setting. Another reason for the lack of detected differences can stem from the absence of a clear stress response and cognitive fatigue in participants: if participants did not experience stress or cognitive fatigue, it could have been more difficult for the environment to provide restorative effects [8]. The lack of observed differences between environments could also have resulted from the specific wood furnishings: the wooden desk may not have provided sufficient stimulation to induce restorative effects. The existing studies that observed the most promising effects of wood exposure on people used rooms with larger wood coverage [13, 14, 72], suggesting that even a relatively large desk surface tested in our study might not be sufficiently large to provide restorative effects.

Limitations

The most obvious limitations of the study are related to the nature and size of the study sample. Most participants were at least loosely acquainted with the study's first author, who was leading the experimental sessions. This might have urged participants to behave and respond differently than they would have in a more neutral context. In addition, the study sample was imbalanced in terms of gender, with most of the participants being female, and we did not control for the menstrual cycle phase, which could have impacted the results. The age range of participants was somewhat wide, and some variability in stress reactivity between participants may have been a result of differences in age. A relatively small sample size may have left the study underpowered–not only unable to detect potential differences in outcomes between desktop conditions but also unable to identify some of the potential subtle changes in outcomes across all participants, such as small differences in pleasure scores between study phases.

Conclusions and recommendations for future studies

On average, MAT may not lead to a reliable stress response. The task generally increased self-reported arousal and most measures of physiological arousal, indicating that it successfully activated participants to an extent. However, MAT did not impact all measures of physiological arousal, and it did not significantly affect the self-reported affective state of pleasure, indicating that the *average* response of participants cannot be straightforwardly interpreted as a stress response, but instead as activation required to successfully meet task demands. Clear stress response in the entire sample may have not appeared mainly due to a subgroup of participants who reacted to MAT positively—with increased affective state of pleasure. The role of MAT as a cognitive task in restoration research seems similarly limited, at least when MAT lasts only 5 min and when the goal is to reliably induce cognitive fatigue. However, MAT might become more useful if it would be longer (to attempt to induce cognitive fatigue) and if the testing condition would be more threatening (to attempt to induce stress), for example, by including a larger evaluative audience. The single-item measures that examined affective states seemed to be sufficiently sensitive to detect changing states of pleasure and arousal for their use to be recommended in restoration research. The comparison of outcomes between desktop conditions revealed that a larger wooden desktop is unlikely to lead to considerable restorative effects, but larger studies might detect potential (smaller) effects of the exposure to wooden desks, especially if the wood coverage increases. Taken together, the results of this study can inform and guide future studies, increasing their chances to recognize restorative environments.

Future studies may benefit from piloting their experimental design and measures before engaging larger subject pools. Methodological investigations are needed to identify how to induce an adequate degree of stress and cognitive fatigue for restoration studies, which would support more robust and comparable research in the field. For example, testing a longer version of MAT may reveal more about its capacity to reliably induce cognitive fatigue and stress. The single-item measures of affective states used in this study were robust, and we encourage other researchers to use them. However, comparing them with more commonly used (and longer) measures (e.g., PANAS) in the context of restoration research would be a useful contribution. The settings where the studies are deployed should be assessed in detail to examine how people are affected by characteristics such as indoor air quality, amount of natural elements (e.g., plants, wood), light quality, and other properties.

Abbreviations

ANOVA: Analysis of variance; ART: Attention restoration theory; CI: Confidence interval; df: Degrees of freedom; EMM: Estimated marginal mean; M: Mean; MAT: Mental Arithmetic Task; PANAS: Positive and Negative Affect Schedule; RMSSD: Root mean square of successive beat-to-beat interval differences; SCL: Skin conductance level; SCR: Skin conductance response; SE: Standard error; SRT: Stress reduction theory; TSST: Trier Social Stress Test.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s10086-022-02042-5.

Additional file 1: Table S1. Pleasure scores across study phases for participants with unusual and usual responses. **Table S2.** Arousal scores across study phases for participants with unusual and usual pleasure response patterns. **Table S3.** Comparison of arousal scores across study phases between participants with unusual and usual pleasure response patterns using the Wilcoxon rank-sum test. **Table S4.** Physiological activity across study phases for participants with unusual and usual pleasure response patterns. **Table S5.** Comparison of physiological activity across study phases within participants with unusual and usual pleasure response patterns using the Wilcoxon signed-rank test. **Table S6.** MAT results on the first and second task administration, split by participants with unusual and usual pleasure score patterns. **Figure S1.** Arousal scores across study phases for participants with unusual and usual pleasure response patterns.

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Author contributions

DL and MB designed the study. DL and JŽ collected the data. DL analyzed the data and prepared the first draft of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets and the R analysis code used in the current study are available in the Zenodo repository, https://doi.org/10.5281/zenodo.5616116.

Declarations

Competing interests

The authors declare that they have no competing interests.

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Publisher's Note

Chapter 3

Summary of Studies

3.1 Article 1

In Article 1, we critically reviewed the methodology and results of studies that examined how people respond to visual exposure of wood in terms of physiological activity, affective states, and cognitive performance. We reviewed nine studies with 386 participants in total.

We identified many approaches through which the methodology of the reviewed studies could be strengthened. Several studies assessed physiological activity which was not coupled with the suitable study design or with other appropriate measures, which limited interpretation of physiological data. This was especially problematic in studies that exposed people to experimental settings for a very brief period of time (90s) [23,54,66,67], which can capture fleeting (affective) states that are often manifested in overlapping patterns of physiological activity [68,69]. The assessments of physiological activity are more useful and easier to interpret when coupled with a stress-inducing activity and a suitable measure of affective states. Measuring affective states is also important to capture changes in feelings that are not necessarily reflected in the changes of physiological activity [85]. To examine affective states, most of the reviewed studies used Profile of Mood States [74], which measures six specific states that were deemed important by psychiatrists assessing the effects of various drugs on patients [75]. It is unclear why these specific affective phenomena are expected to vary in indoor environments, and we encourage researchers in the field to select measures with justified reasons. Researchers are also encouraged to examine how people perform cognitively in response to visual wood exposure, which was examined in only two out of nine reviewed studies [17,72]. In examining cognitive performance, researchers should generally follow several considerations, including (1) measuring cognitive performance both before and after exposure to natural stimuli, (2) employing a cognitive task (before the exposure) that is demanding enough to sufficiently deplete cognitive capabilities, and (3) selecting the duration of the rest period that will be long enough to allow restorative qualities of an environment to take effect but short enough that cognitive capabilities will not recover regardless of the environment [42,43,47].

Regarding the influence of wood exposure on indicators of stress, the results of four studies with shorter exposure durations to wood provide relatively little information

[23,54,66,67]. Four out of five studies with longer exposure durations detected at least some favourable (or seemingly favourable) outcomes in wooden environments [17,70–73]. The results from [17] and Burnard and Kutnar [72] are promising since both studies found that the physiological arousal of participants is lower in the wooden environments. However, neither study detected any differences between the settings regarding the degree of stress recovery, and in both cases the findings were not corroborated by additional measures of affective states, physiological arousal, or cognitive performance. Studies from Zhang et al. [70,71] and Demattè et al. [73] observed more favourable affective states in the wooden environment, but in neither case it is clear if this was influenced by visual or olfactory properties of the experimental room(s). Only Fell's [17] study reported cognitive performance outcome and it did not find any differences between the wooden and non-wooden environments.

Overall, the existing research suggests that visual wood exposure may lead to certain favourable outcomes, but the evidence is limited. In general, studies are limited by not examining multiple dimensions of stress indicators simultaneously, which limits the interpretability of their findings. Taken together, the studies reveal a potential for the benefits of wood use in buildings, but it is critical that future studies confirm and expand current findings.

3.2 Article 2

In Article 2, we aimed to investigate 1) general preference for modified wood compared with unmodified wooden materials (and a non-wood control sample), 2) the association between perceived wood properties and wood preference, and 3) the relationship between the tactile and tactile–visual domain of material perception (where different materials were presented as different handrail samples). We also examined whether perception and evaluation of wood differ between participants from two countries with different practices of wood use.

The results on the preference of materials show that wooden materials were generally similarly liked and more liked than the steel sample, regardless how the samples were assessed—whether participants were able to only touch the samples or to both touch and see them. These results are in line with other studies, which have observed that wood is generally favoured over other common building materials [15,53]. However, our findings contrast with the observations that treated materials are less preferred than the original, unmodified samples [57]. This suggests that modified wood exhibits tactile and visual properties that are, in terms of human preference, comparable to those of unmodified wood and different to those of wood that has been treated otherwise (e.g., with coating). Splitting the results by country lead to similar findings: wooden samples, regardless of their treatment, generally received similar preference scores within each country (and generally higher than the steel sample), suggesting that potential cultural influences might not substantially influence the perception and evaluation of (modified) wood samples.

Many perceived material properties were associated with the preference for materials in both the tactile and tactile–visual tasks. Materials rated as liked were also rated as somewhat less cold, less damp, more usual, less artificial, less unpleasant, and, only in the tactile–visual task, more expensive and more matte. The observed associations between material properties and preference tend to be minor, which suggests that additional visual and tactile properties, beyond those examined in this study, are important in predicting material preference. Perceived material smoothness, hardness, and colour lightness were not associated with preference scores. Our findings were consistent with some observations reported in the existing literature but not with others. For example, like in our study, Fujisaki and colleagues [36] observed that perceived warmth is associated with higher preference, but in contrast to our study, the same authors observed that perceived dampness was linked to higher preference, while we observed that dryer materials were preferred. This suggests that some properties, such as warmth, might be related to preference of materials in a similar way across different contexts, while some other properties, such as dampness, relate to preference in different ways across contexts.

Comparison of the results between the tactile and tactile–visual tasks showed that the scores of the two tasks correlate with each other. The highest correlation coefficients between the two tasks were observed in the rating items predominantly assessed by touch (e.g., “smooth”), while somewhat weaker correlations were observed in other attributes (e.g., “expensive”), suggesting that the perception of these properties changes to a greater extent when people can inspect materials visually. Interestingly, the correlations on the items “artificial,” “unpleasant”, and “like” were relatively high, comparable to the correlations observed in the items assessing tactile sensory properties, suggesting that the tactile experience importantly influences the perception of naturalness and preference for materials. This finding is consistent with the results of previous studies that reached similar conclusions: tactile domain is important in overall material perception [35,36,48].

The results of this study confirm and extend previous findings showing that wooden materials tend to be more liked than other common materials—in our case, more than steel. The results also suggest that modified wood samples are preferred similarly to unmodified wooden materials. The findings are consistent across Slovenia and Norway, suggesting that different practices of wood use in these two countries do not significantly influence the perception of wooden materials. Preference of materials is associated with certain perceived material properties, and tactile experience has a significant role in the overall perception of materials. Altogether, the results suggest that wood, either unmodified or modified, may be a promising addition to restorative indoor environments, at least when applied to handrails.

3.3 Article 3

In Article 3, we examined preferences of people for different wooden desk materials, desk designs, and desks that combine different designs and materials. In general, the results show considerable variability in preference ratings, suggesting that no single material or desk can satisfy all tastes. Still, the results suggest that some wooden materials

and desks are more liked than others, and that the material, desk elements, arrangement of desk elements, and amount of wood all play an important role in preference.
The both-storage desks (where both sides of the desk had some type of storage) were less liked than both-stand desks (where the same type of legs were used at both sides of the desk) and one-stand-one-storage desks (a mix between the first two desk types). The desks containing the shelf and poles elements were less liked than desks containing other elements (i.e., cabinet, drawers, square, board). The desk design with the board element on one side and the cabinet element on the other was particularly liked.

Some wooden materials, especially oak and maple, were more liked than others, and some other materials, especially spruce, pine, and aspen, were less liked than others. There were no obvious overall relationships between the colour and preference ratings of materials once the three lowest rated materials were excluded. Interestingly, these three materials were lighter in colour, which partially contrasts with the findings by Fujisaki and colleagues [36], who observed that people evaluating the aesthetics of wooden materials not intended for any particular use preferred materials with a lighter colour. Perhaps participants in our study associated very light colour with wooden materials commonly used in construction (e.g., spruce), which they did not consider particularly suitable for use in furniture, such as desks.

Desks with the white material were rated similarly to desks with oak and maple and liked more than desks with guibourtia. This somewhat contrasts with the results of two other studies which observed that wood tends be more appealing to people than some other common materials when used for desk tops [86] and handrails [87]. In these two studies, participants were able to see and touch the materials, and the tactile experience may have contributed to the generally high preference for wooden materials. This could explain the somewhat diverging findings between these studies and the current study, in which participants could only see the images of the materials. Another explanation may be that preferences for materials are context specific. That is, people may prefer wood in some situations or for some products, but are ambivalent or prefer other materials in different uses.

The preference for the desk seems to be higher when it is made entirely of wood or without any wood than when it is made with a medium amount of wood (i.e., when materials are mixed). The preference for wood coverage could thus be different for desks than for rooms, where the opposite trend was observed: a medium amount of wood in a room seem to be preferred to a room furnished without any wood (i.e., white room) and a room made entirely of wood [61].

Taken together, the results suggest that despite the variability of preference ratings, 1) people can discriminate between a variety of (sometimes similar) wooden materials and desks in terms of preference, and 2) preference for a particular desk cannot necessarily be predicted from separate preference assessments of the desk design and wooden material that comprise that desk.

The findings can be seen as some of the initial steps towards designing furnishings that are part of restorative indoor environments. Visually appealing furnishings are likely an important element of restorative spaces, and desks are among the furnishings that might be used frequently, especially in offices.

3.4 Article 4

In Article 4, we investigated the effects of tactile and visual exposure to (untreated and treated) wood, glass, and mineral filled thermoplastic composite desktop materials on cognitive performance and affective states.

When pooled data was inspected (combining all desktop materials), both arousal and pleasure dimensions of affective states decreased after participants rested for 15 minutes sitting at a desk. This suggests that participants were experiencing more feelings such as sleepiness, tiredness, or boredom in the last stage of the experiment. The observed trend of decreasing arousal and pleasure did not differ between materials – wooden materials did not seem to influence the affective states, as we expected. Similar results were observed in the two studies by Tsunetsugu et al. [54,67], where differences in affective states were not detected between the test settings differing in the amount of incorporated wood. However, certain studies did detect an effect of wood exposure on affective states. Compared to the present study, these incorporated a larger amount of wood in their test environments [66] and those who used solid wood also had detectable levels of wood scents in the air [71,73]. The lower amount of wood coverage implemented in our study might be the reason for the diverging results of the present study and other findings. Indeed, according to SRT and ART, environments that are generally richer in natural stimuli are more to likely to benefit humans [11,12]. Perhaps the small desk surface was not stimulating enough to generate these benefits, despite participants being instructed to keep their gaze at the material throughout the experiment. It is also possible that such less intense environmental stimulations might benefit people, but that these benefits would become apparent only during the recovery following an induction of stress or fatigue [47]. As was the case in the examination of affective states, we did not find any differences in cognitive performance between the tested desk materials. Only two existing studies tested the effects of wood exposure on cognitive performance; one did not report the results [72] and the other did not observe any differences between the wooden and non-wooden environment [17]. Despite our results being in line with the latter finding, they run counter to the findings observed in several other studies with similar research protocols, which mainly differ by incorporating other elements of nature instead of wood [2]. While wood may not exhibit attention enhancing properties similar to other elements of nature, it is also possible that other factors played a role. One possibility is that the present study did not sufficiently induce cognitive fatigue. ART is specific to predict *restoration* from induced attention fatigue but not improvement in cognitive capabilities, if these are not fatigued prior to the exposure to natural environments. However, several studies found that exposure to nature improved cognitive performance even without prior induction of attention fatigue, suggesting that other mechanisms, such as changes in affective states, may be important [47]. Another reason for the absence of effects on cognitive performance may be related to the cognitive task we deployed. It has been proposed that cognitive tasks with certain properties are more likely to capture the differences in performance in attention restoration studies. Among other qualities, tasks should be high in cognitive demand, which may not have been the case in this study. Namely, the percentage of correct answers in the Simon task was often in the high nineties, with several sessions where all the answers were correct. Furthermore, the results generally improved on the second administration of the task, suggesting that the employed task was not sufficiently difficult to lead to attention fatigue after the first administration.

Overall, the findings suggest that a visual and tactile exposure to a wooden small desk surface might not be enough to significantly improve human affective states and cognitive performance, even though the study tested a variety of materials.

3.5 Article 5

In Article 5, we tested the suitability of a selected task and outcomes for restoration research, specifically in the context of people's exposure to indoor wood. We aimed to test whether the Mental Arithmetic Task (MAT)[88] reliably induces stress, as reflected in cardiovascular and electrodermal activity, and affective states, as captured by two items assessing pleasure and arousal (based on the circumplex model of affect) [83]. We were additionally interested in whether MAT can be a viable cognitive task in restoration research.

The results show that, on average, MAT may not lead to a reliable stress response. The task generally increased self-reported arousal and most measures of physiological arousal, indicating that it successfully activated participants to an extent. However, MAT did not impact all measures of physiological arousal, and it did not significantly affect the self-reported affective state of pleasure, indicating that the *average* response of participants cannot be straightforwardly interpreted as a stress response, but instead as activation required to successfully meet task demands. Clear stress response in the entire sample may have not appeared mainly due to a subgroup of participants who reacted to MAT positively—with increased affective state of pleasure.

The single-item measures that examined affective states seemed to be sufficiently sensitive to detect changing states of pleasure and arousal for their use to be recommended in restoration research.

The results of MAT showed that participants generally improved from the 1st to 2nd administration on both MAT outcomes: number of provided responses and the proportion of correct responses. This suggests that the potential cognitive fatigue induced by the 1st administration of the task was offset by learning and practice gained from completing the task. Alternatively, participants might have been more distracted at the 1st task administration, before getting acclimatized to the experimental session ahead of the 2nd administration of the task. Higher scores at the 2nd administration of the task could still show positive effects of restorative environments; indeed, many studies exploring attention restoration in natural environments detect higher scores at the 2nd task administration [47,89]. However, the ART claims that exposure to nature *restores* fatigued cognitive capacities [11]. This suggests that the positive effects of natural environments on cognitive performance will be less likely present if participants are not cognitively fatigued and operate at their peak cognitive capacities, leaving the natural environment no maneuvering space: cognitive capacities cannot be restored if they have not been depleted. The role of MAT as a cognitive task in restoration research thus seems limited, at least when MAT lasts only 5 minutes and when the goal is to reliably induce cognitive fatigue. However, MAT might become more useful if it would be longer (to attempt to induce cognitive fatigue) and if the testing condition would be more threatening (to attempt to induce stress), for example, by including a larger evaluative audience.

In Article 5, we also tested whether people's affective states, physiological activity, and cognitive performance differ while they sit behind a larger desk that has either a wooden desktop or a desktop covered with a white cloth. There were no significant differences in the examined outcomes between the two desktop conditions. This can be due to the low number of participants, making the study underpowered to detect presumably small effects of the exposure to a wooden setting. Another reason for the lack of detected differences can stem from the absence of a clear stress response and cognitive fatigue in participants: if participants did not experience stress or cognitive fatigue, it could have been more difficult for the environment to provide restorative effects [47]. The lack of observed differences between environments could also have resulted from the specific wood furnishings: the wooden desk may not have provided sufficient stimulation to induce restorative effects. The existing studies that observed the most promising effects of wood exposure on people used rooms with larger wood coverage [17,71,72], suggesting that even a relatively large desk surface tested in our study might not be sufficiently large to provide restorative effects. The comparison of outcomes between desktop conditions thus revealed that a larger wooden desktop is unlikely to lead to considerable restorative effects, but larger studies might detect potential (smaller) effects of the exposure to wooden desks, especially if the wood coverage increases.

Chapter 4

Conclusions

4.1 Summary

The research presented in this thesis examined the role of wood in restorative environments, contributing to the broader field of studying the impact of the built environment on human wellbeing. Specifically, the research focused on examining how people perceive wood in different contexts and respond to spaces furnished with wooden desktops.

The literature review (Article 1) provides a critical analysis of existing results and methodology in the field of impacts of visual exposure to wood on people. We identified several ways in which the methodology could be improved and synthesised the results of existing studies, which show promising but limited evidence that people are affected positively when they are exposed to wood visually.

Four empirical studies tested whether wooden materials can improve the comfort and wellbeing of building occupants by testing how people perceive and respond to different wooden materials tested in different circumstances (Articles 2, 3, 4 and 5). One study additionally tested a study protocol with a selected task and measurement tools, providing methodological recommendations for future studies (Article 5).

In Article 2, we showed that across two countries—Slovenia and Norway—people expressed similar preference ratings for unmodified and modified wooden handrail samples and generally preferred wood over the control sample (steel). We observed that the tactile experience of materials was important in the overall (tactile and visual) evaluation of materials, and we identified several material properties that were associated with people's preferences for materials. In Article 3, we observed that people's preferences for different desk materials and designs vary widely, but that some materials and designs are on average preferred to others. We showed that the type and amount of desk materials as well as desk design all have an important role in people's preference for visual appearance of desks. In Article 4, we showed that exposure to a small wooden desktop is unlikely to significantly impact people's affective states and cognitive performance. In Article 5, we showed that even a larger desktop surface is unlikely to considerably affect several indicators of human wellbeing. However, the statistical power for this part of data analysis was low, and only large effects were likely to be detected. In the same article, we also showed that the Mental Arithmetic Task did not lead to reliable increases in stress or cognitive fatigue, which suggests that the applied tasks should generally be more stressful and cognitively demanding. We also observed that the single-item measures of affective states were robust and could be used in similar research contexts.

Overall, the findings of the studies reported in this thesis suggest that people tend to prefer wooden materials in different contexts but that visual exposure to wooden desktops is unlikely to significantly impact people's affective states, physiological activity, or cognitive performance. Future studies should continue to examine human preferences for wood in different contexts and try to identify whether spaces furnished with wood can lead to reliable positive impacts on people and which characteristics of those spaces are responsible for the positive effects.

4.2 Contributions to Science and Considerations for Future Research

The findings reported in this thesis examine the role of wood in restorative environments and with this contribute to the broader field investigating the impact of the built environment on human wellbeing. The literature review provides a critical synthesis of existing findings and methodology in the field of human exposure to wood and presents recommendations for future studies, including the guidelines on preparing robust study protocols and selecting suitable psychological and physiological measures (Article 1). The four empirical studies tested if wooden materials have the potential to improve comfort and wellbeing of building occupants, by testing how people perceive and respond to a variety of wooden materials tested in different contexts (Articles 2, 3, 4, 5). One study tested a study protocol with specific approaches and measures that can provide methodological recommendations to future studies (Article 5). Taken together, these studies advance the field by extending knowledge on how people perceive and respond to wood applied in different contexts (and how this relates to specific properties of wood or its application), and by providing methodological insights that can improve future studies on the topic.

The studies reported in this thesis provided several insights on how people perceive and respond to wood, and which methodological approaches and measures are most promising for future research. The studies that examined human preference for wood confirmed and expanded existing findings, showing that people tend to prefer wood in different contexts of wood use. However, these studies also showed that the preferences of people tend to vary and that it is challenging to predict preference for wood in general terms, because the preference for specific type and amount of wood can change depending on the context in which wood is applied. Designers can take hints from our and similar findings, but they must be cautious to select or design furniture that matches the preferences of users, which we have shown vary considerably. Involving users in selecting their materials and furniture may produce the best outcomes in terms of restorativeness.

Our findings could be extended by testing additional wooden materials treated with different processes and applied in different contexts. Based on the current knowledge, it is reasonable to expect that each context of wood use will produce somewhat unique findings in terms of human preference for wood. The role of material properties that influence the perception of materials could be further clarified by testing materials that are similar in all but one property (e.g., varying only on roughness).

The studies that examined how people respond to wood showed that exposures to relatively low amounts of wood coverage are unlikely to lead to large positive impacts. However, it should be noted that smaller but still relevant effects of wood exposure might have been missed by our studies due to the lack of statistical power. Future studies are encouraged to employ larger sample sizes and increased wood coverage to improve the chances of detecting potential restorative effects of wooden settings.

We have provided several methodological recommendations for future studies, from both reviewing the current literature and from our own empirical findings. When examining the effects of wood exposure in built environments, future studies should strive toward simultaneously investigating affective, physiological, and cognitive performance outcomes. By considering the interplay among these concepts we can better understand how people respond to different indoor settings. Each of the incorporated measures should be chosen carefully to fit with each other as well as with the general study design. In general, studies should: 1) incorporate a variety of physiological measures to better encompass variable changes in physiological arousal levels; 2) include a suitable measure of affective states (e.g. a measure of core affect) that will both help explain physiological data and provide additional information about the subjects' response to environments; 3) incorporate an appropriate task assessing executive functions, ideally combined with an intervention that will lead to attention fatigue in participants. The single-item measures of affective states that we tested seem robust, and we encourage other researchers to use them. We also showed that some cognitive tasks might not be sufficiently demanding, which lowers the chances of detecting potential environmental effects on cognitive performance. Future studies are encouraged to employ tasks demanding enough to induce attention fatigue and to avoid the ceiling effect, where the range of the scores is restricted and prevents potential differences between the environments to occur. Researchers are also encouraged to prioritize the investigation of stress *recovery*, that is, capturing subjects' physiological, affective, and cognitive performance outcomes following the induction of stress.

Despite the abovementioned guidelines, future studies may benefit from piloting their experimental design and measures before engaging larger subject pools. Methodological investigations are needed to identify how to induce an adequate degree of stress and cognitive fatigue for restoration studies, which would support more robust and comparable research in the field. For example, testing a longer version of MAT may reveal more about its capacity to reliably induce cognitive fatigue and stress. Similarly, the single-item measures of affective states that we used could be compared with more commonly used (and longer) measures (e.g., Positive and Negative Affect Schedule [90]) in the context of restoration research.

Upcoming studies should also be guided by the theory more closely related to wooden indoor environments, rather than by ART [11] and SRT [12]—the two theories commonly cited to explain the human response to rich, outdoor natural environments, while their value in explaining responses to single elements of nature, such as wood, is likely limited.

Despite conflicting findings, it seems that applying wood indoors has the potential to improve comfort and wellbeing of occupants. Wood can be used in structural, functional, and decorative parts of the building, complementing other elements of nature when the goal is to bring nature indoors. Applying wood indoors is a relatively affordable intervention that can be implemented on a large scale and does not require effort from people, like so many other interventions targeting wellbeing do. For these and other reasons, exposing people to wood indoors is a potential environmental intervention that remains worthy of future investigation.

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Povzetek v slovenskem jeziku

5.1 Uvod

Naravna okolja lahko nudijo pogoje, ki so ugodni za okrevanje po stresu [3]. Pri ljudeh, ki so izpostavljeni elementom narave, se kažejo nižja fiziološka vzburjenost, prijetnejša čustvena stanja in večja kognitivna zmogljivost [2]. Zaradi teh učinkov naj bi bila naravna okolja restorativna, saj obnavljajo (ali izboljšujejo) počutje ljudi. Ker večina sodobnega življenja poteka v zaprtih prostorih [7], imajo ljudje omejen dostop do narave in njenih pozitivnih učinkov. Na srečo je lahko vnašanje narave v notranje prostore izvedljiva in učinkovita rešitev: prisotnost narave v notranjosti lahko povečamo že s fotografijami pokrajin, notranjimi rastlinami ali vonjem svežega cvetja [2].

Pozitivni učinki, ki jih ljudje doživljajo ob stiku z naravo oz. njenimi elementi, se odražajo v človekovih okoljskih preferencah: ljudem je naravno okolje praviloma bolj všeč kot grajeno. Okolja z večjim zaznanim potencialom za nudenje restorativnih učinkov (narava) so v splošnem deležna višjih preferenčnih ocen, posamezniki, ki bolj potrebujejo restoracijo (tisti, ki doživljajo stres), pa kažejo še večje preference do naravnih okolij v primerjavi z grajenimi [13,14]. To kaže, da se lahko okoljske preference uporabljajo kot kazalnik potencialne restorativnosti okolja: prostori, ki so ljudem privlačnejši, bodo verjetneje izboljšali njihovo počutje.

Les kot naravni material je še posebej zanimiv za vnašanje narave v notranje prostore. Za razliko od večine naravnih elementov ga je mogoče uporabiti v konstrukcijskih in funkcionalnih elementih stavbe, kot so tramovi, talne obloge in pohištvo [15]. Vsestranskost lesa izhaja iz njegovih ugodnih mehanskih lastnosti, vključno z visokim razmerjem med trdnostjo in maso, možnostjo strojne obdelave in dimenzijsko stabilnostjo [16]. Večina prikazov biofilnega oblikovanja vključuje prostore, opremljene z lesom [17,18], obstoječe študije pa kažejo, da je stik z lesom koristen za uporabnike stavb. Ljudje imajo raje lesne materiale in okolja; po izpostavljenosti lesu v notranjih prostorih so bolj sproščeni in bolje opravljajo teste kognitivnega delovanja [19–21]. Vendar pa pozitivni učinki izpostavljenosti lesu niso vedno opazni [17,22–24]. To neskladje lahko izhaja iz raznolikosti študij, v katerih so bile preizkušene različne vrste lesa, ki so bile uporabljene v različnih barvah, vzorcih, količinah in postavitvah. Te različne lastnosti bi lahko imele ključno vlogo pri odzivu ljudi na lesene notranje prostore, vendar ni jasno, katere lastnosti lesa so najpomembnejše za sprožitev pozitivnega odziva. Večina študij preučuje, kako ljudje zaznavajo eno ali nekaj vrst lesa v primerjavi z drugimi vsakdanjimi materiali [25], le redko pa se primerja več vrst lesa med seboj.

Za globlji vpogled v metodologijo in ugotovitve obstoječih študij je potreben kritičen pregled literature. Področje je nato potrebno razširiti z empiričnimi študijami, ki temeljijo na sedanjem znanju in ocenjujejo preference ljudi do lesenih okolij in njihov odziv nanje s kombinacijo primernih merskih pristopov. Rezultati teh študij bodo pripomogli k informiranju raziskav in prakse, katerih cilj je izboljšati grajeno okolje za vse uporabnike.

5.2 Raziskovalni nameni, cilji in hipoteze

Splošni cilj predlaganih raziskav je ugotoviti primernost lesa za uporabo v restorativnih notranjih okoljih, kar se odraža v človekovih preferencah do materialov in okolij ter v fizioloških, čustvenih in kognitivnih odzivih na različna notranja okolja. Najprej smo kritično ocenili metodologijo in rezultate obstoječih študij, ki so preučevale odzive ljudi na lesena notranja okolja (Članek 1). Nato smo izvedli štiri empirične študije, v katerih smo preučevali človekove preference in odzive na lesne materiale (v primerjavi z nelesnimi materiali). V prvi empirični študiji (Članek 2) smo preučevali preference ljudi do šestih ograjnih ročajev iz različnih materialov z različnimi obdelavami. Druga empirična raziskava (Članek 3) je preučevala preference ljudi do lesnih materialov, dizajnov miz in dizajnov lesenih miz. Tretja empirična raziskava je preučevala odziv ljudi, ki so bili izpostavljeni desetim različicam majhne površine mize (Članek 4). Četrta empirična raziskava je preverjala odziv ljudi na večjo leseno mizno površino, hkrati pa je preučevala primernost protokola študije za nadaljnje raziskave (Članek 5).

Na splošno smo predvidevali, da bodo imeli ljudje raje lesne materiale kot nelesne in da bodo njihovi fiziološki, afektivni in kognitivni indikatorji dobrega počutja ugodnejši v okoljih z lesom kot v okoljih brez lesa. Natančneje, domnevali smo, 1) da bodo ljudje preferirali vseh pet lesenih ograjnih ročajev v primerjavi s kontrolnim materialom (Članek 2); 2) da bodo udeleženci podali višje preferenčne ocene dizajnom miz z več lesa v primerjavi z mizami z manj lesa (Članek 3) in 3) da bodo čustvena stanja, kognitivna zmogljivost in fiziološko vzburjenje posameznikov ugodnejši, ko bodo izpostavljeni lesenim miznim ploščam v primerjavi z izpostavljenostjo kontrolnim materialom (Članka 4 in 5).

5.3 Materiali in metode

5.3.1 Članek 1

Namen raziskave je bil kritično pregledati metodologijo in rezultate študij, ki so preučevale, kako se ljudje odzivajo na vizualno izpostavljenost lesu v smislu fiziološke aktivnosti, čustvenih stanj in kognitivne zmogljivosti. Za pregled obstoječe literature smo v spletnih bazah podatkov poiskali študije v angleškem jeziku, ki so preučevale vsaj en fiziološki, afektivni ali kognitivni izid kot odziv na vizualno izpostavljenost lesu v notranjih prostorih. Natančneje, v bazah Scopus, JSTOR, Web of Science in Google Scholar smo iskali vse naslove (v angleškem jeziku), ki vsebujejo besedo "les" ali "lesni" skupaj s katerim koli od naslednjih izrazov ali njihovih izpeljank: psihologija, čustva, afekt, razpoloženje, fiziologija, aktiviranost, človeški stres, odziv na stres, pozornost, kognicija. Članke, ki so nastali na podlagi tega iskanja, smo pregledali posamično in za nadaljnji pregled izbrali tiste, ki so izpolnjevali naša merila. Pri analizi teh študij smo kritično ocenili njihovo metodologijo in rezultate. Postopek pregleda literature in poročanja je potekal po načelih, ki jih priporočajo Cochranove smernice za sistematične preglede intervencij [81] in izjave PRISMA za poročanje sistematičnih pregledov literature [82].

5.3.2 Članek 2

Študija je preučevala preference ljudi do različnih lesnih materialov in poskušala povezati preferenčne ocene s subjektivnimi zaznavami različnih lastnosti lesa, kot sta hrapavost in naravnost. Uporabili smo šest valjastih vzorcev ograjnih ročajev; enega iz nerjavečega jekla in pet iz modificiranega ali nemodificiranega lesa. Natančneje, vključili smo ročaje iz nemodificirane smreke, nemodificiranega bora, acetiliranega bora »radiata«, termično modificirane smreke in termično modificiranega bora. V študiji je sodelovalo 100 starejših odraslih, starejših od 60 let, iz Slovenije in Norveške. Študija je bila sestavljena iz treh nalog. Pri prvi nalogi so se udeleženci materialov lahko le dotaknili (ne pa jih tudi videli): dobili so navodilo, da morajo imeti med testom zaprte oči. Na podlagi taktilne izkušnje z materiali so udeleženci podali odgovor na lestvici semantičnega diferenciala (ki sprašuje po senzoričnih in afektivnih lastnostih), ki jim je bila prebrana. Nato so udeleženci ocenili materiale v drugem delu študije: taktilno-vizualni nalogi, pri kateri so se lahko materialov dotikali in jih tudi videli. Tretji del študije je bil sestavljen iz naloge razvrščanja glede na preferenco. Udeležencem so bili predstavljeni vsi materiali hkrati, da so jih lahko pregledali taktilno in vizualno. Materiale so nato razvrstili od najbolj do najmanj priljubljenih, tako da so ob njih položili kartice s številkami od ena (najbolj priljubljeni) do šest (najmanj priljubljeni).

5.3.3 Članek 3

V študiji smo preučevali preference ljudi do pogostih lesnih materialov, dizajnov pisalnih miz in dizajnov lesenih pisalnih miz. Za študijo smo izbrali 20 najpogostejših lesnih materialov, ki se uporabljajo v notranjem pohištvu, in pripravili 18 različic najpogostejših dizajnov miz. Slike teh lesnih materialov in dizajnov pisalnih miz so bile ocenjene v prvi fazi, v kateri je 50 udeležencev ocenjevalo preference do (slik) vseh lesnih materialov in dizajnov pisalnih miz na podlagi devetstopenjske ocenjevalne lestvice (1 – izredno mi ni všeč, 5 – niti všeč niti ne všeč, 9 – izredno všeč). Nato smo pripravili slike 20 lesenih pisalnih miz, ki so združevale tri najbolj priljubljene lesne materiale in dizajne miz iz prve faze študije. V drugi fazi študije je 50 novih udeležencev z isto devetstopenjsko ocenjevalno lestvico podalo svoje preference glede slik teh lesenih pisalnih miz.

5.3.4 Članek 4

V študiji smo preučevali odziv ljudi na sedenje za različnimi površinami pisalne mize. Površine miz so bile izdelane iz 10 različnih materialov z dimenzijami 80 × 80 cm. Med materiali so bili neobdelan smrekov les, naoljen smrekov les, lakiran smrekov les, neobdelan hrastov les, naoljen hrastov les, lakiran hrastov les, neobdelan hrastov furnir, imitacija lesa, steklo (na imitaciji lesa) in termoplastični kompozit z mineralnim polnilom.

Čustvena stanja smo preučevali z dvema lestvicama s po eno postavko, ki zajemata stanja prijetnosti in aktiviranosti [83]. Postavki sta vprašali: "Kako prijetno/aktivirano se počutite v tem trenutku?". Udeleženci so svoje odgovore podali na 9-stopenjski lestvici (1 – izjemno neprijetno/aktivirano, 5 – nevtralno, 9 – izjemno prijetno/aktivirano). Kognitivna zmogljivost je bila ocenjena s Simonovo nalogo, ki meri inhibitorni nadzor – sposobnost premagovanja impulza oz. težnje, ki je posledica notranjih ali zunanjih vabljivih dejavnikov [84].

V študiji je sodelovalo 16 oseb. Udeleženci so raziskavo pričeli ob kontrolni mizi. Pred izvedbo kognitivne naloge in poročanjem o čustvenih stanjih so eno minuto počivali v tišini. Udeležencem je bilo naročeno, naj v vseh obdobjih počitka gledajo na površino mize. Udeleženci so se nato iz kontrolne mize presedli za mizo, ki je bila sestavljena iz enega od 10 različnih materialov (vrstni red materialov je bil izbran naključno). Ponovno so izvedli kognitivno nalogo in poročali o svojih čustvenih stanjih (pred čimer so za mizo počivali 1 minuto). Nato so udeleženci počivali še 15 minut, pri čemer so svoje (gole) roke položili na mizo in jih pustili v mirovanju, njihov pogled pa je bil usmerjen v površino mize. Po počitku so udeleženci še tretjič in zadnjič izvedli kognitivno nalogo in poročali o svojem čustvenem stanju. Udeleženci so celotno seanso ponovili desetkrat, enkrat za vsak material na mizi.

5.3.5 Članek 5

V študiji smo preučevali, kako se posamezniki odzovejo na dejavnost, ki povzroča stres, in kako si opomorejo po njej, ko sedijo za večjo mizo iz lesa (v primerjavi z mizo brez lesa). Lesena miza je bila izdelana iz hrastovega furnirja, saj se je že prej pokazalo, da lahko pohištvo s hrastovim furnirjem pozitivno vpliva na vsaj en parameter človekovega počutja (tj. na koncentracijo kortizola, ki je pogost biomarker stresa) [72]. Poleg odziva na stres in okrevanja po njem smo ugotavljali, ali so vrsta, trajanje in čas izbranih nalog in merilnih pristopov obetavni za uporabo v raziskavah restoracije. V študiji je sodelovalo 22 oseb. Vsak udeleženec je raziskavo začel za majhno mizo bež barve in počival 10 minut. Nato so udeleženci poročali o svojih čustvenih stanjih, opravili kognitivno nalogo, ki povzroča stres (miselno računanje), in drugič poročali o svojih čustvenih stanjih. Nato so se preselili na večjo belo ali leseno mizo (približno 90 x 200 cm), kjer so počivali 10 minut. Pred zaključkom poskusa so udeleženci ponovno poročali o svojih čustvenih stanjih ter izvedli kognitivno nalogo. Skozi celotno raziskavo smo pri udeležencih spremljali elektrodermalno aktivnost, srčni utrip in variabilnost srčnega utripa.

5.4 Rezultati in diskusija

5.4.1 Članek 1

V raziskavi smo pregledali devet študij s skupno 386 udeleženci. Identificirali smo številne pristope, s katerimi bi lahko okrepili metodologijo tovrstnih študij. V več študijah je bila ocenjena fiziološka aktivnost, ki ni bila povezana z ustrezno zasnovo študije ali z drugimi ustreznimi merami, kar je omejilo interpretacijo fizioloških podatkov. Za preučevanje čustvenih stanj je večina pregledanih študij uporabila Profil razpoloženjskih stanj (ang. Profile of Mood States) [74], ki meri šest specifičnih stanj, katera so se zdela pomembna psihiatrom, ki so ocenjevali učinke različnih zdravil na paciente [75]. Ni jasno, zakaj naj bi se ta specifična čustvena stanja spreminjala zaradi notranjih okolij, zato spodbujamo raziskovalce na tem področju, da izberejo orodja za preučevanje čustvenih stanj z utemeljenimi razlogi. Raziskovalce tudi spodbujamo, da preučijo kognitivno zmogljivost pri odzivu na vizualno izpostavljenost lesu, kar je bilo preučeno le v dveh od devetih pregledanih študij [17,72]. Pri preučevanju kognitivne zmogljivosti je potrebno upoštevati več metodoloških pristopov [42,43,47].

Kar zadeva vpliv izpostavljenosti lesu na kazalnike stresa, rezultati štirih študij s krajšim trajanjem izpostavljenosti lesu nudijo razmeroma malo informacij [23,54,66,67]. Štiri od petih študij z daljšim trajanjem izpostavljenosti lesu so ugotovile vsaj nekaj pozitivnih (ali navidezno pozitivnih) izidov v lesenih okoljih [17,70–73]. Fell [17] ter Burnard in Kutnar [72] so zaznali obetavne rezultate v prid lesu, saj je bilo v obeh študijah ugotovljeno, da je fiziološka aktivacija udeležencev v lesenih okoljih nižja. Vendar nobena od študij ni odkrila razlik med okolji pri stopnji okrevanja po stresu, in v obeh primerih ugotovitve niso bile podkrepljene z dodatnimi pozitivnimi izidi na področju čustvenih stanj, fiziološke aktivacije ali kognitivne zmogljivosti. V študijah, ki so jih opravili Zhang idr. [70,71] in Demattè idr. [73], so se v lesenem okolju pokazala prijetnejša čustva, vendar v nobenem primeru ni jasno, ali so na to vplivale vizualne ali olfaktorne lastnosti eksperimentalnih prostorov. Le Fellova [17] študija je poročala rezultate kognitivne zmogljivosti, pri kateri ni bilo razlik med lesnim in nelesnim okoljem.

Na splošno obstoječe raziskave kažejo, da lahko vizualna izpostavljenost lesu vodi do nekaterih pozitivnih izidov, vendar so dokazi omejeni, zato morajo prihodnje študije te ugotovitve potrditi in razširiti.

5.4.2 Članek 2

V študiji smo preučevali 1) splošno preferenco do modificiranega lesa v primerjavi z nemodificiranimi lesnimi materiali (in kontrolnim nelesnim vzorcem – jeklom), 2) povezavo med zaznanimi lastnostmi lesa in preferenco do lesa ter 3) povezavo med taktilnim in taktilno-vizualnim načinom zaznavanja materiala (pri čemer so bili različni materiali predstavljeni kot različni vzorci ograjnih ročajev). Primerjali smo tudi rezultate preferenc med dvema državama z različnima praksama uporabe lesa – Slovenijo in Norveško.

Rezultati o preferenci materialov kažejo, da so bili različni lesni materiali na splošno podobno preferirani in bolj preferirani kot vzorec jekla, ne glede na to, kako so bili vzorci ocenjeni – ali so se jih udeleženci lahko samo dotikali ali pa so se jih lahko dotikali in si jih tudi ogledali. Ti rezultati so v skladu z drugimi študijami, ki so ugotovile, da je les na splošno bolj priljubljen kot drugi tipični gradbeni materiali [15,53]. Vendar so naše ugotovitve v nasprotju z opažanji, da so obdelani materiali manj priljubljeni kot izvirni, nemodificirani materiali [57]. To kaže, da ima modificiran les otipne in vizualne lastnosti, ki so z vidika preferenc ljudi primerljive z lastnostmi nemodificiranega lesa in drugačne od lastnosti lesa, ki je bil obdelan drugače (npr. s premazom). Analiza rezultatov ločeno po državah je privedla do podobnih ugotovitev: vzorci lesa so ne glede na njihovo obdelavo na splošno prejeli podobne preferenčne ocene v obeh državah (in na splošno višje ocene kot vzorec jekla), kar kaže na to, da morebitni kulturni vplivi ne vplivajo bistveno na zaznavanje in vrednotenje vzorcev (modificiranega) lesa.

Številne zaznane lastnosti materialov so bile povezane s preferenco do materialov tako pri taktilni kot taktilno-vizualni nalogi. Materiali, ki so prejeli visoke preferenčne ocene, so bili ocenjeni tudi kot nekoliko manj hladni, manj vlažni, bolj običajni, manj umetni, manj neprijetni ter, samo pri taktilno-vizualni nalogi, dražji in bolj mat. Zaznana gladkost materiala, trdota in svetlost niso bili povezani s preferenčnimi ocenami. Rezultati taktilne in taktilno-vizualne naloge so si med seboj podobni, kar nakazuje, da taktilna izkušnja pomembno vpliva na splošno preferenco do materialov. Ta ugotovitev je skladna z rezultati prejšnjih študij, ki so prišle do podobnega zaključka: taktilno zaznavanje je pomembno za splošno zaznavanje materialov [35,36,48].

5.4.3 Članek 3

Študija je preučevala preference ljudi do različnih lesnih materialov za mize, dizajnov miz in miz, ki združujejo različne materiale in dizajne miz. Na splošno so rezultati pokazali precejšnjo raznolikost pri preferenčnih ocenah, kar kaže na to, da noben material ali miza ne more zadovoljiti vseh okusov. Kljub temu rezultati kažejo, da so nekateri lesni materiali in mize bolj priljubljeni kot drugi ter da imajo material, elementi mize, razporeditev elementov mize in količina lesa pomembno vlogo pri preferencah.

Mize z dvema elementoma za shrambo (na obeh straneh mize sta bila elementa namenjena shranjevanju) so bile manj priljubljene kot mize z dvema stojaloma (na obeh straneh mize so bile uporabljene iste pohištvene noge) in mize z enim stojalom in enim elementom namenjenim shrambi (mešanica med prvima dvema vrstama miz). Mize, ki so vsebovale valjasto nogo in shrambni element s polico, so bile manj priljubljene kot mize, ki so vsebovale druge elemente (tj. element z omarico, predali, kvadratnim stojalom, ploščo, ki služi kot stojalo). Posebej priljubljen je bil dizajn mize z elementom s ploščo na eni strani in elementom z omarico na drugi strani.

Nekateri lesni materiali, zlasti hrast in javor, so bili bolj priljubljeni kot drugi, nekateri drugi materiali, zlasti smreka, bor in topol, pa so bili manj priljubljeni kot drugi. Mize z belim materialom so bile ocenjene podobno kot mize s hrastom in javorjem ter višje kot mize z guibourtio. To je nekoliko v nasprotju z rezultati dveh drugih študij, ki sta pokazali, da je les ljudem običajno bolj všeč kot nekateri drugi pogosti materiali, ko se les uporablja za mizne plošče [86] in ograjne ročaje (Članek 2). Morda imajo ljudje v nekaterih situacijah ali za nekatere izdelke raje les, pri drugih uporabah pa so neopredeljeni ali imajo raje druge materiale.

Zdi se, da je ljudem miza bolj všeč, če je ta v celoti izdelana iz lesa ali pa je popolnoma brez lesa, kot če je izdelana s srednjo količino lesa (tj. če so materiali mešani). Zaželena količina lesa je tako pri mizah morda drugačna kot pri sobah, kjer je bil opažen nasproten trend in sicer da je ljudem bolj všeč soba s srednjo količino lesa kot soba brez lesa (tj. bela soba) in soba, ki je v celoti izdelana iz lesa [61].

5.4.4 Članek 4

V študiji so bili raziskani učinki taktilne in vizualne izpostavljenosti (neobdelanim in obdelanim) vzorcem lesa, stekla in termoplastičnega kompozitnega materiala z mineralnim polnilom na kognitivno zmogljivost in čustvena stanja. Izpostavljenost različnim materialom ni bila povezana z različnimi čustvenimi stanji. Podobni rezultati so bili opaženi v dveh študijah, ki sta jih izvedla [54,67], kjer med testnimi prostori, ki so se razlikovali po količini lesa, niso bile ugotovljene razlike v čustvenih stanjih. Nekatere druge študije pa so zaznale vpliv izpostavljenosti lesu na čustvena stanja. V primerjavi s pričujočo študijo so te študije v svoja testna okolja vključile večjo količino lesa [66], pri tistih, ki so uporabljali masivni les, pa so bile zaznavne tudi vonjave lesa [71,73]. Manjša količina lesa prisotna v naši študiji je lahko razlog za razlike med našimi rezultati in rezultati drugih. Glede na teorijo zmanjšanja stresa (ang. stress reduction theory) in teorijo restoracije pozornosti (ang. attention restoration theory) so namreč okolja, ki so na splošno bogatejša z naravnimi dražljaji, verjetneje koristna za ljudi [11,12]. Morda majhne površine miz niso nudile dovolj stimulacije, da bi vodile do pozitivnih učinkov.

Razlik v kognitivni zmogljivosti ljudi med testiranimi materiali miz nismo zaznali. Le dve obstoječi študiji sta preizkušali učinke izpostavljenosti lesu na kognitivno zmogljivost; ena ni poročala rezultatov [72], druga pa ni opazila nobenih razlik med lesenim in nelesnim okoljem [17]. Čeprav so naši rezultati v skladu s slednjo ugotovitvijo, so v nasprotju z ugotovitvami več drugih študij s podobnimi raziskovalnimi protokoli, ki se razlikujejo predvsem po tem, da so namesto lesa vključili druge elemente narave [2]. Morda les na kognitivno zmogljivost ne vpliva podobno kot drugi elementi narave, možno pa je tudi, da so pri razlagi pomembni drugi dejavniki. Morda nismo povzročili zadostne izčrpanosti kognitivnih virov ali pa smo uporabili nalogo, ki ni bila dovolj kognitivno zahtevna.

V celoti gledano rezultati kažejo, da vizualna in taktilna izpostavljenost majhni leseni površini mize morda ni dovolj za bistveno izboljšanje čustvenega stanja in kognitivne zmogljivosti ljudi, čeprav so bili v študiji preizkušeni različni materiali.

5.4.5 Članek 5

Glavni namen študije je bil preveriti primernost izbrane naloge in izidov za raziskave restoracije, zlasti v okviru izpostavljenosti ljudi lesu v zaprtih prostorih. Sekundarni cilj študije je bil preveriti, ali se testirani fiziološki, čustveni in kognitivni izidi pri ljudeh razlikujejo med lesenimi in nelesnimi notranjimi okolji.

Rezultati so pokazali, da mentalna aritmetična naloga v povprečju ne vodi do zanesljivega odziva na stres. Naloga je na splošno povečala samooceno aktiviranosti in večino meritev fiziološke aktiviranosti, kar kaže, da je udeležence do neke mere uspešno aktivirala. Vendar naloga ni vplivala na vse mere fiziološke aktiviranosti in ni bistveno vplivala na samoocenjeno čustveno stanje prijetnosti, kar kaže na to, da povprečnega odziva udeležencev ni mogoče razlagati kot odziv na stres, temveč kot aktivacijo, potrebno za uspešno izpolnjevanje zahtev naloge. Jasen stresni odziv v celotnem vzorcu se morda ni pojavil predvsem zaradi podskupine udeležencev, ki so se na nalogo odzvali pozitivno - s povečanim čustvenim stanjem prijetnosti.

Zdi se, da so mere čustvenih stanj z eno postavko dovolj občutljive za zaznavanje spreminjajočih se stanj prijetnosti in aktiviranosti, da je njihova uporaba priporočljiva v raziskavah restoracije.

Rezultati mentalne aritmetične naloge so pokazali, da so udeleženci izboljšali rezultate med prvim in drugim reševanjem, tako pri številu podanih odgovorov kot pri deležu pravilnih odgovorov. To kaže, da je trening pridobljen s prvim izvajanjem naloge prevladal nad morebitnim izčrpanjem kognitivnih virov po reševanju naloge. Vloga mentalne aritmetične naloge kot kognitivne naloge v raziskavah restoracije se tako zdi omejena, vsaj kadar naloga traja le 5 minut in kadar je cilj zanesljivo povzročiti izčrpanost kognitivnih virov. Vendar pa bi naloga lahko postala uporabnejša, če bi bila daljša (da bi poskušali povzročiti izčrpanost kognitivnih virov) in če bi bilo testno okolje bolj ogrožajoče (da bi poskušali povzročiti stres), na primer z vključitvijo večjega ocenjevalnega občinstva.

Čustvena stanja, fiziološka aktivnost in kognitivna zmogljivost se niso razlikovali med različnimi tipi mize (tj. lesena miza v primerjavi z mizo pokrito z belim prtom). To je lahko posledica majhnega števila udeležencev, zaradi česar je imela študija prenizko statistično moč za odkrivanje domnevno majhnih učinkov izpostavljenosti lesu. Drugi razlog za odsotnost razlik lahko izhaja iz odsotnosti jasnega odziva na stres in kognitivne izčrpanosti pri udeležencih: če udeleženci niso doživljali stresa ali kognitivne izčrpanosti, bi lahko okolje težje nudilo restorativne učinke [47]. Pomanjkanje razlik med okolji bi lahko bilo tudi posledica specifične aplikacije lesa: lesena miza morda ni zagotavljala zadostne stimulacije, da bi povzročila restorativne učinke. V obstoječih študijah, v katerih so opazili najbolj pozitivne učinke izpostavljenosti lesu na ljudi, so bili uporabljeni prostori z večjo količino lesa [17,71,72], kar kaže na to, da tudi razmeroma velika površina mize, preizkušena v naši študiji, morda ni bila dovolj velika za zagotavljanje restorativnih učinkov. Primerjava rezultatov med mizami je tako pokazala, da večja lesena površina mize verjetno ne more povzročiti znatnih restorativnih učinkov, vendar bi večje študije lahko odkrile morebitne (manjše) učinke izpostavljenosti lesenim pisalnim mizam, zlasti če se poveča količina vključenega lesa.

5.5 Zaključek

Raziskave predstavljene v tej disertaciji preučujejo vlogo lesa v restorativnih okoljih in s tem prispevajo k širšemu področju preučevanja vpliva grajenega okolja na človekovo počutje. Pregled literature vsebuje kritično analizo obstoječih rezultatov in metodologije na področju učinkov izpostavljenosti lesu na ljudi ter predstavi priporočila za prihodnje študije, vključno s smernicami za pripravo kakovostnih študijskih protokolov ter izbiro ustreznih psiholoških in fizioloških merskih orodij (Članek 1). V štirih empiričnih študijah smo preverili, ali lahko leseni materiali izboljšajo udobje in počutje uporabnikov stavb, in sicer s testiranjem, kako ljudje zaznavajo in se odzivajo na različne lesne materiale, preizkušene v različnih okoliščinah (Članki 2, 3, 4 in 5). V eni raziskavi je bil preizkušen protokol študije z izbrano nalogo in merskimi orodji, kar nudi metodološka priporočila prihodnjim študijam (Članek 5). V celoti gledano raziskave prispevajo znanje o tem, kako ljudje zaznavajo in se odzivajo na les, uporabljen v različnih kontekstih (in kako je to povezano s specifičnimi lastnostmi lesa oz. aplikacije lesa), ter nudijo metodološka priporočila, ki lahko pripomorejo prihodnjim študijam na tem področju.

Kljub nasprotujočim si ugotovitvam se zdi, da ima uporaba lesa v notranjih prostorih potencial za izboljšanje udobja in počutja ljudi. Les se lahko uporablja v konstrukcijskih, funkcionalnih in dekorativnih delih stavbe ter dopolnjuje druge naravne elemente, kadar je cilj vnesti naravo v notranje prostore. Uporaba lesa v notranjih prostorih je razmeroma cenovno dostopna intervencija, ki se lahko implementira v velikem obsegu in od ljudi ne zahteva truda, kot to počnejo številni drugi posegi, namenjeni izboljšanju počutja. Zaradi teh in drugih razlogov je izpostavljanje ljudi lesu v notranjih prostorih potencialna okoljska intervencija, ki jo je vredno raziskovati tudi v prihodnje.