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Research Article

Psychological and physiological effects of visual stimulation with artificial natural structures and indoor plants: A randomized controlled trial

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Abstract: (1) Background: The link between natural environments and positive effects on humans is well established. Spending time in nature or naturally designed spaces is associated with positive physiological and psychological effects. We wanted to investigate whether positive effects could also be observed with structures that were created completely digitally. (2) Methods: For this purpose, we conducted a three-arm randomized controlled trial to test the following main hypothesis: Viewing artificial natural structures has positive effects on participants, comparable to the effects of an indoor plant. We expected the artificial natural structures to lower stress, blood pressure, and pulse, and to improve emotional aspects such as well-being and relaxation. For this purpose, we carried out two interventions and a control situation. Mixed ANOVAS were conducted to test the hypotheses. (3) Results: We found a significant interaction effect for the variable stress. The stress level, assessed on a four-point scale, decreased the most in the group with the artificial natural structures, from 2.10 to 1.63 between pre- and post-intervention. Furthermore, the participants rated the artificial natural structures as significantly more aesthetic than the indoor plant. (4) Conclusion: The study provides indications of a positive effect of the artificial natural structures.

Implications: This randomized controlled study investigates the effectiveness of artificially designed structures in terms of psychological and physiological parameters compared to plants. These structures are particularly suitable for use in urban spaces where real nature cannot flourish (e.g., subway stations). The study shows initial evidence of a positive effect on stress, which was stronger than in the control group. However, some limitations, such as a small sample size, need to be considered when interpreting the results. Further research is warranted.

Keywords: houseplants; stress; well-being; design; aesthetics; health; nature; urbanization

1. Introduction

More people live in urban areas than in rural areas since 2007. Currently, more than 4 billion people are living in cities, and the trend is rising. This development is particularly strong in high-income countries. In Western Europe, America, Australia, Japan, and the Middle East, more than 80 per cent of the population lives in urban areas (Ritchie & Roser, 2018). Although urbanization sometimes brings positive changes to people's health, such as increased access to social or health services, people living in cities may also face increased health risks (Montgomery, 2008). For example, urbanization may be associated with an increase in lifestyle risk factors such as physical inactivity, low fruit and vegetable consumption, and high body mass index, which may ultimately lead to an increased risk of cardiometabolic disease (Riha et al., 2014). Increasing urbanization may also have negative consequences on mental health. A literature review including 113 studies suggests an association between living in an urban area and lower mental health due to social, economic, and environmental factors prevalent in cities. These include social inequalities, social insecurity, pollution, and lack of contact with nature (Ventriglio et al., 2021). Some mental illnesses, such as depression (He et al., 2020), eating disorders (Gorrell et al., 2019), schizophrenia (Richter et al., 2021), and anxiety disorders (Cho et al., 2016), are more common in urban areas than in rural areas. A representative study in Germany examined the relationship between urbanization and the prevalence of psychiatric disorders. The results showed that higher levels of urbanization were associated with higher 12-month prevalence rates for almost all major psychiatric disorders. The weighted prevalence percentages were highest in the most urbanized category (Dekker et al., 2008).

Conversely, a natural environment has positive effects on people. Numerous studies support this assumption, as the following examples illustrate. A previous review investigated the effects of different forms of nature therapy, including forest therapy/forest bathing, urban green space therapy, plant therapy, and wood material therapy (Song et al., 2016). The included studies were examined in terms of physiological indicators such as brain activity, autonomic nervous system activity, endocrine activity, and immune activity. The researchers found positive effects of the nature therapy forms and attribute great importance to this form of health promotion in the future (Song et al., 2016). Mental health also appears to benefit from nature and nature-based spaces. Mindfulness-based stress reduction (MBSR) training conducted in a natural outdoor setting leads to better mental health and well-being than the same training conducted indoors (Choe et al., 2020). Viewing indoor plants can also have positive effects, such as higher scores for comfort, naturalness, relaxation, increased positive mood (Jeong & Park, 2021), or decreased feelings of stress (Beukeboom et al., 2012). However, not only viewing real plants can result in positive reactions. Viewing artificial plants (Jeong & Park, 2021) or images depicting natural sceneries (Beukeboom et al., 2012; Jiang et al., 2020; Song et al., 2018) is also associated with greater well-being. When viewing landscape images, participants sometimes felt more nature-oriented, relaxed, and at ease and had lower anxiety scores than after viewing images depicting urban scenes (Jiang et al., 2020).

The color green is often associated with positive emotions such as relaxation and comfort (Kaya & Epps, 2004). Thus, the color design of the environment alone can have positive effects on people. However, a new study shows that the positive effect is due to an image of plants rather than to the green color. The combination of green color and an image of plants seems to be particularly health promoting (Michels et al., 2022). Healthcare providers can take advantage of these effects as part of health promotion efforts. Patients placed in a room with plants after surgery had lower systolic blood pressure, less pain, and less anxiety and fatigue than patients in the control group (Park & Mattson, 2009). The positive effects associated with exposure to nature and images of nature may be explained in part by the perceived attractiveness of the environment, plants, and images (Beukeboom et al., 2012; Dijkstra et al., 2008). In addition to attractiveness, there are other explanations for the healing effect of nature. For example, the biophilic hypothesis (Wilson, 1984) suggests that the love of nature and all living things is genetically ingrained in us humans. Another possibility is that a close connection to nature brought a survival advantage when humans lived in even more natural environments. It can be assumed that people who had knowledge about the weather, plants, and the environment were more likely to survive than people who had a poor connection to their environment and its opportunities and dangers (Buss, 2000).

In many healthcare settings, the use of real plants is either impractical or sometimes even prohibited, including in hospitals and clinics due to hygiene standards. For example, fungal spores associated with mycoses in patients may be present in plant soil (Summerbell et al., 1989). In addition, indoor plants cannot always be used safely in nursing homes because people with dementia sometimes tend to eat the plants or soil (Rappe & Lindén, 2004). For these environments, effective alternatives for real plants may be important. In summary, both natural and artificial plants and images of nature have a positive effect on people. It is assumed that this is due to the perceived attractiveness of the objects. Although, as described, several studies have already been conducted that examine the impact of nature, plants, depictions of nature, or artificial plants, we are not aware of any study that investigates the effect of artificially designed structures on people. Therefore, the present study represents a relevant addition to the currently available knowledge in this field of research.

2. Aims and hypotheses

The study aimed to investigate whether artificial natural structures have the same or a similar effect on participants as the sight of real natural objects such as an indoor plant. Within the framework of the study, we wanted to investigate the effect on the participants' stress perception, mood, blood pressure, and pulse. In addition, we aimed to find out which installation (indoor plant or artificial natural structures) the participants find more visually appealing and which room atmosphere they find more pleasant. Especially in environments where real indoor plants cannot be used – for example operating theatres, hospitals, etc. – artificial natural structures could be a good alternative due to their flexible and cost-effective applicability. This project aimed to develop an aesthetic, health-promoting, and cost-effective biophilic design for flexible use in rooms and buildings.

We had three hypotheses:

1. Viewing artificial natural structures has positive effects (less stress, better mood, lower blood pressure, and lower pulse) on the participants, comparable to the effects of an indoor plant.
2. The participants perceive the atmosphere in the room with the artificial natural structures to be just as pleasant as the atmosphere in the room with the indoor plant.
3. The participants perceive the artificial natural structures to be just as visually appealing as the indoor plant.

3. Materials and methods

Before the start of data collection, we registered the study procedure at the Center for Open Science (Bettinger & Schweighart, 2022a). In addition, a study protocol was published in advance (Bettinger & Schweighart, 2022b). The second author developed the nature-imitating installation as part of his master's degree in information design. Fractal geometry served as a source of inspiration, as it occurs frequently in nature. It describes the hierarchical repetition of the same shape on several scaling levels (Ball, 2016). The structure examined here is based on a purely technical-looking basic form that the author designed digitally. The initial element was created through duplication at different scaling levels. In the second stage, we arranged numerous basic elements into an expanded shape, which again resembled the fundamental shape. The result was an organic structure that can now be combined with identical elements to create a larger structure. The distinct scaling levels of the structure are detailed in the study protocol by Bettinger & Schweighart (2022b). We then proceeded to laser-cut the structure from dark green polyester felt sheets. The characteristic of polyester accentuates the artificial aspect of the structure. Additionally, due to its texture, felt is appropriate as its fibers evoke moss. Ultimately, an installation of about 2 meters by 1.5 meters was created, which could be mounted on the wall. A picture of the artificial natural structures, attached to the wall, can also be seen in the article by Bettinger & Schweighart (2022b).

3.1. Participants

We included participants in the study who met the following inclusion criteria: (1) they were older than 18 years; and (2) they were able to voluntarily consent to the study. Participants were excluded if any of the following exclusion criteria were met: (1) they knew about the project in advance; (2) they were severely visually impaired; and (3) they had a mental illness. Detailed demographic characteristics of the sample can be found in the results section.

3.2. Recruitment

We invited potential participants who met the inclusion criteria to take part in the study. Recruitment occurred via social media networks such as local Facebook groups, but also by using information signs in the area near the university. Interested persons could participate in the study without pre-registration. Before data collection, the aim of the study, the procedure, and the data protection were explained to the participants in detail verbally and in writing. Subsequently, the subjects gave their written consent. Upon consent, we checked whether the participants met the inclusion criteria. If the inclusion and exclusion criteria were checked positively, the interested participants took part in the study. Participants could withdraw from the study at any time during the data collection until the completion of the data analysis. For this purpose, the participants' contact details were assigned to an identification number using a list. We destroyed this list after the completion of the data analysis. Withdrawal from participation was no longer possible thereafter. We informed the participants of this in advance.

3.3. Randomization process

3.4. We assigned participants to one of the three conditions using computer-generated randomization software (https://zufallsgenerator.app/). This happened after they completed the first questionnaire and had their blood pressure and pulse measured.*Sample size*

We calculated the sample size a priori with GPower (Faul et al., 2009). Assuming an effect size of .20, an alpha level of .05, a power of 80 per cent, three groups, and two measurement time points, this resulted in a required sample of 66 subjects. However, this number was not reached. A total of 51 people were included in the study. The primary reason for not reaching the desired number of participants is that the experiment was only set up for two days. We used facilities of the university for the study, which unfortunately we could not use for a longer period. A repeat of the experiment was not possible, as due to being a master's thesis, the study was time-limited.

3.5. Procedure

In this study, we investigated two interventions and one control situation. In room 1, participants saw the artificial natural structures placed on a wall. In an identical room, an indoor plant (ivy, Latin name: Epipremnum aureum) was placed on the same wall. Both installations took up the same area on the wall (about 2 meters by 1.5 meters). In the control room, which also was identical in construction, the wall remained empty. In all three rooms, we placed identical chairs at the same distance from the center of the wall (2.5 meters) for the participants to sit on. The rooms were painted white and the windows were darkened during the study to exclude effects due to different lighting conditions. The temperature was kept constant in all three rooms and we reduced background noise near the experimental rooms as much as possible. Figures 1,2, and 3 illustrate the experimental set-up in the three different rooms.

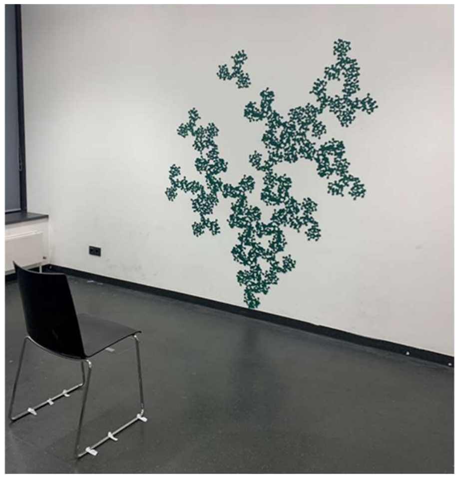

Figure 1. Study setup Room 1

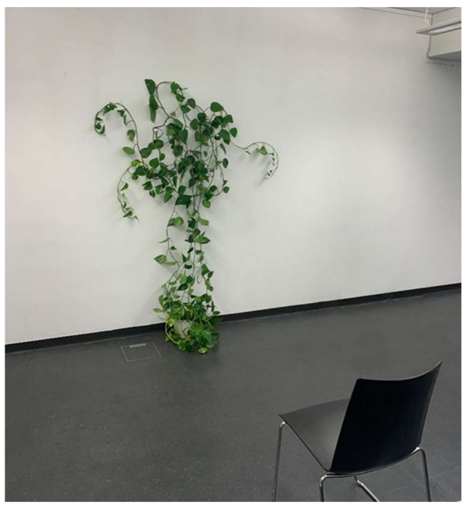

Figure 2. Study setup Room 2

Figure 3. Study setup Room 3

We conducted the study on two consecutive days. When the study participants arrived, they received information about participation in the study and an informed consent form. After they returned the signed consent form, we collected baseline data, which took approximately 10 minutes. First, we measured the participants' pulse and blood pressure and then asked them to fill out a questionnaire. We attempted to minimize potential confounding factors during data collection by ensuring the data was collected in a quiet room where there were no other individuals present. Moreover, pulse and blood pressure were always measured by the same person.

Subsequently, randomization was performed with the assistance of computer software. There was no blinding in the study, as we were aware of the subject's group assignment. Blinding of the study conductors could not be carried out due to personnel resources. After the assignment, we escorted the participants to their respective rooms. We asked them to sit on the chair and to stay there for the duration of the study, to put their mobile phone on airplane mode, and not to use it. Then the intervention took place by leaving the participants in the assigned room for three minutes. We assumed that after this time the expected effects will be measurable since in the study of Ochiai et al. (2017) effects were already detectable after one minute following visual stimulation by a bonsai plant. After the three-minute intervention phase, the participants stayed in the room and we collected the data at time point T2. We measured pulse and blood pressure a second time, and then the participants filled out the second questionnaire. The participant journey from recruitment to completion is shown in Figure 4.

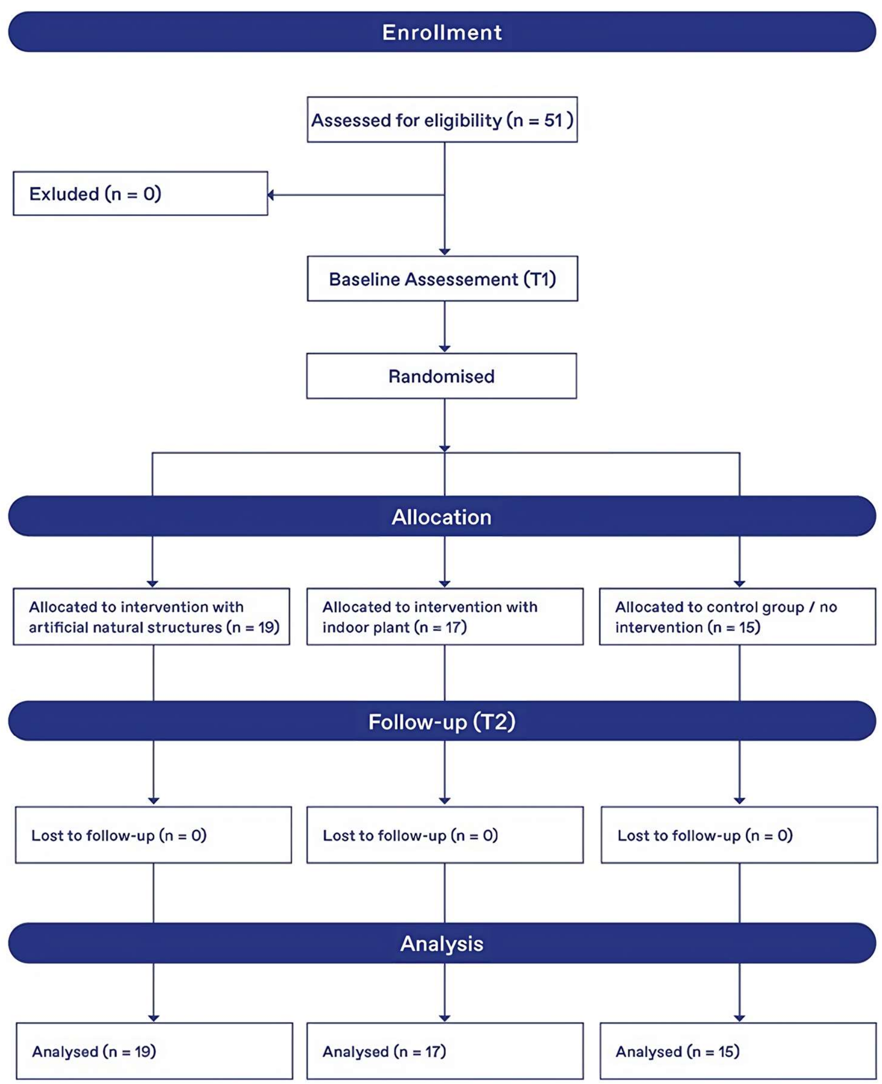

Figure 4. Study procedure from recruitment to the analysis

3.6. Measurements

We first collected sociodemographic information using a questionnaire that assessed gender, age, school-leaving certificate, and marital status. Stress was collected as the primary measure. For this purpose, we used the Short Regensburg Stress Scale (StReSS-10), which contains 10 items from the commonly used Perceived Stress Questionnaire (PSQ) (Levenstein et al., 1993). We chose this instrument because it is based on the PSQ, but the instructions ask about current feelings of stress and do not collect data concerning the last four weeks as in the PSQ. For the German version of the 20-item PSQ, good values for the internal consistency of the scales were found (Cronbach's alpha between .79 and .87). Validation of the German version of the PSQ also provides evidence for construct validity as well as external validity (Fliege et al., 2001). Secondary measures include physiological values such as pulse and blood pressure. For this purpose, we used a device that measures pulse and blood pressure at the wrist (Curamed BDU 751). Moreover, secondary measures include current mood, for which we used the German Current Mood Scale (ASTS) (Dalbert, 2002), an instrument adapted from the Profile of Mood (POMS) (McNair et al., 1971). This instrument assesses mood, using 19 items and 5 subscales (sadness, hopelessness, fatigue, anger, and positive mood). We have decided on the above-mentioned instruments for the recording of stress (StReSS-10 based on PSQ) and mood (ASTS based on POMS), as these are validated, often used, and record the measures important to us. In addition, semantic differentials (SD) were used to measure mental conditions. On a 10-item scale, at the end of which there were pairs of opposites (relaxed – unrelaxed, anxious – not anxious, well-being – no well-being, satisfied – not satisfied), the test persons were asked to rate their respective condition. A seven-point scale covering different facial expressions (very happy face - very sad face) was also included in the questionnaire. We assessed the room's atmosphere using three self-developed items (I found the atmosphere of the room pleasant; I felt comfortable in the room; I enjoyed spending time in the room) ranging from 1 = "I do not agree at all" to 5 = "I totally agree". We further assessed the aesthetics of the installations of room 1 and room 2 using a 10-point semantic differential from very aesthetic to not at all aesthetic.

3.7. Data Analysis

All analyses were conducted using Statistical Package for the Social Sciences (SPSS) version 29.0 and were tested at .05 significance level. Cronbach's alpha was acceptable to excellent for all variables with values between .75 and .95. Baseline characteristics were compared between the three groups using chi-square tests for categorical variables, Kruskall-Wallis tests for ordinal variables, and one-way Analyses of variance (ANOVAs) for continuous variables or Kruskal-Wallis tests when the assumptions for an ANOVA were not met. To test for differences in the ordinal-scaled items before and after visual stimulation, we performed Wilcoxon-signed-rank tests. If visual inspection of the histogram of difference scores did not reveal a symmetrical distribution of scores, we performed sign tests to examine changes between pre- and post-measurement. In the following, a 3x2 mixed between-within ANOVA was carried out with the between-subjects factor group and the within-subjects factor time. We included all continuous variables, such as blood pressure, pulse, stress, and the mood scales (ASTS). We first checked the data for normal distribution and transformed it if necessary. For this purpose, the inverse transformation was used due to highly skewed data. Despite the transformation, no normal distribution could be achieved for the Anger scale at both measurement times, which is why it is not considered any further. This is largely due to an extreme left skew, as all participants exhibited little to no anger. We then checked the data for outliers using box plots. There were only slight outliers, which is why all cases were evaluated unchanged and no cases were excluded. The fact that the within-subject factor time has only two levels in our study means that sphericity is given and we do not need to control this with the Mauchly test. The homogeneity of variance was examined. Levene's test of equality of error variance yielded that there was no significant difference between the variances of the groups. Finally, Box's tests of equality of covariance matrices were examined. The values were not significant for all variables (p > .05). Finally, we were interested in whether the participants perceived the wall installations as aesthetically similar and whether there were differences between the groups in terms of the atmosphere of the room. To investigate this, we calculated a t-test to answer the question about differences in the atmosphere of the room, as this was a continuous scale. Aesthetics were measured using a ten-point single item (SD), so in this case we calculated a Mann-Whitney-U test to test for group differences.

4. Results

The majority of participants were female (63%) and relatively young (mean = 24.50 years; SE = 8.43). Of the respondents, 43 % were single, while 57 % reported being in a relationship. All but one person stated that they had graduated from the highest education level in Germany. The socio-demographic variables of the study participants as well as the values of the primary and secondary measurements can be found in Table 1. The table further demonstrates that the tests for group differences at Baseline showed no significant differences in the variables (p > .05).

Table 1. Socio-demographic variables as well as primary and secondary measurements including baseline differences

Outcome variables (instrument)	**Group 1 (artificial natural structures) n = 19**	**Group 2 (indoor plant) n = 17**	**Group 3 (control group) n = 15**	**p-values**
Age[a]	M = 25.26 SE = 2.21 MD = 23.00	M = 24.71 SE = 2.41 MD = 22.00	M = 23.21 SE = 1.02 MD = 22.00	.923
Gender[b]	Male n = 7 Female n = 12	Male n = 6 Female n = 11	Male n = 6 Female n = 9	.962
Marital status[b]	Single n = 9 In a relationship n = 10	Single n = 7 In a relationship n = 10	Single n = 6 In a relationship n = 9	.893
School-leaving certificate[b]	Highest school leaving certificate n = 18 Intermediate school leaving certificate n = 1	Highest school leaving certificate n = 17 Intermediate school leaving certificate n = 0	Highest school leaving certificate n = 15 Intermediate school leaving certificate n = 0	.424
Systolic blood pressure[c]	M = 143.00 SE = 5.03	M = 146.41 SE = 6.71	M = 137.27 SE = 3.77	.512
Diastolic blood pressure[c]	M = 87.16 SE = 2.03	M = 95.00 SE = 5.11	M = 87.10 SE = 2.24	.355
Pulse[c]	M = 80.10 SE = 2.87	M = 76.59 SE = 3.75	M = 80.10 SE = 2.74	.673
Stress (StReSS-10)[a]	M = 2.10 SE = .10 MD = 2.00	M = 2.12 SE = .11 MD = 2.10	M = 2.00 SE = .11 MD = 1.90	.379
Grief (ASTS)[a]	M = 1.84 SE = .21 MD = 1.67	M = 1.94 SE = .24 MD = 1.67	M = 2.04 SE = .27 MD = 1.67	.834
Anger (ASTS)[a]	M = 1.50 SE = .20 MD = 1.00	M = 1.22 SE = .13 MD = 1.00	M = 1.29 SE = .22 MD = 1.00	.360

Tiredness (ASTS)[a]	M = 3.40 SE = .31 MD = 3.00	M = 3.28 SE = .28 MD = 3.00	M = 3.30 SE = .30 MD = 3.50	.970
Hopelessness (ASTS)[a]	M = 1.63 SE = .18 MD = 1.67	M = 1.67 SE = .20 MD = 1.33	M = 1.53 SE = .24 MD = 1.00	.556
Positive Mood (ASTS)[c]	M = 4.8 SE = .25	M = 4.8 SE = .24	M = 4.9 SE = .20	.976
Relaxation (SD)[a]	M = 6.37 SE = .40 MD = 7.00	M = 6.53 SE = .45 MD = 6.00	M = 6.47 SE = .45 MD = 6.00	.965
Anxiety (SD)[a]	M = 2.16 SE = .37 MD = 2.00	M = 2.09 SE = .48 MD = 2.00	M = 2.07 SE = .45 MD = 2.00	.855
Well-being (SD)[a]	M = 7.05 SE = .41 MD = 8.00	R1 M = 6.88 SE = .44 MD = 7.00	M = 7.87 SE = .34 MD = 8.00	.249
Contentment (SD)[a]	M = 7.16 SE = .47 MD = 8.00	M = 7.29 SE = .48 MD = 8.00	M = 7.33 SE = .47 MD = 8.00	.999
Facial Expression[a]	M = 2.63 SE = .23 MD = 3.00	M = 2.35 SE = .19 MD = 2.00	M = 2.33 SE = .21 MD = 2.00	.630

M = Mean

SE = Standard error

MD = Median (is given if the non-parametric Kruskal-Wallis test was used)

StReSS-10 = Short Regensburg Stress Scale

ASTS = Current Mood Scale (aktuelle Stimmungsskala)

SD = semantic differential

[a] Kruskal-Wallis test

[b] Chi-square test

[c] One-way ANOVA

Table 2 illustrates the results of the analyses to investigate whether there were differences in the semantic differentials between measurement time points 1 and 2. For group 1, who received the intervention with the artificial natural structures, we found significant differences in the variables relaxation, anxiety, well-being, and facial expression. For those variables, we noticed an improvement after the intervention (relaxation and well-being increased, anxiety decreased, facial expression became happier). For group 2 (indoor plant), significant differences were found in the areas of relaxation and well-being, again with improvements. Concerning group 3 (control group) we found a significant increase in relaxation after the intervention. In addition, anxiety decreased significantly.

Table 2. Differences in ordinal variables between the two measurement times for each group independently

		Relaxation	Anxiety	Well-being	Contentment	Facial Expression
Group 1	M/MD T1	6.37/7.00	2.16/2.00	7.05/8.00	7.16/8.00	2.63/3.00
	M/MD T2	8.00/8.00	1.26/1.00	8.00/8.00	7.79/8.00	2.11/2.00
	z-Value	**2.58**[a]	**-3.10**[b]	**2.07**[b]	1.90[a]	**-2.21**[b]
	p-Value	**.010***	**< .001***	**.035***	.057	**.027***
Group 2	M/MD T1	6.53/6.00	2.06/2.00	6.88/7.00	7.29/8.00	2.35/2.00
	M/MD T2	7.94/8.00	1.59/1.00	7.88/8.00	7.82/9.00	2.11/2.00
	z-Value	**2.60**[b]	-1.94[a]	**2.21**[b]	.988[a]	-1.41[a]
	p-Value	**.006***	.052	**.021***	.323	.157
Group 3	M/MD T1	6.47/7.00	2.07/2.00	7.87/8.00	7.33/8.00	2.33/2.00
	M/MD T2	8.00/9.00	1.27/1.00	7.73/8.00	6.93/8.00	2.47/2.00
	z-Value	**3.10**[b]	**-2.04**[b]	-.24[a]	-.603[b]	.707[a]
	p-Value	**< .001***	**.031***	.809	.549	.480

M = mean value

MD = median

T1 = first measurement time

T2 = second measurement time

[a] Wilcoxon signed-rank test

[b] Sign test

Bold and * = significant

The computation of the mixed ANOVA yielded the following results: we found a significant interaction effect of time × group for the variable stress (F(2,48) = 5.132, p = .010, partial η^2 = .176). According to Cohen, there is a strong effect (< .14). Simple main effects analyses revealed significant differences between the measurement time points for group 1 (F(1) = 48.763, p < .001, partial η^2 = .730) and group 2 (F(1) = 13.412, p = .002, partial η^2 = .456). Again, we found strong effects in each case. No significant simple main effect of the within-subjects factor time was found for group 3 (F(1) = 1.755, p = .207, partial η^2 = .111). We found no other significant interaction effects for the other variables. Table 3 shows the results of the ANOVA analyses including the mean values and standard errors of the variables over time for each group.

Table 3. Results of the mixed ANOVA

Outcome variables	Group 1		Group 2		Group 3		Time effect			Group effect			Group-time interaction		
	M (SE) T1	M (SE) T2	M (SE) T1	M (SE) T2	M (SE) T1	M (SE) T2	F	p	Partial η^2	F	p	Partial η^2	F	p	Partial η^2
Systolic blood pressure	143.00 (5.03)	143.26 (5.38)	146.41 (6.71)	141.59 (5.72)	137.27 (3.77)	136.67 (3.66)	.581	.450	.012	.567	.571	.023	.499	.610	.020

Diastolic blood pressure[a]	87.16 (2.03)	90.47 (2.99)	95.00 (5.11)	91.12 (2.97)	97.07 (2.34)	91.60 (2.78)	1.412	.241	.029	.363	.698	.015	1.187	.314	.047
Pulse	80.05 (2.87)	77.26 (2.43)	76.59 (3.75)	71.47 (2.98)	80.07 (2.74)	75.80 (2.21)	**13.85**	**<.001***	**.224**	.843	.437	.034	.417	.661	.017
Stress[a] (Scale 1-4)	2.10 (.09)	1.63 (.08)	2.12 (.11)	1.75 (.10)	1.99 (.11)	1.89 (.11)	**43.15**	**<.001***	**.473**	.344	.711	.014	**5.132**	**.010***	**.176**
Grief[a] (Scale 1-7)	1.84 (.21)	1.68 (.21)	1.94 (.24)	1.55 (.16)	2.04 (.27)	1.89 (.29)	**9.677**	**.003***	**.168**	.234	.792	.010	.414	.664	.017
Tiredness (Scale 1-7)	3.39 (.31)	3.09 (.34)	3.28 (.28)	2.69 (.31)	3.30 (.30)	3.30 (.35)	**6.517**	**.014***	**.120**	.305	.739	.013	2.018	.144	.078
Hopeless-ness[a] (Scale 1-7)	1.63 (.18)	1.46 (.14)	1.67 (.20)	1.55 (.20)	1.53 (.24)	1.38 (.16)	2.777	.102	.055	.323	.725	.013	.094	.911	.004
Positive Mood (Scale 1-7)	4.81 (.25)	4.93 (.26)	4.82 (.24)	4.87 (.23)	4.88 (.20)	4.68 (.29)	.013	.910	.000	.039	.962	.002	1.331	.274	.053

[a] = inverted variables

M (SE) T1 = mean value and standard error first measurement time

M (SE) T2 = mean value and standard error second measurement time

η^2 = effect size (partial eta square)

Bold and * = significant

Figure 5 shows that the stress level within the two measurement time points decreased the most in group 1, followed by group 2, while in group 3 it decreased the least.

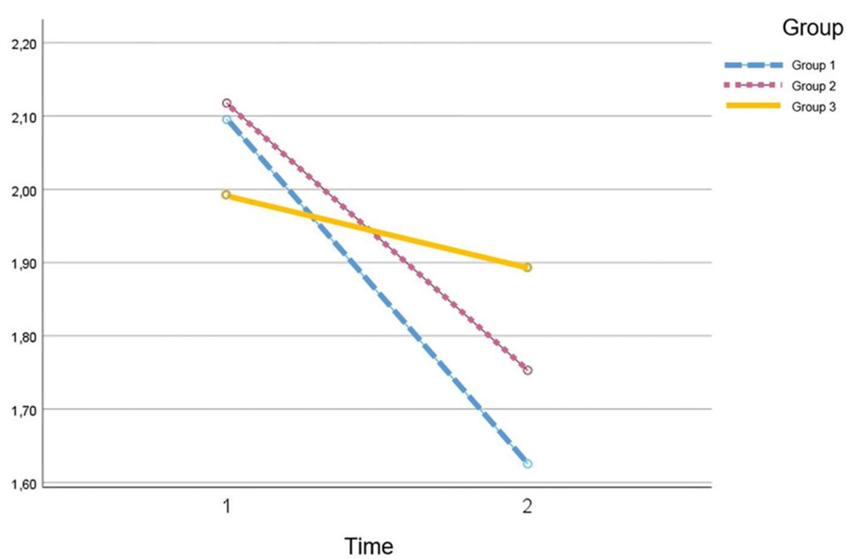

Figure 5. Change in stress level within the three groups between pre-test and post-test

We expected that participants in the two rooms with installations would find the atmosphere similarly pleasant and the installations similarly visually appealing. The results show that the participants who were assigned to room 1 and thus underwent an intervention based on the artificial natural structures rated them as significantly more aesthetic than the participants in room 2 who looked at the indoor plant. Table 4 also shows that there was no significant difference in the perceived atmosphere of the room. Spearman's Rho showed a strong positive correlation between the atmosphere and aesthetics of the installation (ρ = .608, p < .001).

Table 4. Differences between group 1 and 2 regarding room atmosphere and aesthetics of the installation

Outcome variables	Group 1 (artificial natural structures)	Group 2 (indoor plant)	Statistics	p-value
Room atmosphere[a] (Scale 1-5)	M = 4.02 SE = .18	M = 3.57 SE = .22	T(df) = 1.587(31)	.123
Aesthetics of the wall installation[b] (10-point SD)	M = 7.16 SE = .56 MD = 8.00	M = 5.64 SE = .55 MD = 5.50	**U = 79.50** **Z = -1.986**	**.047***

[a] = unpaired t-test

[b] = Mann-Whitney-U test

SD = Semantic differential

M = Mean

SE = Standard error

MD = Median (is given for the non-parametric Mann-Whitney-U test)

Bold and * = significant

4. Discussion

This study investigated the effectiveness of artificial natural structures on stress level, pulse, blood pressure, and mood. The intervention with the artificial structures was compared to an indoor plant as well as to a control room. Based on preliminary research, we expected that the participants would experience a significant improvement with regard to the variables studied, as would the participants who were in the room with the indoor plant. We expected no effects for the control group. The results show, in terms of the semantic differentials, that for the participants of group 1 (artificial natural structures), there were significant improvements in the variables relaxation, anxiety, well-being, and facial expression. For group 2 (indoor plant), we found significant differences in the areas of relaxation and well-being, while participants in the control group also improved significantly in the variables of relaxation and anxiety. The improvements are in line with previous study results. For example, studies show that looking at artificial plants (Jeong & Park, 2021) or even looking at images with nature scenes can lead to a greater sense of well-being (Beukeboom et al., 2012; Jiang et al., 2020; Song et al., 2018). Well-being increased significantly in the groups that were in the rooms with installation, while no effect was found in the control group. The study by Jiang et al. (2020) shows that viewing images depicting nature scenes can furthermore lead to increased relaxation and less anxiety compared to viewing urban scenes. Again, in our study, the participants who received the intervention with the artificial natural structures felt more relaxed and less anxious. We also measured a significant improvement in relaxedness among the participants who were in the room with the indoor plant. In contrast, we did not observe any reduction in anxiety in this group. We did not expect any significant differences in the control room. We cannot conclusively explain why the participants from this group were significantly more relaxed and less anxious after the intervention. We suspect that sitting quietly in an empty room without mobile phones and distractions had a relaxing and anxiety-relieving effect on the participants.

To compare the effects of the interventions between the three groups, we conducted mixed ANOVAs. The results show a positive interaction effect for our primary measure of stress. The participants of group 1 (artificial natural structures) experienced the greatest decrease in stress level, followed by group 2 (indoor plant) and the control group. This result is in line with the findings of the study by Hassan et al. (2020). In this research, the authors investigated how the presence of an indoor plant affects subjects who are asked to solve a task on a computer. If there was a plant in the environment, the mental stress was significantly lower. Contrary to our expectations, we found no significant interaction effects for the other variables pulse, blood pressure, and mood. This could be due in part to the short duration spent in the rooms. Alternatively, the sample size may have been too small to detect effects. It is important to conduct further research to re-examine the results.

We were also interested in how visually appealing the participants found the wall installations and whether they rated the atmosphere in room 1 and 2 differently. We hypothesized that there were no differences in terms of aesthetics and atmosphere. However, the results show that the participants perceived the artificial natural structures as more aesthetically pleasing than the indoor plant. This difference is significant. The room atmosphere was also perceived as more pleasant in room 1, but here we could not find a significant difference. In addition, there is a strong correlation between room atmosphere and the aesthetics of the installation. The aesthetics of health-promoting design play a role, as it is assumed that a stress-reducing effect sometimes results from perceived aesthetics. The study by Dijkstra et al. (2008) demonstrates that indoor plants in a hospital room reduce the perception of stress through the perceived attractiveness of the room. This would explain why stress decreased more in group 1 than in group 2, as the participants found the artificial natural structures more visually appealing.

However, besides the factor of aesthetics, there are other explanatory approaches. The connection to nature appears to be inherent in humans. Wilson (1984) developed the biophilic hypothesis, which suggests that humans have an innate desire for nature and living things and that the human-nature connection is beneficial for people. He further postulates that this desire is genetically ingrained. This inherent drive for nature may as well serve as an explanation for why numerous studies demonstrate positive effects of nature, nature-like spaces, images, or plants, and why the present research was able to show a stress-reducing effect of the artificially designed natural structures. Another explanation might have been an evolutionary advantage in times when people lived more in harmony with nature. Those who had a greater interest in nature and thus more knowledge about, for example, edible plants or good materials for shelters, had an advantage over those who did not have this connection (Buss, 2000). Could the connection to nature have thus been vital for survival, and is this why it is ingrained in us? What we can summarize is that if this basic human need is met, we can see a positive effect on people and their well-being, while artificial and urban environments have a negative effect on mental health (see for example Cho et al., 2016; He et al., 2020; Richter et al., 2021).

In conclusion, it can be stated that the hypotheses we examined in this study could partially be confirmed. There was a significant interaction effect for stress after the computation of the ANOVAs, but not for the other variables. Regarding the semantic differentials, we found some significant effects. Furthermore, contrary to our expectations, the aesthetics of the artificial natural structures were rated significantly higher than those of the indoor plant. The results of this study suggest that artificial natural structures may even be more effective than indoor plants in terms of potential health promotion. We draw this conclusion from the fact that stress levels decreased more in room 1 than in room 2. Furthermore, there were four significant improvements in the semantic differentials in room

1. In room 2, where the indoor plant was placed on the wall, we found significant improvements in two variables, as in the control room.

5. Limitations

There are limitations to this study that need to be mentioned. First, it must be noted that the sample is relatively small and that the number of participants calculated in advance was not reached. On one hand, the small sample size adversely affects the generalizability of the results. On the other hand, a small sample size contributes to low statistical power, which in turn increases both the probability of a type II error (failing to detect an effect of the intervention) and a type I error (detecting an effect that doesn't actually exist). Furthermore, the sample is highly homogeneous in terms of age and education level. This limits the generalizability of the results as well. Additionally, it must be noted that the majority of the participants were probably students of the communication design programme, as the study was carried out in the programme's building. In our opinion, this may have led to an increased aesthetic appreciation of the artificial natural structures. Moreover, several hypothesis tests were conducted as part of the present study. This may lead to an increased probability of type I errors. No corrections were made, which should be taken into account when interpreting the results. Furthermore, there was no blinding of the study conductors, which poses a risk of bias. This was not possible due to limited personnel resources. Future studies should ensure blinding to increase the scientific quality. Finally, yet importantly, the wall installation in room 1 was green. Thus, we cannot say whether the effect was primarily due to the shape of the installation or to the colour. Because of these limitations, further research is needed.

6. Conclusion

In terms of stress, we found a significant interaction effect. The stress level decreased the most in the room with the artificial natural structures. For the other variables, no further significant effects were found after conducting the mixed ANOVAs. Nevertheless, this study provides first indications of a health-promoting potential of artificial natural structures. Furthermore, the participants rated the artificial natural structures as more aesthetically pleasing than the indoor plant. The artificial natural structures can thus potentially be used as an aesthetic, low-cost, effective, and health-promoting alternative to indoor plants. Further research is necessary to confirm the results.

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