

Psychophysiological Effects of a Single, Short, and Moderately Bright Room Light Exposure on Mildly Depressed Geriatric Inpatients: A Pilot Study

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Keywords

Geriatric · Depression · Bright light · Mood · Heart rate · Heart rate variability · Artificial sunlight

Abstract

Background: Light interventions typically exert their mood-related effects during morning bright light exposures over several weeks. Evidence about immediate ambient room light effects on depressed individuals is still sparse. **Objective:** The present study aimed at examining the acute effects of a single moderately bright room light exposure on mood, and behavioural and cardiac stress reactions of mildly depressed geriatric inpatients during a short cognitive stimulation and while resting. **Methods:** Twenty-one inpatients were tested in a balanced cross-over design on 2 consecutive days under either conventional room light (standard light) or artificial sunlight conditions for 30 min. Room illumination was implemented with an artificial skylight, which perfectly imitated solar indoor illumination (e.g., cloudless sky and bright artificial sun). Light-induced changes of mood, heart rate, and heart rate variability were recorded while performing a perseveration test (acted as cognitive

stimulation) twice. Additionally, light-related behaviour was observed during a resting period between the cognitive tests and various subjective ratings were obtained. **Results:** Compared to standard light, exposure to artificial sunlight had a subjective calming effect over time ($p = 0.029$) as well as decreased heart rate and increased vagal tone (root mean squared of successive inter-beat intervals), both under cognitive workload and in resting conditions. Effect sizes of reported cardiac reactions were large. Cognitive variables were not influenced by light. Additionally, under the higher corneal illuminance of the artificial sunlight, patients perceived stronger glare ($p = 0.030$) and kept their eyes closed for longer times ($p = 0.033$) during the resting period. However, patients did not avoid bright light exposure while resting but voluntarily stayed within the area directly lit by the artificial sun nearly all the time (97%). **Conclusion:** To our knowledge, this study for the first time demonstrated immediate psychophysiological effects of a single, short room light exposure in mildly depressed geriatric inpatients during a short cognitive stimulation and while resting. The findings complement reported evidence on immediate alerting and mood-related effects of bright light exposures.

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Introduction

Light therapy has become a treatment option for various neurological and psychiatric disorders such as sleep disorders, seasonal/non-seasonal affective disorders, and dementia [for reviews see 1–3], because of its short response latency, and the existence of solely minor side effects (usually at the beginning of the treatment, which vanish within days). Light therapy is typically administered daily in the early morning for at least several weeks. The recommended light dose amounts to 5,000 lux-h, equalling a light exposure of 5,000 lux for 1 h or 10,000 lux for 30 min.

In contrast to classical bright light therapy, only a few studies have investigated the effects of bright ambient room exposure so far. Almost all of these studies measured light effects on different symptoms [4–6] of people with dementia. To our knowledge, up to now, only 2 studies have published data on mood-related effects of repeated room light exposures on people with depression. In 1995, a single-centre study [7] could show for the first time that room light treatment with 1,500 lux for 2 h over a period of 10 days improved depressive symptoms in patients with seasonal affective disorder significantly more than in those with non-seasonal affective disorder independent of whether light was given in the morning or evening. A second multicentre study in Sweden [8] could show that ambient room light exposure was effective in reducing depressive symptoms in outpatients with mild seasonal affective disorder. In this study, room light levels varied between 1,100 and 4,300 lux, and light exposure was given every morning on weekdays for 3 consecutive weeks. So far, there have been no studies published on potential room light effects of depressive geriatric inpatients.

The mechanism whereby bright white light exerts its antidepressant effects is still unclear. It is well known that bright light affects 2 distinct classes of monoamines (the tryptamines serotonin and melatonin [9], and the catecholamines norepinephrine and dopamine [10]), and that it has a strong impact on human circadian physiology (e.g., phase advance and increase in the amplitude of circadian parameters [11]).

It is generally supposed that the biological effects of light are mediated by recently discovered retinal ganglion cells containing the photopigment melanopsin, which is maximally sensitive to blue light [12]. As a function of intensity, spectral composition, timing, duration, and history of light exposure, these ganglion cells, supported by the classical rod/cones system, project their

input to the suprachiasmatic nuclei of the anterior hypothalamus [13].

Additionally, neuroimaging studies with healthy subjects [14, 15] demonstrated that immediately after light onset, responses are observed in alertness-related subcortical structures (e.g., hypothalamus, brainstem, thalamus) and in limbic areas (e.g., amygdala and hippocampus). After several minutes, light-related responses were detected at the cortical level in prefrontal and parietal areas, while participants were engaged in non-visual cognitive tasks.

Furthermore, light may exert autonomic control via the suprachiasmatic nuclei's projections to the paraventricular nucleus of the hypothalamus, which modulates sympathetic control of the cardiovascular state [16]. Related to that, the autonomous nervous system (ANS) exhibits clear circadian rhythmicity as demonstrated by distinct day-night variation in heart rate, blood pressure, and heart rate variability (HRV) [17].

Surprisingly, to our knowledge only 2 studies regarding bright light effects on the ANS in people with affective disorders were published until now, despite the well-documented effects of bright light on the ANS and the antidepressant properties of bright light therapy. More than 25 years ago, Rechlin et al. [18] investigated the effects of an adjunctive bright light therapy in 30 inpatients with major depression, showing that 40% of the patients experienced improvement of mood. This responder group also showed an increase in parasympathetic tone, measured immediately after light exposure by a 5-min electrocardiogram (ECG). The second study [19] indirectly addressed this research topic by exploring the effect of low-intensity coloured light exposures on the ANS in healthy individuals with elevated anxiety and depression scores. In contrast to Rechlin et al. [18], this study demonstrated a wavelength-specific decrease in the parasympathetic nervous system's activity. Taken together, empirical evidence of immediate bright light effects on the ANS of depressed individuals has been inconclusive so far.

The present study aimed at examining acute effects of a single light exposure on mood, and behavioural and cardiac stress responses on mildly depressed geriatric inpatients in the course of a short cognitive stimulation and while resting. In contrast to previous light therapy research, we did not utilize a standard bright light device positioned on the table and delivering more than 5,000 lux but compared the effects of a special ambient room lighting system (mimicking solar indoor illumination realistically) with standard room lighting.

Table 1. Diagnoses, list of medication, and additional somatic, drug-treated comorbidities

Diagnoses (ICD-10)	Subjects (ID)	Type of antidepressant	Additional psychiatric medication	Hypertensives	Additional somatic comorbidities
F31.3	14	SSRI	benzodiazepine		menopausal symptoms, rheumatism
	19	SNDRI, SSRI	atypical antipsychotic, benzodiazepine		hypothyroidism
	35	SSRI	atypical antipsychotic		hypothyroidism, osteoporosis
F31.4	20	SNDRI, NaSSA	atypical antipsychotic, benzodiazepine		
F32.1	13	NaSSA	atypical antipsychotic, benzodiazepine		
	44	SNDRI, SSRI	benzodiazepine		hypothyroidism
F32.2	34	SSRI	benzodiazepine	angiotensin receptor blocker	hypothyroidism, hypercholesterolemia
F33.1	29	SSRI, SSNRI	atypical antipsychotic, benzodiazepine	ACE inhibitor	pain, incontinence
	33	NaSSA	benzodiazepine		
	36	SSRI	atypical antipsychotic, benzodiazepine	angiotensin receptor blocker	hypothyroidism, hypercholesterolemia
	41	SSNRI, SSRI	atypical antipsychotic, benzodiazepine		
	43	SNDRI	atypical antipsychotic, benzodiazepine	beta-blocker	eye disease
	46	SSRI	atypical antipsychotic		osteoporosis
F33.2	32	SSRI	atypical antipsychotic, benzodiazepine	ACE inhibitor	hypercholesterolemia
	38	NaSSA	atypical antipsychotic, benzodiazepine	beta-blocker	hypothyroidism, hypercholesterolemia, diabetes
	39	SSRI, SNDRI	atypical antipsychotic, benzodiazepine	angiotensin receptor blocker	
	47	SSRI, NaSSA	benzodiazepine		hypercholesterolemia
	48	SSRI	benzodiazepine	ACE inhibitor	diabetes
F33.3	10	SSRI, NaSSA	atypical antipsychotic		
	23	SSRI, NaSSA	atypical antipsychotic, benzodiazepine		
	31	SSRI	atypical antipsychotic, benzodiazepine	ACE inhibitor	hypothyroidism

SSRI, selective serotonin reuptake inhibitor; SNDRI, selective norepinephrine-dopamine reuptake inhibitor; NaSSA, noradrenergic and specific serotonergic antidepressant; SSNRI, selective serotonin-norepinephrine reuptake inhibitor.

Methods

Study Sample

All subjects were assessed by the same diagnostic procedure (i.e., psychiatric, neurological and neuropsychological examination) before study inclusion. Additionally, ICD-10 diagnoses were assigned to all subjects by a consensus diagnostic conference.

For study inclusion, patients had to suffer from a bipolar affective disorder with a current episode of moderate to severe depres-

sion (F31.3, F31.4), a moderate to severe depressive episode (F32.1, F32.2), or a recurrent depressive disorder with moderate to severe symptoms (F33.1, F33.2, F33.3). Additionally, all subjects had to have a Mini-Mental State Examination (MMSE [20]) score of ≥ 26 . The exclusion criteria for subjects covered a change of medication during the 2 consecutive test days, another major psychiatric illness (such as schizophrenia, phobic disorder, or obsessive-compulsive disorder), active alcohol or drug dependence, and primary neurological illness (such as dementia, stroke, Parkinson disease, and multiple sclerosis).

Table 2. Photometrical measurements

Light condition	Horizontal illuminance (centre of the test desk), lux	Mean vertical illuminance (at eye level), lux	Correlated colour temperature (at eye level), K
Conventional room light	250	140	3,750
Artificial sunlight	250	1,700 (horizontal view) 650 (view to desk)	4,060

Luxmeter: LMT B 360 (LMT Lichtmesstechnik GmbH, Berlin, Germany); spectroradiometer: specbos 1201 (JETI Technische Instrumente GmbH, Jena, Germany).

**Fig. 1.** Artificial sunlight (CoeLux 45 LC®).

Subjects were recruited with an invitation to voluntarily participate in a 2-day 30-min cognitive training in the late afternoon.

For the 2-factor within subjects repeated-measures design of the present study, sample size was estimated with a power analysis (*g*power* [21]). With an assumed medium effect size of 0.25 (legitimated by an unpublished pilot study with the same artificial sunlight system but a slightly different study protocol where we could reveal large light effects) as well as correlations among repeated measures of 0.5 (legitimated by subsequent measurements within short time frames), and a significance level of 5%, a power of at least 80%, and a non-sphericity correction of 1, at least 18 subjects had to be included in the study.

In total, 21 depressive geriatric inpatients (17 females; mean age: 70.1 ± 5.6 years) were enrolled in the present study. All subjects were treated with antidepressants, and either with benzodiazepines, atypical antipsychotics, or both (Table 1). Nearly half of the subjects (9 out of 21) suffered from hypertension and received pharmacological treatment. Additionally, 15 subjects were given a maximum of 2 supplementary drugs for the treatment of other somatic comorbidities such as osteoporosis, hypothyroidism, hypercholesterolaemia, diabetes, pain, incontinence, or glaucoma. In general, patients' treatment was based on a multimodal therapy concept, and thus medicinal treatment was supplemented by psy-

chological therapies, physiotherapy, and ergotherapy on work-days.

From a somatic comorbidity perspective, 1 patient had a myocardial infarction and 4 patients suffered from cancer. In addition, 6 patients had limited mobility during the present study due to a prosthesis or aftereffect of falls, but they were able to move independently, either alone or with a walking aid.

Light Intervention

A group therapy room at the geriatric-psychiatric ward in a regional hospital in Austria (Hall, Tyrol) was equipped with a standard LED room lighting system ("Square 5×5 dynamic" and "Square Line sixtyfive mono,"; Projektleuchten, Dortmund, Germany) and an artificial sunlight system with a sky area of 0.5×1.0 m (CoeLux 45 LC®, CoeLux Srl, Lomazzo, Italy) mimicking a cloudless blue sky with a fixed sun position (45° solar elevation angle). The artificial sunlight system is shown in Figure 1.

Both lighting systems emitted solely light in the visible range. Thus, no potentially harmful infrared and ultraviolet radiation entered the participants' eyes. The blinds in the room were closed during data collection to completely exclude residual daylight.

Horizontal illuminances at the working area were kept the same under both artificial lighting conditions (250 lux; Table 2). The light colour at eye level was neutral-white (Table 2). The 2 light conditions differed remarkably in terms of illuminance levels at the eyes (140 lux vs. 1,700 lux at the maximum) and luminance levels in the field of view of the participants (standard light: 60 cd/m²; artificial sunlight: artificial sky 500–800 cd/m² and artificial sun more than 1,000,000 cd/m²).

Test Battery

Rating Scales

The 3 bipolar KUSTA scales [22] were used to assess mood state ("bad mood – good mood"), activity state ("tiredness – activation"), and tension state ("tension – relaxation") at the beginning and at the end of each test session. On each scale, participants rated their mood on a verbally anchored 17-point scale ranging from "extremely strong" in one dimension to "neutral" to "extremely strong" in the other dimension.

Additionally, patients rated the level of relaxation during resting period 2 (Fig. 2) on an 11-point scale ranging from 0 "not at all" to 10 "very relaxed," estimated the period of time staying alone in the test room on a 6-point scale ("3 min," "5 min," "7 min," "9 min," "11 min," "13 min"), and rated the pleasantness of the light on a 6-point scale ranging from "very pleasant" to "very unpleasant."

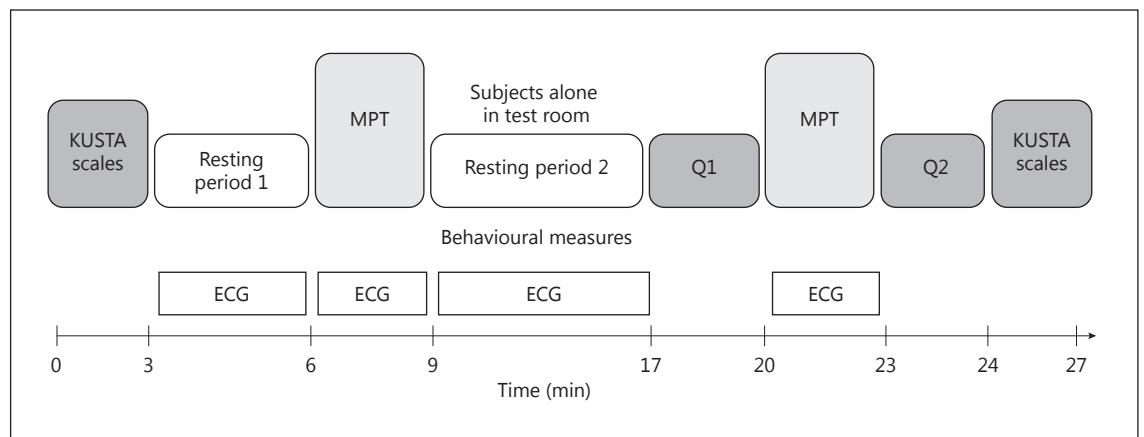


Fig. 2. Study protocol. Q1, rating items regarding the relaxation state, time estimation, and pleasantness of the lighting condition; Q2, rating item about the perceived glare.

ant.” At the end of each test session, participants rated the glare on a 4-point scale ranging from “not glared” to “strongly glared.”

Mittenecker Pointing Test

Participants were cognitively stimulated by means of the Mittenecker Pointing Test (MPT), which is a random sequence generation test also applicable in severely impaired clinical samples [23].

Participants were instructed to press 9 keys of a modified keyboard while producing a most random/orderless sequence. A signal tone was presented every 1.2 s to pace the speed of pressing the keys. The test required 180 keystrokes (in total 216 s). A practice phase comprising 30 keystrokes preceded the actual test and ensured correct test execution.

Two central perseveration measures, symbol redundancy (SR) and context redundancy (CR), were derived from the MPT. SR, primarily related to memory updating, refers to the inequality of the relative frequencies of chosen keys and ranges from 0 to 1. SR values near 0 indicate that the sequence approximates randomness. CR, also ranging from 0 to 1, measures the deviation of the frequency distribution of pairs of adjacent responses from equality. CR is high when responses are continuously influenced by previously chosen alternatives and mainly indexes the functionality of inhibitory processes (for details on the MPT scores, see [23]).

Heart Rate

The ECG was recorded during both resting periods and under cognitive workload by means of a 3-lead ECG recorder (Nexus 4; Mindmedia, The Netherlands) with a sampling rate of 1,024 Hz and 24-bit ADC output resolution. Pre-gelled electrodes were placed below the right and left clavicle and below the left pectoral muscle near the apex of the heart. The ECG was recorded in an upright seating position, and the first and last 10 s of each data record period were excluded from analysis.

After applying an automatic QRS detection algorithm (QR-STool, University of Arizona, USA), NN intervals (i.e., time intervals between individual R-wave peaks) were extracted from the raw ECG signal. Consecutively, NN intervals were visually inspected for ectopic beats and artefacts (detection tolerance: $\pm 20\%$ dif-

ference in consecutive NN intervals) and were corrected by a cubic-spline interpolation by means of the software ANS-Explorer (Zentrum für neuropsychologische Forschung, Trier, Germany). Potential light effects were studied on heart rate and the time-domain HRV parameter RMSSD (root mean squared of successive interbeat intervals).

Behavioural Measures

During the second resting period (8 min), 2 behavioural parameters (duration of eyes closed and duration of sitting in the area directly lit by the artificial sun of the skylight) were obtained with the aid of a camera. Due to the fact that all subjects could move independently, they were free to change the seating position and thus light exposure level while resting.

An accelerometer (Actiwatch Spectrum Plus®; Philips Respironics, The Netherlands) was attached on the non-dominant wrist, which continuously recorded physical activity during the resting periods as well. Activity bouts were recorded with a sampling rate of 32 Hz and summed up over an epoch of 15 s.

Study Protocol

Data collection took place on weekdays from January 2016 to June 2016 and started between 5 pm and 6 pm. This time period was chosen to cause no disturbance of the daily living and treatment routines.

Generally, patients followed well-structured wake-up, eating, socializing, and therapy times on workdays. These social rhythms act as strong non-photic zeitgebers and stabilized patients' circadian rhythms in addition to the ongoing pharmacological treatment before data collection started.

Study participants stayed in interior spaces of the clinic most of the time during the day. Daylight penetration in bedrooms, therapy rooms and recreational areas was modest. Overall brightness levels of artificial room light fulfilled current lighting standards and did not exceed vertical illuminances of 150 lux.

A balanced cross-over design, counterbalancing the 2 room light conditions, was implemented to avoid possible order effects. The medication of each subject was not changed during the 2 consecutive test days.

At the beginning of each test day, the test protocol was explained and ECG electrodes were attached, followed by the instruction and practice phase of the MPT.

Then, the participants completed the KUSTA scales, followed by a resting period of 3 min (resting period 1). After completing the MPT, an 8-min resting period took place (resting period 2). During the second resting period, participants stayed alone in the test room, and behavioural measures of the subjects were recorded by the test instructor in an adjacent room. Afterwards, participants completed the 3 additional ratings. After the second task period, participants rated the perceived glare and completed the KUSTA scales for the second time. Figure 2 illustrates the study protocol as a flow chart.

The study was conducted in accordance with the 1964 Declaration of Helsinki and was approved by the Ethics Committee of the Medical University of Innsbruck, Austria. Informed consent was obtained from all patients prior to participation.

Data Analysis

Two-way repeated-measures ANOVAs with the 2 within-subject factors time (2 levels: first measurement, second measurement) and light condition (2 levels: standard light, artificial sunlight) were run to determine the effect of the different light interventions on changes of mood, perseveration, heart rate, and HRV.

Analysis of the studentized residuals were utilized to show that central assumptions of a 2-way repeated ANOVA were not violated, e.g. normality as assessed by the Shapiro-Wilk test of normality, and absence of outliers as assessed by no studentized residuals greater than ± 3 standard deviations.

Paired-samples *t* tests were used to determine whether there were statistically significant differences between standard light compared to artificial sunlight in the ratings recorded only once per test day, and in the behavioural data obtained during the 8-min resting period.

Data are mean $\pm$ standard deviation, unless otherwise stated. For mean differences, the 95% confidence intervals (CI) of these differences are given as well. Cohen's *d* and partial η^2 values are given as effect sizes with small ($0.2 \leq d < 0.5$; $0.01 \leq \text{partial } \eta^2 < 0.06$), medium ($0.5 \leq d < 0.8$; $0.06 \leq \text{partial } \eta^2 < 0.14$) and large ($d \geq 0.8$; $\text{partial } \eta^2 \geq 0.14$) effect sizes, respectively. Two-tailed significance levels of < 0.05 were assumed for all statistical tests.

Results

The mean length of hospitalization for study participants was 25 ± 11 days. Patients had their first test day on average on the 12th day (± 8 days) of their inpatient treatment. In addition, subjects had a mean geriatric depression scale score (GDS-15, [24]) of 7.75 ± 2.63 , and a mean MMSE of 28.39 ± 1.33 on the first of the 2 test days.

Changes of Mood

The analysis of the scale "bad mood – good mood" did not yield a significant 2-way interaction between time and light condition, $F(1, 20) = 0.856$, $p = 0.366$, or a significant

main effect of light, $F(1, 20) = 0.826$, $p = 0.374$, and main effect of time, $F(1, 20) = 2.628$, $p = 0.121$.

The analysis of the scale "tiredness – activation" did not reveal any significant effects either, e.g. interaction time by light condition, $F(1, 20) = 0.017$, $p = 0.897$; light: $F(1, 20) = 0.952$, $p = 0.341$; time: $F(1, 20) = 0.714$, $p = 0.408$.

There was a trend toward a statistically significant interaction between time and light condition in the analysis of the scale "tension – relaxation," $F(1, 20) = 3.558$, $p = 0.074$, $\eta^2 = 0.151$. Simple main effects showed that subjective calmness improved over time during exposure to artificial sunlight only (first measurement: -2.52 ± 3.82 , second measurement: -1.29 ± 3.13), $p = 0.029$, $\eta^2 = 0.218$, but not during exposure to standard light, $p = 0.661$. The main effects of light, $F(1, 20) = 0.013$, $p = 0.911$, and time, $F(1, 20) = 1.963$, $p = 0.177$, were not significant.

Cognitive Changes

Cognitive variables were not influenced by the light condition. In the analysis of SR, the interaction between time and light condition, $F(1, 20) = 0.537$, $p = 0.472$, and the main effect of light, $F(1, 20) = 0.005$, $p = 0.945$, were not significant. The main effect of time showed a trend toward significance, $F(1, 20) = 3.606$, $p = 0.072$, indicating better performance in the first compared to the second measurement (mean difference: 0.020, 95% CI, 0.000–0.005).

Similarly, there was no significant interaction effect, $F(1, 20) = 1.850$, $p = 0.189$, and no significant main effect of light, $F(1, 20) = 0.161$, $p = 0.693$, in the analysis of CR. However, only the main effect of time was significant, $F(1, 20) = 4.901$, $p = 0.039$, $\eta^2 = 0.197$, showing better performance in the first compared to the second measurement, independent of the light condition (mean difference: 0.030, 95% CI, 0.002–0.059).

Cardiac Changes

During Cognitive Workload

The analysis of heart rate showed a higher heart rate in the standard light ($81.16 \pm 9.92 \text{ min}^{-1}$) than in the artificial sunlight condition ($78.16 \pm 10.04 \text{ min}^{-1}$), $F(1, 20) = 5.443$, $p = 0.030$, $\eta^2 = 0.214$ (mean difference: 3.00 min^{-1} , 95% CI, 0.318–5.694 min^{-1}). The interaction effect, $F(1, 20) = 0.092$, $p = 0.765$, and the main effect of time, $F(1, 20) = 0.001$, $p = 0.974$, were not significant.

Complementary results were observed for RMSSD. RMSSD was lower during exposure to standard light ($15.81 \pm 16.93 \text{ ms}$) compared to artificial sunlight ($19.28 \pm 18.99 \text{ ms}$), mean difference: 3.47 ms (95% CI, 0.589–

6.345 ms), $F(1, 20) = 6.314$, $p = 0.021$, $\eta^2 = 0.240$. Interaction effect, $F(1, 20) = 0.515$, $p = 0.481$, and main effect of time, $F(1, 20) = 0.418$, $p = 0.525$, were not significant.

During Resting Periods

Heart rate was higher under the standard light ($79.92 \pm 10.89 \text{ min}^{-1}$) compared to the artificial sunlight condition ($77.32 \pm 11.69 \text{ min}^{-1}$), mean difference: 2.59 min^{-1} (95% CI, $0.302\text{--}4.886 \text{ min}^{-1}$), $F(1, 20) = 5.575$, $p = 0.028$, $\eta^2 = 0.218$. The interaction effect, $F(1, 20) = 0.187$, $p = 0.670$, and the main effect of time, $F(1, 20) = 0.618$, $p = 0.441$, were not significant.

RMSSD was lower during exposure to standard light ($18.62 \pm 16.24 \text{ ms}$) compared to artificial sunlight ($21.57 \pm 20.61 \text{ ms}$), mean difference: 2.96 ms (95% CI, $0.326\text{--}5.585 \text{ ms}$), $F(1, 20) = 5.497$, $p = 0.029$, $\eta^2 = 0.216$; Interaction effect, $F(1, 20) = 0.023$, $p = 0.880$, and main effect of time, $F(1, 20) = 0.019$, $p = 0.892$, were not significant.

Additional Ratings and Behavioural Data

There were no significant differences between the 2 lighting conditions in physical activity measured with a wrist-worn accelerometer ($t(20) = 0.738$, $p = 0.469$) within resting period 2. Additionally, the relative amount of time in which eyes were closed during resting period 2 was lower under standard light ($47\% \pm 41$) compared to artificial sunlight ($66\% \pm 39$); $t(20) = 2.294$, $p = 0.033$, Cohen's $d = 0.46$. Furthermore, the relative amount of time sitting in the area lit by the artificial sun of the skylight was longer ($t(20) = 26.807$; $p < 0.001$, Cohen's $d = 1.95$) than the time sitting outside this area. Participants were sitting in the area lit by the artificial sun during $97 \pm 8\%$ of the time.

There were no significant differences between the 2 lighting conditions in the ratings of the level of relaxation ($t(20) = 0.096$, $p = 0.924$), estimation of time being alone in the test room ($t(20) = 0.346$, $p = 0.733$) and feelings of pleasantness of the light ($t(20) = 0.462$, $p = 0.649$) immediately after resting period 2.

However, overall ratings of glare were lower under standard light (1.05 ± 0.22) compared to artificial sunlight (1.33 ± 0.48) at the end of each test day; $t(20) = -2.335$, $p = 0.030$, Cohen's $d = 0.70$.

Seasonal Impact of Varying Day Length Periods

To rule out a potential impact of different daylight exposure levels on patients participating in the study in winter compared to summer months, additionally a repeated-measures ANOVA with 2 within-subject factors (factor 1: time; factor 2: light) and 1 between-subject factor

(factor 3: season) was calculated. The supplementary factor season split the sample into 2 groups (winter group with a mean day length of 10.4 h: $n = 11$; summer group with a mean day length of 14.5 h: $n = 10$) and is based on the switch to daylight saving time (March 27th, 2016). We could reveal no seasonal impact on all measures (MPT scores, KUSTA scales, cardiac parameters, and behavioural measures) in the present study.

Discussion

Light interventions typically exert their mood-related effects in the course of morning bright light exposures, either generated by light therapy boxes or ambient bright light exposure, over several weeks. However, the evidence about immediate, short-term ambient light effects on depressed individuals is still sparse. This study examined acute behavioural and psychophysiological effects of a short single ambient room light exposure, characterized by its moderate brightness and strong psychological illusion of a cloudless sky and artificial sun, on depressed geriatric inpatients during a mild cognitive stimulation and while resting.

Our results showed that patients felt more relaxed at the end of the test session compared to its beginning under artificial sunlight conditions only, but not when exposed to standard room light. This result was supported physiologically by a lower heart rate and larger HRV (increased vagal tone) during the artificial sunlight condition compared to the standard light condition under cognitive workload as well as while resting. The effect sizes of these light-related differences can be described as large.

It is well documented that medical examinations (e.g., ECG measurements [25]) or cognitive tests [26], as implemented in our study protocol, act as stressors. On the other hand, previous research has found strong evidence for a link between exposure to natural environments and recovery from physiological stress through reducing negative affect and decreasing physiological arousal [27, 28].

As already reported by Canazei et al. [29] in healthy subjects, the artificial sunlight system generated a very natural ambient room light atmosphere. It perfectly mimicked solar indoor illumination by means of a skylight, and thus offered a contact to nature on a bright sunny day in the late afternoon.

Consequently, our study results are in line with previous research reporting that natural environments may reduce negative mood states and physiological symptoms of stress.

A further aim of the study was to determine potential side effects of this ambient room light exposure. Ratings of glare were significantly lower under standard light compared to artificial sunlight. Furthermore, patients kept their eyes closed longer during exposure to artificial sunlight than standard light. It can be hypothesized that these observations may be caused by higher corneal illuminance levels under artificial sunlight (650–1,700 lux) and are in line with studies showing higher light sensitivity of older adults [30] and photophobic symptoms of people with depression [31]. Surprisingly, no light avoidance behaviour was observed during the longer resting period. Patients stayed nearly all the time (97%) in the area directly lit by the artificial sun. These findings suggest that naturally lit environments, even though perceived as brighter and influencing gaze behaviour, are preferred places to stay.

To our knowledge, only the study by Virk et al. [32] has so far documented mood effects of a single short bright-light exposure of 10,000 lux in the morning in untreated patients with seasonal affective disorders. They showed that brief administrations of light were clinically effective within 20 min and that improvements of mood even occurred after the first bright light exposure. The present study demonstrated that exposure to a far less bright ambient room light in the late afternoon in depressed geriatric inpatients yielded an immediate psychophysiological relaxation effect after a mild stressor, which is a novel finding.

While perceived calmness increased during exposure to artificial sunlight only, mood scores did not improve under either light condition. It is important to note that the exposure to artificial sunlight may have been too short (less than 30 min) and too low (1,700 lux is significantly less than 10,000 lux, which is the recommended intensity for a 30-min light therapy session) to establish significant anti-depressive effects.

It is well documented that light levels in hospitals or care facilities are low during the day [33]. Light levels at the geriatric station of this study were similarly low. Furthermore, bright light usually exerts alerting effects with light onset [14], especially when light levels are low before photic stimulation [34]. Interestingly, the ratings of activation were not changed under artificial sunlight in the present study. Again, the intensity of the artificial sunlight may have been too low to establish alerting effects. In addition, patients predominantly had their eyes closed during the second resting period and had an inclined head posture while performing the cognitive task, thereby further decreasing light input into the eyes and reducing the chance to initiate an alerting effect.

As expected, cognitive workload deployed an impact on the mildly depressed, non-demented geriatric inpatients in the course of each test day. Both performance parameters of the short random motor generation test, which are related to the functionality of memory-updating, inhibitory processes, and cognitive flexibility, dropped in the second test of the day. The decline may either represent an increase in fatigue or a decrease in motivation over time. Additionally, it can be concluded that a single, 30 min, moderately bright light exposure was too short or too low in its light dose to have an impact on the cognitive functionality of our study participants.

All patients in this study were treated with antidepressants and other psychiatric and somatic medication. Previous studies suggested that HRV may act as a marker of depression, because remitted and current major depressive disorders were associated with increased resting heart rates and lowered HRV. However, this association appears to be mainly driven by the effect of antidepressants [35]. Depressed individuals who were using tricyclic antidepressants, selective serotonin reuptake inhibitors or other antidepressants had lower HRV compared with age-matched healthy controls and depressed individuals without medication [36]. Furthermore, it is well known that other psychotropic medication [37] and antihypertensive drugs [38] modulate HRV.

In the present study, all patients were on stable medication during both test days, which occurred on average half way through their hospital stay (i.e., on the 12th and 13th days of the mean 25-day inpatient treatment). Furthermore, subjects only had mild depressive symptoms on the first test day (mean GDS score: 7.75). Consequently, it can be excluded that neither varying drug treatments nor acute depressive symptoms may have significantly influenced the results.

Our study has some limitations. First, we were unable to determine how long the perceived calming effect and the cardiac reaction of the single, short artificial sunlight exposure would last and if a longer exposure would result in a sustained or even increased light effect. Second, the study was performed in a heterogeneous group of depressed geriatric patients, and the sample size was rather small. Clearly, a follow-up study with a larger sample size is necessary to support the described effects of the artificial sunlight.

In conclusion, our pilot study demonstrated that a short single exposure to artificial sunlight had a subjective calming effect as well as a physiological effect on the heart in terms of decreased heart rate and increased vagal tone in depressed geriatric inpatients during mild cognitive stim-

ulation as well as while resting. Thereby, the present study increases the body of evidence that daylight exposure is beneficial to light-deprived hospitalized older adults and that artificial sunlight may complement prevailing or insufficient daylight levels due to seasonal or weather-related factors or due to the building environment.

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Disclosure Statement

The persons involved in the development and sales of the artificial sunlight system were neither involved in designing the study, collecting and analysing data nor publishing the results. Two authors (M.C. and W.P.) are employed at the R&D and lighting design company Bartenbach GmbH (Aldrans, Austria). The authors report no conflicts of interest.

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