



# Ambient bright light in dementia: Effects on behaviour and circadian rhythmicity

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## Abstract

Behavioural and psychological symptoms, such as nocturnal restlessness and wandering, are seen in 90% of patients with dementia at some point in their course. Non-pharmacologic interventions, such as high-intensity lighting, can play an important role in managing these behavioural and psychological symptoms by impacting both the visual and the circadian system. In order to assess the effects of prolonged exposure to high-intensity light (about 1800 lx horizontal on table level) on behaviour and circadian rhythmicity of institutionalised older adults with dementia, ceiling-mounted luminaires emitting bluish (6500 K) and yellowish (2700 K) light were installed in an intervention group that was compared to a control group of traditional dim lighting equipment. The study was performed from May to August 2006. Effects of the lighting intervention were assessed by the Dutch Behaviour Observation Scale for Intramural Psychogeriatrics (GIP), and tympanic temperature measurements. In the bluish light scenario, a significant improvement in restless behaviour was observed in the intervention group, as well as a significant increase in the range of tympanic temperature. These effects were not found in the yellowish light scenario. Further evidence is found that high-intensity bluish light may play a role in managing restless behaviour and improving circadian rhythmicity in institutionalised older adults with dementia.

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## 1. Introduction

An estimated 24.3 million people worldwide cope with dementia syndrome, and this number is to rise to 81.1 million by 2040 [1]. Behavioural and psychological symptoms are seen in 90% of patients with dementia at some point in their course [2], irrespective of the level of cognitive impairments. Non-pharmacologic or non-medical interventions can play an important role in managing these problems [2]. The foundation of non-pharmacologic management is recognising that the person with dementia is no longer able to adapt, and that instead the living environment must be adapted to the person's specific needs [3]. Such adaptations are believed to be effective in improving health, behaviour, and well-being [4,5]. Special

lighting is one of such important non-pharmacological interventions [6]. The best-known benefits of light are visual, i.e., being able to see, and the prevention of falls. Moreover, light plays a role in regulating important biochemical processes, immunologic mechanisms, and neuroendocrine control (for instance, melatonin and cortisol), via the skin and via the eye [7,8]. Exposure to light is the most important stimulus for synchronising the biological clock [9], suppressing pineal melatonin production [10], elevating core body temperature [11], and enhancing alertness [11,12]. The circadian system, which is orchestrated by the hypothalamic suprachiasmatic nuclei (SCN), influences virtually all tissue in the human body. Light activates intrinsically photosensitive retinal ganglion cells (ipRGCs) in the eye, which discharge nerve impulses that are transmitted to the SCN in the brain [13]. The action spectrum of the ipRGCs [14] is different from those of photoreceptors for scotopic and photopic vision.

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The ipRGCs are particularly sensitive to short-wavelength light, i.e., bluegreen light [15]. In people with Alzheimer's, degenerative changes in the SCN appear to be a biological basis for circadian disturbances, which might be reversed by stimulation of the SCN by light [16]. The timing of the sleep-wake cycle can show a far wider variation; times of sleep and activity can vary substantially from day to day, or can be temporarily inverted [17]. Restlessness, disturbed sleep cycles and wandering form a high burden for caregivers, and are among the main reasons for institutionalisation [17–22]. In institutional settings, these problems concerning the proper functioning of the circadian rhythmicity deteriorate and in combination with behavioural problems pose stress on professional carers and other residents.

In older adults, light levels needed for the orchestration of the SCN are significantly higher than those required for proper vision, due to opacification and yellowing of the vitreous and the lens [19,23]. In practice, many older adults are not exposed to illuminance levels that are sufficiently high, due to poorly lit homes (up to 400 lx), and the short periods of time spent outdoors. This forms a great contrast with the horizontal illuminances found outdoors that can reach between 10,000 and 100,000 lx during daytime.

It is hypothesised that high-intensity lighting, with luminance levels of well over 1000 lx, may play a role in the management of dementia. Although the vast majority of people with dementia live in the own home, most lighting studies focus on older adults in nursing homes, due to better options for controlled study design and the costs for the expensive lighting equipment. In many nursing homes, bright light treatment by table-mounted luminaires requiring much supervision is applied to entrain the biological clock. The results of this therapy on managing sleep, behavioural, mood, and cognitive disturbances show preliminary positive signs, but more research is needed [16]. Another approach that is gaining popularity, also for ethical and practical reasons, is to increase the general illuminance in rooms by ceiling-mounted lighting. A study by van Someren et al. [24] providing light of over 1100 lx (790 lx min, 2190 lx max) during the whole day to 22 people with dementia resulted in an increased stability of the rest-activity rhythm in participants with intact vision. A cluster-unit crossover intervention trial by Sloane et al. [25] on the effects of high-intensity light found that night-time sleep of older adults with dementia ( $n = 66$ ) improved when exposed to morning and all-day light, with the increase most prominent in participants with severe or very severe dementia. Unfortunately, it is unknown how long the effects of bright light last and how to predict which people respond positively to light treatment [18]. Also, many studies lack a description of the lighting used. In summary, adequate lighting to improve behaviour and circadian rhythmicity, which people are exposed to in an ethical and unobtrusive way, is yet to be researched and modelled in more detail.

This field study aims to assess effects of prolonged exposure to high-intensity light with a high, bluish correlated colour temperature (CCT), and a low, yellowish CCT, emitted from ceiling-mounted luminaires on behaviour and circadian rhythmicity of institutionalised older adults with dementia, compared to a control group of traditional dim lighting equipment.

## 2. Methods

### 2.1. The building and nursing

The psychogeriatric ward in this study was located in the city of Eindhoven, the Netherlands. The psychogeriatric ward was located on the ground floor and consisted of three communal living rooms (Figs. 1 and 2), connected to the shared bedrooms by a circular corridor. Windows of thermally insulating glass were present in about two thirds of the walls of rooms 2 and 3, and about half of room 1. Windows were facing west in room 1, north-east in room 2, and south west in room 3. The orientations of the rooms were not considered in the study.

Mean air temperature in the living room was kept at room temperature. The clothes worn were standard clothing packages, including dresses or trousers, blouses and sweaters. Most residents were involved in sedentary activity, including reading and watching television.

In general, residents were out of bed between 07:00 and 21:00 h. Some residents went to bed to rest about 13:30 h. More stable 'Zeitgebers' were formed by the fixed times of meals (08:00–10:00, 12:00, 12:30, 17:00 h), and tea and coffee breaks (07:00, 10:30, 16:00, 19:00, 21:00 h). The meals were served in the living room, underneath the test luminaires.

During the experiment, five members of staff, including nurses, were available per living room from 07:00 to 15:00 h (total of 15), and two members of staff from 15:00 to



Fig. 1. One of the living rooms, with lighting equipment installed above the dining tables.

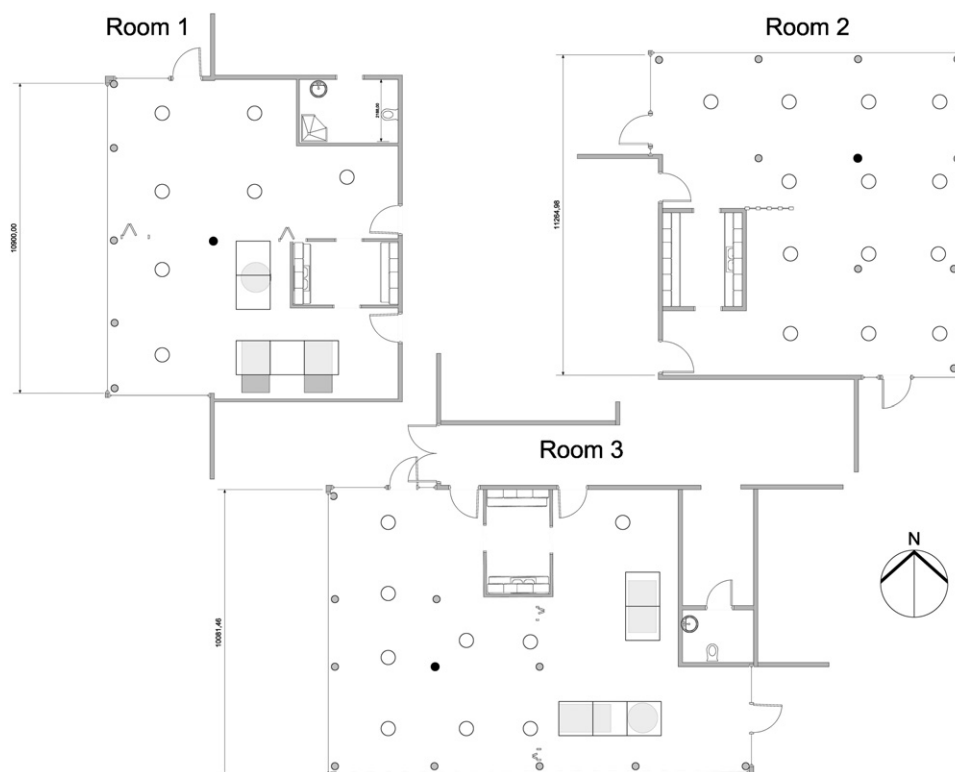


Fig. 2. Layout of the living rooms. The luminaires are shown as clusters of squares.

23:00 h (six in total). During the night shift there were three members of staff to manage the three living rooms together.

## 2.2. Subjects

Informed consent was signed by 42 residents and/or their responsible relatives out of a total population of 61 residents of the psychogeriatric ward. Of these 42 residents, only 26 people started with the test protocol. Bed-ridden residents were excluded from the study. The control group consisted of 10 people, and the intervention group of 16 people. In the control group, one person passed away during intervention 2, and one person did not participate in the tympanic temperature measurements because of hearing aids. Institutionalisation took place on the basis of an indication for psychogeriatric care by a needs assessment centre. All participants were clinically diagnosed by the medical staff, resulting in diagnoses of probable Alzheimer's disease (AD), vascular dementia (VD), or mixed Alzheimer's disease and vascular dementia (MX) (Table 1). Residents with types of dementia other than Alzheimer's disease were not excluded because rhythm disturbances also occur in patients with other types of dementia. There may, however, be differences in the type and severity of the disturbance as well as in the response of the disturbances to bright light therapy [24].

There was no clinical basis for assigning the people over the living rooms when entering the nursing home. The residents spent most of their days in one of three shared

Table 1  
Population of the wards

	Gender		Age (years)		Clinical diagnosis		
	Male	Female	Mean	SD	AD	VD	MX
Control group	3	7	84.4	5.7	6	1	3
Intervention group	4	12	86.3	7.6	10	5	1
Total	7	19	85.6	6.9	16	6	4

living room they had been assigned to. The interior design and type of furniture were of the same type for all living rooms. The residents had been living in that ward for  $22 \pm 19$  (mean, SD) months with a minimum of 3 months and a maximum of 77 months. Two thirds of the residents received visitors at least twice a week. Medical records indicated severe visual deficiencies in only six residents (cataract and impaired vision (75%)). In summer, seven people stayed indoors, while the 19 spent some limited time outdoors.

## 2.3. Study design

The intervention study was performed between May and August 2006 (Table 2). Pre-, mid-, and post-trial assessments of various parameters/scales were taken in weeks 20, 24, and 32 to investigate any generalisation of effects to behaviour and circadian rhythmicity on the ward. In the week prior to the lighting intervention, GIP scores, environmental light levels, and tympanic temperature were

Table 2  
Study design

Week number	Lighting condition (mean $E_{\text{horizontal}}$ without daylight (lx)/CCT (K)) rooms 1 and 3	Measurements and assessments (rooms 1, 2 and 3)	Remarks
15			Rearranging tables and furniture in living rooms
16			Installing lighting equipment
17–19	Baseline (200/2700)		
20	Baseline (200/2700)	Tympanic temperature, illumination at eye level (11 ×); GIP (1 ×)	
21–23	Bluish (1750–1810/6500)		
24	Bluish (1750–1810/6500)	Tympanic temperature, illumination at eye level (11 ×); GIP (1 ×)	
25	Baseline (200/2700)		Holiday period of half of the resident population
26–28	Baseline (200/2700)		
29–31	Yellowish (1750–1810/2700)		
32	Yellowish (1750–1810/2700)	Tympanic temperature, illumination at eye level (11 ×); GIP (1 ×)	

assessed in compliance with instructions supplied to all participating members of staff. The study coordinator visited the ward to ensure that assessments and procedures were carried out consistently. Hereafter, the installed bright light equipment in living rooms 1 and 3 was turned on. Both groups followed the same experimental protocol. Living room number 2 was the control room. Subjects in the intervention groups were exposed to experimental conditions of a bluish CCT for 3 weeks. Then the experimental lighting was turned off, for the situation to return to baseline conditions for 2 weeks. Thereafter, the experimental lighting in rooms 1 and 3 was turned back on in a yellowish CCT for three weeks. After the second period of high-intensity lighting, lights were switched down to baseline level. By the end of the two interventions, assessments of GIP scores, tympanic temperature and illumination levels took place.

#### 2.4. Behaviour

The Dutch Behaviour Observation Scale for Intramural Psychogeriatrics (*Gedragsobservatieschaal voor de Intramurale Psychogeriatric, GIP*) [26–28], used in this study for determining the behavioural conditions of the residents, is made up of 14 subscales that can be used separately. Of the 14 subscales, only five subscales for apathic behaviour, disturbances of consciousness, restless behaviour, depressive/sad behaviour, and anxious behaviour were used. An assessment of limitations in activities of daily living is not included in the GIP scale, but can be derived from it by approximation [28]. This part of the study could not be carried out blindly for two reasons: (i) the nurses filling out the scoring lists make overtime observations and thus have to be familiar with the subject and (ii) the type of lighting intervention is visible (none, versus bluish or yellowish lighting). Nurses involved in this study were already

familiar with assessing GIP scores and with the residents and their behaviour. They were instructed to fill out the lists in compliance with their observations, and not with expectations or possible outcomes of the study.

#### 2.5. Tympanic temperature

In a study on rats, Scheer et al. [29] demonstrated that the endogenous circadian rhythm in core body temperature depends crucially on the presence of functional SCN, and that light has an immediate and circadian-phase dependent core body temperature suppressing effect in rats with intact SCN. This study used tympanic temperature as a marker of circadian rhythm. In general, there are four types of age-related changes in circadian rhythm; (i) reduction in amplitude, (ii) earlier circadian rhythm phase, (iii) shortening of natural free-running period, and (iv) worsening of toleration of abrupt phase shifts [30]. Body temperature is known to fluctuate over the day, with amplitude of 0.5 K in healthy adults, and a minimum between 04:00 and 06:00 h, and a maximum plateau between 12:00 and 18:00 h [31].

Tympanic temperature was measured 11 times a day by a Braun 4520 ear thermometer. The nurses received instructions on how to measure tympanic temperature correctly, and were asked to measure three times and fill out the average temperature. Moreover, the study coordinator also participated in the temperature measurements. The sampling hours were (i) at wake up (dark conditions in the private room), (ii) 1 h after wake up, (iii) 2 h after wake up, (iv) approximately 5 h after wake up, (v) approximately 8 h after wake up, (vi) 3 h before going to bed, (vii) 2 h before going to bed, (viii) 1 h before going to bed, (ix) bed time (dark conditions in room), (x) early night-time measurement, and (xi) late night-time measurement. During tympanic temperature measurements, vertical illuminance measurements took place simultaneously at the eye level of

the subjects. Data were reduced to single values for mean tympanic temperature, mean range of tympanic temperature (two times the amplitude) and mean late-night temperature, which were considered in further analysis.

## 2.6. Lighting equipment and measurements

In living rooms 1 and 3 the existing ceiling-mounted illumination above the table that was used by the participants for their meals, was replaced by five new luminaires of the type Philips Strato TPH710 SKY. Each new fitting contained eight high-intensity fluorescent tubes (TL5-49W/827/865). The general colour-rendering index ( $R_a$ ) of the lighting was 85. Based on simulations in the computer program DIALux 4.1 by DIAL GmbH, an arrangement of luminaires was designed in order to obtain the largest illuminance level on vertical eye level as possible without causing visual discomfort, in an in vivo situation. The most efficient lay-out was a combination of two clusters of luminaires, i.e., one cluster of two and a second cluster of three luminaires above the dining tables. When measuring the equipment at night, to exclude daylight, horizontal illuminance levels at table height reached 1750–1810 lx. Ariës [32] hypothesises that vertical light intensities of 1000–1500 lx should bring about biological stimulation in people without impairments to the eye. Aarts and Westerlaken [23] state that illuminance levels for older adults with aged eye tissue should be at least 3 times higher due to the diminished light transmittance of the eye. During daytime, higher illuminance levels (about 3.0 klx) are impossible to obtain in our setting without the use of excess equipment. The luminaires were installed away (2–6 m) from the windows, near the core of the building (Fig. 2).

The lighting equipment was switched on from baseline conditions ( $E_{\text{horizontal}}$  about 200 lx, added artificial light) each morning at 07:30 h, and allowed to gradually reach at least 1000 lx vertical by 08:00 h. This amount of lighting was gradually lowered at 18:00 h in order to reach a level of 200 lx at 18:30 h. In order to maximise the exposure to 'bright' light, the lighting was not dimmed during lunch break. The lighting during the first intervention had a CCT of 6500 and 2700 K during the second intervention. This corresponds to bluish and yellowish colours, respectively.

Since the direction of light at the retina plays an important role in non-visual effects of lighting [32], the vertical illuminance at the position of the eye was measured with a Hagner cell type SD 2, simultaneously with tympanic temperature; taking into account the participants' viewing direction and angle.

## 2.7. Statistical analyses

Analyses of the effects of the two lighting scenarios, on GIP-scores and tympanic temperature were performed with both parametric and non-parametric statistical methods. Data analysis was carried out using SPSS 14.0

for Windows. The critical  $p$ -value was set at .05 for between-group comparisons of behaviour and tympanic temperature at baseline. The Bonferroni correction was applied to all other comparisons (critical  $p$ -value of .025).

Non-parametric statistics for independent and related samples were employed to test whether observed behaviour (GIP) differed between the control and intervention groups, and within groups, for the various lighting scenarios. Mann–Whitney  $U$  tests were used for between-group differences, and Wilcoxon signed ranks tests were used for within-group differences. For the analyses of tympanic temperature, independent samples  $t$ -tests were used for between group differences, and loose paired-samples  $t$ -tests for within group differences (Fig. 3).

## 3. Results

### 3.1. Lighting measurements

Lighting measurements showed that vertical illuminance at baseline did not differ significantly the groups (Table 3, Fig. 4). The vertical illuminance during both interventions was significantly higher in the intervention group than in the control group ( $p = .000$  and  $.015$ ). The people in the intervention group were thus exposed to higher lighting levels, even though depending on the orientation and seating distance from the window, the amount of light on the individual eye differed.

### 3.2. Behaviour

The median values of the five researched GIP subscales are given in Table 4. To allow for comparison, hypothetical means (ordinal scale) are given in Table 4 as well.

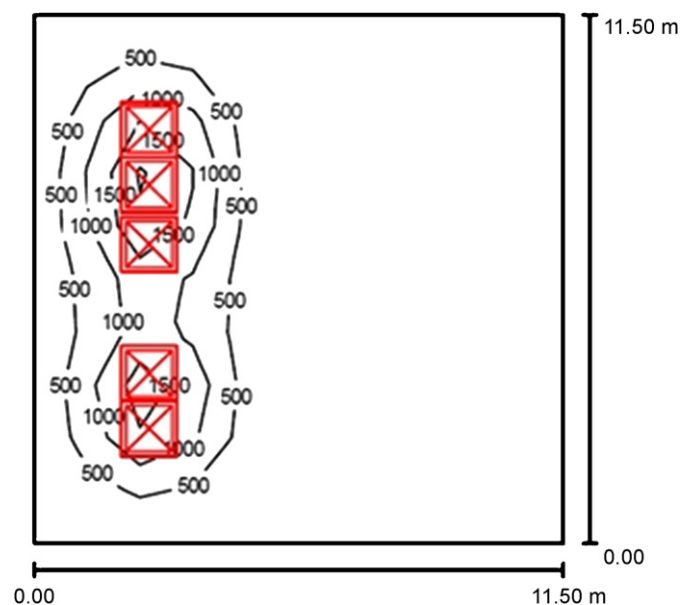


Fig. 3. Luminaire lay-out simulated in DIALux, showing isographs for horizontal illumination at a height of 1.2 m.

Table 3  
Vertical illuminances measured at the eye in the control and intervention rooms at the three research stages

$E_{\text{vertical}}$ (lx)	Baseline			Intervention 1			Intervention 2		
	Control group	Intervention group	$p$ -value	Control group	Intervention group	$p$ -value	Control group	Intervention group	$p$ -value
Mean	156	86	.220	144	413	.000	43	410	.015
Max	316	211		416	1140		100	1310	

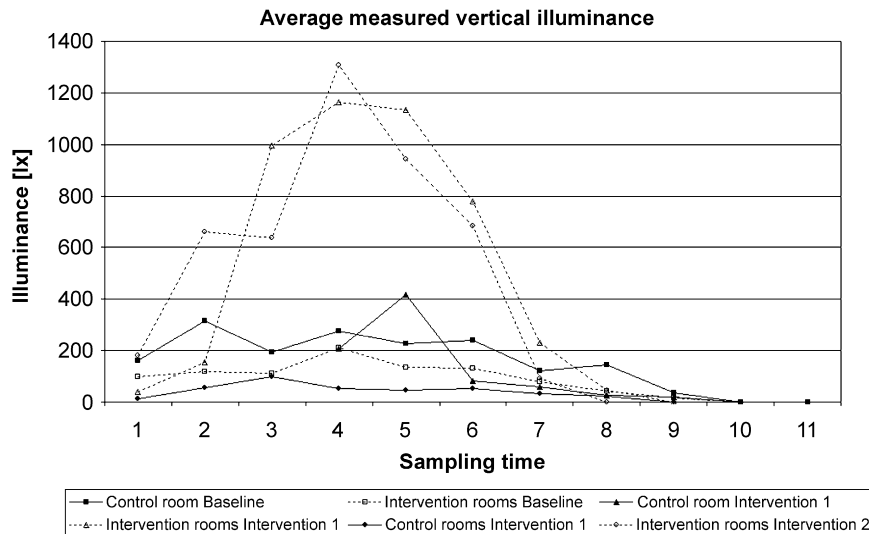


Fig. 4. Average measured vertical illuminance in the rooms at the three research stages.

Mann–Whitney  $U$  tests showed a significant difference in GIP subscale scores for anxious behaviour between the two groups at baseline ( $p < .05$ ), as well as a statistical trend ( $p < .1$ ) for depressive/sad behaviour. Therefore, these two subscales were omitted from further study, since for proper comparison baseline scores need to be comparable. Only the subscales for apathic behaviour, disturbances of consciousness and restless behaviour were considered for further analyses.

Wilcoxon signed ranks tests (Table 5), used to find significant differences between results of the interventions and baseline conditions, showed a significant decrease ( $p < .01$ ) for disturbances of consciousness after intervention 1 for the control group. After intervention 2, only a decrease ( $p < .05$ ) was found for disturbances of consciousness compared to baseline. The GIP score, however, was somewhat higher compared to intervention 1. For the intervention group, a significant increase ( $p > .025$ ) was found for apathic behaviour, as well as a significant decrease for restless behaviour ( $p < .01$ ). There were no significant differences after intervention 2 compared to baseline conditions.

When the differences from the Wilcoxon signed ranks tests were compared again to the results of the Mann–Whitney  $U$  tests, there were no significant between-group differences for apathic behaviour after intervention 1. There were also no significant between-group differences for disturbances of consciousness. We did see a trend

( $.05 > p > .025$ ) in restless behaviour after intervention 1, indicating that the scores for restless behaviour of the two groups differ from each other, and that the bluish light intervention (6500 K) reduced restless behaviour (minus one scale unit on a scale ranging from 0 to 15, from 3.5 to 2.5 median values) compared to the control. No significant differences were found after the yellowish light intervention, implying that the spectral built-up of the light may play an important role.

### 3.3. Tympanic temperature

Mean tympanic temperature, mean range of tympanic temperature and mean late-night temperature are given in Table 4. Independent  $t$ -tests (Table 4) showed that the tympanic temperature parameters did not differ from each other significantly, and can therefore be used for further analyses. Results of paired-samples  $t$ -tests (Table 5) showed a significant increase ( $p < .005$ ) in mean temperature within the control group after intervention 1. When analysing mean temperature range, there were no differences within the control group, while the intervention group showed a significant increase ( $p < .005$ ) after intervention 1 and a significant decrease after intervention 2 ( $p < .01$ ). When analysing mean late-night temperature, both the control and the lighting groups showed significant increases ( $p < .025$  and  $p = .000$ ) in temperature after intervention 2.

Table 4

Median scores of GIP subscales and mean tympanic temperatures of control and intervention groups, and results ( $p$ -values) of Mann–Whitney  $U$  tests (GIP) and independent-samples  $t$ -tests ( $T_{\text{timp}}$ ) for between-group differences at various research stages.

	Baseline			Assessment period 1			Assessment period 2		
	Control group	Intervention group	$p$ -value	Control group	Intervention group	$p$ -value	Control group	Intervention group	$p$ -value
GIP subscale <sup>*,a,b</sup>									
Apathic behaviour	$n = 11$ 8.5 (9.4)	$n = 15$ 7.5 (9.1)		$n = 11$ 8 (8.7)	$n = 15$ 10 (10.5)		$n = 10$ 10 (9.7)	$n = 15$ 9 (10)	
Disturbances of consciousness	8 (8.5)	6.5 (7.1)		6.5 (5.6)	4.5 (6.1)		7 (6.6)	6 (7.6)	
Restless behaviour	5.5 (5)	3.5 (3.5)		4 (4)	2.5 (2.3)	.041	4.5 (5.0)	2.5 (3.3)	.055
Depressive/sad behaviour <sup>c</sup>	4.5 (5.1)	2.5 (3.8)	.061	2 (3.1)	2 (3)		4 (5.1)	2.5 (4.4)	
Anxious behaviour <sup>c</sup>	5.5 (5.9)	1 (2.9)	.041	3.5 (3.5)	0.5 (1.9)		8 (7.6)	2 (3.3)	
$T_{\text{timp}}$ parameter <sup>d</sup>									
Mean temperature (°C)	$n = 10$ 35.7	$n = 15$ 35.8		$n = 10$ 36.0	$n = 15$ 35.7	.069	$n = 9$ 35.9	$n = 15$ 36.2	
Mean range (K)	1.2	1.3		1.2	1.8	<b>.002</b>	1.2	1.0	
Mean late-night temperature (°C)	$n = 9$ 35.6	$n = 15$ 35.5		$n = 9$ 35.6	$n = 15$ 35.7		$n = 8$ 36.1	$n = 15$ 36.2	

\*Exact significant differences (two-tailed,  $\alpha = 0.05$  at baseline;  $\alpha = 0.025$  after interventions 1 and 2) marked bold.

<sup>a</sup>The .5 median scores in even sample sizes are the mean value of the GIP scores 1 below and 1 above the median value. GIP scores are always natural numbers.

<sup>b</sup>Hypothetical mean values of GIP subscale scores are given between brackets.

<sup>c</sup>No analyses for between-group differences after assessment periods 1 and 2.

<sup>d</sup>Significant differences (two-tailed,  $\alpha = 0.05$  at baseline;  $\alpha = 0.025$  after interventions 1 and 2) marked bold.

Table 5

Results ( $p$ -values) of nonparametric Wilcoxon signed ranks tests (GIP), and results of parametric paired-samples  $t$ -tests ( $T_{\text{timp}}$ ), comparing assessment periods 1 and 2 to baseline conditions

	Control group		Intervention group	
	Assessment period 1	Assessment period 2	Assessment period 1	Assessment period 2
GIP subscale <sup>*</sup>				
Apathic behaviour			<b>.017</b>	
Disturbances of consciousness	<b>.005</b>	.030		
Restless behaviour	.058		<b>.005</b>	
$T_{\text{timp}}$ parameter <sup>a</sup>				
Mean temperature	<b>.003</b>			
Mean range			<b>.002</b>	<b>.009</b>
Mean late-night temperature		<b>.011</b>		<b>.000</b>

\*Asymptotic significant differences ( $\alpha = 0.025$ ) marked bold.

<sup>a</sup>Significant differences (two-tailed,  $\alpha = 0.025$ ) marked bold.

When these differences were compared again with the results from the independent  $t$ -tests, we found a significantly higher mean range for the intervention group after intervention 1 (0.6 K;  $p < .005$ ).

## 4. Discussion

### 4.1. Behaviour and light

Of the five GIP subscales considered in this study, we did not study the effects of lighting on depressive/sad and anxious behaviour due to differences in baseline conditions. After interventions 1 and 2, both control and

intervention groups showed significant between-group changes in various GIP subscale scores. In the control group, there were positive developments in GIP scores for several subscales, implying that there may have been changes in behaviour due to other factors. Although there were no significant differences between the two groups after analysing the significant within-group differences in behaviour, there was a trend for restless behaviour. The baseline value for restless behaviour in both groups was low (median 5.5 and 3.5) and not of major concern to the nursing staff given their observation scores. After the bluish lighting intervention, observed restless behaviour of both groups improved, albeit that the results for the

intervention group were more positive and showed the statistical trend. Even though other factors may have played a role, there was a significant improvement in restless behaviour during the bluish lighting intervention that also showed in the between-group comparisons. This result might have been more pronounced if the subjects had had higher scores for restless behaviour at baseline, for instance, in a group with more advanced dementia.

Although this study did not analyse the effects of ambient bright light on depressive/sad behaviour, there is an American study available on this matter. Hickman et al. [33] studied the effects of a high-intensity, low-glare lighting system on depressive symptoms as expressed on the Cornell Scale for Depression in Dementia in the same settings and population as Sloane et al. [25]. Their findings did not support the use of ambient bright light therapy as a treatment for depressive symptoms, although the therapy is widely propagated as a non-pharmacologic intervention for combating depressive symptoms. Hickman et al. [33] do state that a subpopulation of persons with dementia may benefit from the intervention, and that an individual rather than unit-level intervention approaches are more beneficial.

A problem in this study is the way behaviour was assessed; by partially 'subjective' observations instead of objective measurements. A possible bias in this study might be caused by questions concerning the semantics of the validated GIP scale. The character of the answers on the questionnaire (*never, hardly ever, sometimes* and *often*), in which the underlying meanings of the numbers are not spread evenly across a numeric scale, can lead to considerable deviations. For instance, there is a far smaller interval size between *sometimes* and *often*, than between *never* and *hardly ever*. On the other hand, nurses were familiar with the scoring scale and the resident population, reducing the scale of any bias. These unequal-interval sizes made it important for baseline conditions to be statistically equal to allow for further analyses.

To our knowledge, there are no studies on the natural decline in GIP scores of residents of psychogeriatric wards. It is likely that there is an overall irreversible deterioration in behaviour when dementia progresses until people reach the end-stage of the syndrome. A study by Baker et al. [34] on the influence of multi-sensory stimulation on GIP subscale scores stated that behaviour on the ward remained stable during a 4-week trial. GIP scores and the loss of skills generally differ from person to person and depend heavily on the character of individuals. Since the effects of ambient bright light on behaviour are not fully understood, it is unknown whether lighting has a positive effect on GIP scores, or whether a stand-still in the decline of the behavioural observations should be expected when exposing older adults with dementia to ambient bright light.

Even more relevant issue is how to implement the results in the own home situation. According to Hatfield et al. [22], the deterioration of activity/rest cycles is a common and progressive feature in home-dwelling people

with Alzheimer's. In the future, lighting solution may alleviate the burden of care that rests upon the shoulders of relatives.

#### 4.2. Tympanic temperature

Body core temperature, and thus tympanic temperature, is one of the most powerful and stable indicators of circadian synchrony, reflecting activity of the circadian rhythm's strong oscillator [35]. The average tympanic temperatures found in this study's subjects are about 36 °C. The normal body temperature range for older adults is 36.1 to 37.8 °C [36]. The temperatures found are on the lower side of the normal range, which may indicate disturbances in circadian rhythmicity or an altered metabolism. According to Kenney and Munce [35], lower body core temperatures in older adults appear to reflect nutritional, disease and medication effects. Body core temperature should, in resting and thermoneutral conditions, be similar to that of younger adults. Lower temperatures may also point out to errors in instruments, the way temperature was measured by the staff, and anatomical properties of the ear canal, as is known from studies on infrared tympanic thermometry [37–39]. Tympanic temperature, however, can be measured objectively in contrast to GIP scores. In a study by Aizawa and Tokura [40] on the effect of daytime (09:30 to 18:00 h) exposure to light (4000 and 100 lx) on tympanic temperature in nine healthy young adults, average tympanic temperatures were significantly lower in the bright than in the dim condition. The lower tympanic temperatures found in the study cannot be only attributed to the light intervention, since they were also found in the control group. Perhaps the effects are due to unwanted exposure of participants to outdoor light, and a similar study carried out in winter should further investigate this matter. Other methods often used to assess circadian rhythmicity and sleep-wake patterns are the collection of melatonin from saliva and actigraphy. In our view, these methods posed too much strain on the residents or were not practical from a nursing point of view, and were therefore not applied.

As to the lighting intervention, the bluish light seems to have had a positive effect on amplitude of circadian rhythm, and possibly a stabilising effect on mean tympanic temperature. However, the strengthened amplitude in the intervention group exceeds that of healthy adults. At the same time, such an effect may be due to an altered functioning of the brain in people with dementia.

#### 4.3. Time of study and ambient temperature

This study was carried out in late spring and summer. When weather was good, the majority of participants went outdoors for a period of time, where they were exposed to high levels of natural daylight. Exposure to high-intensity daylight may have influenced mood and circadian rhythmicity to a higher extent as did the lighting intervention,

although the effects of lighting in experiments carried out in winter and spring by van Someren [24] required a day-long exposure to high-intensity light. Moreover, people did not only go outdoors, but also walked or moved around the corridor of the ward. By moving around, the effective light exposure may have been reduced to only 3–4 h per day, for instance, during meals. Even though some residents left the room or fell asleep (eyes closed) during the experiment implying that exposure varied per individual, the exposure to light was always larger in the intervention group than in the control conditions. If outdoor exposure to daylight had played a role, the effects on behaviour and circadian rhythmicity should have shown in the data obtained during the yellowish light intervention, and also in the control group. Future research should be carried out in winter in order to exclude or minimise a number of factors. During winter, the contribution of sunlight to indoor light levels is less than in summer. Moreover, subjects do not go outdoors as frequently, and high outdoor temperatures possibly interacting with body temperature are not found.

It is hypothesised that the hot weather in July may have influenced tympanic temperature or the measurement thereof to an unknown extent. Outdoor air temperature reached a maximum of 36.4 °C on July 19th. On 14 days temperature reached 30 °C. There were 27 days with temperatures exceeding 25 °C. The lowest temperature was measured on July 7: 23.7 °C [41]. A mean maximum outdoor air temperature of 29.2 °C led to an increase in indoor air temperatures that may have influenced the body temperature of the residents. In general, older individuals have a lower basic metabolic rate and activity level, and a higher threshold for sweating than the young; thus, it is more difficult for them to maintain normal body temperature during stressful thermal climatic conditions [42,43]. Higher temperatures may also have had a negative effect on behaviour during the yellowish CCT intervention, as persons are annoyed with the high temperatures or become lethargic. At the same time tympanic temperatures that are a representation of core body temperature were on the lower side, when one would expect an increase in body temperature in people with a diminished threshold for sweating. The additional heat gains from the lighting equipment were less than 1 K, and are therefore not considered as a cause of shifts in circadian rhythmicity.

#### 4.4. Ethical considerations, safety, and benefits of lighting

The ceiling-mounted luminaires used in this study provide an ethical way of exposing people to ambient bright light. Van Someren et al. [24] describe a number of experiments in which subjects were placed in front of a table-mounted artificial light source for 2 h, requiring continuous attendance from nursing staff to guarantee exposure and compliance. Besides ethical concerns, the extra attention of the nurses might introduce a placebo effect, and in work situations extra staff may even not be available [24]. The

luminaires used in this study also support vision and carrying out activities. Nurses expressed concerns about any harmful effects of the installed equipment and the high-intensity light to health and eye sight. Sloane et al. [44] researched the impact of high-intensity, low-glare, ambient light (about 2500 lx, 6500 K, 85 $R_a$ ) on residents and staff of dementia care units in the United States, and compared the outcomes to a control of dim industrial lighting. Eleven symptoms considered as side-effects, namely: eyestrain, seeing spots, problems with glare, eye burning or irritation, eye redness, jitteriness, skin rash on the face or arms, severe agitation, headache, dizziness, and nausea, were minimal. The intensity of light from the equipment is still much lower than outdoor light levels in summer.

A strengthened circadian rhythmicity in combination with improved behaviour has many practical benefits. People with dementia themselves may experience improved sleep, and may go through life in a more dignified manner. The improved health status may even be more inviting for relatives, who are else deterred by behavioural problems, to pay an extra visit. Last but not least, the burden of caregiving may be decreased by the lighting intervention. Care professionals may benefit from the lighting equipment themselves because of visual and non-visual effects the systems have. This could be a relevant addition to future research. Also, beneficial effects of high-intensity lighting in relation to night shifts are worth investigating.

Although lighting undoubtedly has benefits in terms of visual capacities, special artificial lighting can never be a substitute for taking older adults outside or for care capacity problems. Every human being has the right to go outside—not merely for sensory activation—even though there are few (in)formal carers to take residents out for a short walk just to catch some fresh air. This, however, does not imply that residents are not entitled to have the best possible lighting equipment as an additional therapy.

#### 4.5. Conclusion

Our research has found further evidence that high-intensity light with a high CCT (6500 K), emitted by ceiling-mounted luminaires, improves circadian rhythmicity in institutionalised older adults with dementia, and may positively influence restless behaviour, without putting extra strain on the nursing staff or being an invasive treatment for older adults with dementia. Effects were not found for the yellowish light (2700 K) intervention. However, more research is needed to strengthen the new evidence, for instance, by using a less subjective observation scale to assess behaviour, by using subjects with more pronounced restless behaviour, and by conducting experiments in winter.

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