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High colour temperature lighting for institutionalised older people with dementia

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ABSTRACT

Non-pharmacologic interventions, such as high-intensity white light with a high output in the short-wavelength part of the spectrum can play an important role in the care for older people with dementia. In order to assess the effects of prolonged exposure to low intensity light, i.e., $E < 500$ lx, from a light source with a high correlated colour temperature (17,000 K versus 2700 K) on behaviour and circadian rhythmicity of institutionalised older adults with dementia, a cross-over design field study was carried out in a psychogeriatric day care ward in May and June 2008. Effects of the lighting intervention were assessed by the Dutch Behaviour Observation Scale for Intramural Psychogeriatrics (GIP), and tympanic temperature measurements. The two lighting solutions installed, particularly the 17,000 K lighting, led to much lower colour temperatures at eye level in practice. No significant improvements in behaviour and in the range of tympanic temperature were found for the lighting interventions tested. This might indicate that higher illuminance levels are the important factor in establishing successful light therapy, and that higher colour temperature may add up to the effectiveness. At the same time, the 17,000 K light tubes did not result in ultrahigh colour temperatures at the eye level of the subjects, and may even have an adverse effect on some persons with dementia.

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1. Introduction

According to estimations over 24 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 people with dementia at some point in their course [2]. Non-pharmacologic or non-medical interventions can play a role in managing these problems [2]. Special lighting is one of such non-pharmacological interventions [3–5]. Adequate lighting enables people to see and prevents falls. Also, light plays a role in regulating biochemical processes, immunologic mechanisms, and neuroendocrine control, via the skin and via the eye [4,6]. Exposure to light is the most important stimulus for synchronising the biological clock [7], suppressing pineal melatonin production [8], elevating core body temperature [9], and enhancing alertness [9,10]. In older adults (short-wave length) light levels needed for these effects are much higher than those required for proper vision, due to opacification and yellowing of the vitreous and the lens, which stem from biological ageing [11,12]. In practice, many older adults are not exposed to illuminance levels that are sufficiently high. Many homes are poorly-lit (up to 400 lx), and a lot of older people do not go outdoors for prolonged periods of time where illuminance levels are much higher [11,12]. The limited exposure to high levels of lighting is a cause of impaired functioning and problem behaviours, which form a great source of stress and a burden for carers, and are among the main reasons for institutionalisation [13–15].

High-intensity lighting, with illuminance levels of well over 1000 lx, may play a role in the management of dementia. Bright light treatment with the use of light boxes is applied to entrain the biological clock, to modify behavioural symptoms, and improve cognitive functions, by exposing people with dementia to high levels of light (for instance, [16–18]). This requires supervision to make subjects follow the total protocol and may cause a bias in the outcomes of the therapy. The results of bright light therapy on managing sleep, behavioural, mood, and cognitive disturbances show preliminary positive signs, but there is a lack of adequate evidence obtained via randomised controlled trials to allow for a widespread implementation in the field [19–21]. Another approach that is gaining popularity, both from a research, ethical and practical point of view, is to increase the general illuminance in rooms where people with dementia spend their days to a high level

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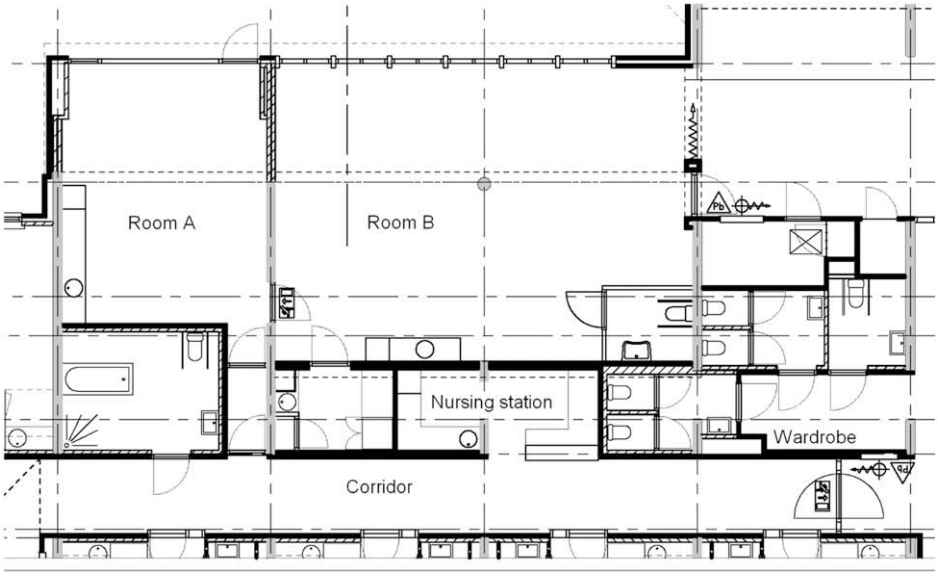

Fig. 1. Floor plan of the day care centre.

[22]. Studies by Rheaume et al. [23], van Someren et al. [24], Riemersma-van der Lek et al. [25], and van Hoof et al. [5] that exposed institutionalised people with dementia to ambient bright light through ceiling-mounted luminaires showed short-term and long-term effects as lessened nocturnal unrest, a more stable sleep–wake cycle, possible improvement to restless and agitated behaviour, increased amplitude of the circadian body temperature cycle, and possible improvements to sleep. Still, the field of study is new and lighting equipment used needs to be researched and modelled in more detail, both in laboratory and field settings. Van Hoof et al. [5] have shown that not only illuminance levels are important, but that the correlated colour temperature (CCT) of the lighting equipment installed plays a role too, and that certain behavioural and circadian effects that are obtained with 6500 K light are not found in 2700 K light. It is hypothesised that light with even higher CCTs may sort more outspoken effects. At the same time, the spectral build-up of the light may be so important that the spectral composition by itself is enough to yield positive effects, and that high-intensity in terms of illuminance levels is not even required. This field study aims to assess effects of prolonged exposure to low intensity white light (500 lx from electrical lighting on the eye level) with a high CCT of 17,000 K, and a low 2700 K CCT, emitted from ceiling-mounted luminaires on behaviour and circadian rhythmicity of older adults with dementia in a day care ward in a care home.

2. Methods

2.1. Study building

The psychogeriatric day care centre in this study was situated in a care home in the town of Gilze–Rijen, the Netherlands (Figs. 1 and 2). The test rooms were located on the ground floor and consisted of 2 communal living/activity rooms (Fig. 1). The rooms contain two large tables where all residents are seated for the larger part of the day. The centres of these tables were located at a distance of approximately 4 m from the windows. There is also a television corner with seats, which together form a third place where residents can sit down for a while. The rooms and the furniture are quite colourful for a health care setting in order to create a non-institutional atmosphere (Fig. 2). Windows of thermally insulating glass were present in the external walls of the rooms, and takes up about two-thirds of the wall surface area. The ratio between window surface and floor surface was approximately 1:3. The height of the rooms was about 2.4 m. Windows were facing east in both rooms.

With the use of the validated light simulation tool Radiance version 3.9, the daylight condition in room A was simulated, and validated with light measurements taken in the room on a sunny day with a clear blue sky in the afternoon. Due to the elevation of the sun and orientation of the room, no direct sunlight could enter. The horizontal and vertical illuminance levels were both taken at a height of 1.2 m with a horizontal grid of 2 by 2 m (Fig. 3). Near the tables, the contribution of daylight was found to be ls than 200 lx horizontal. The vertical illuminance in the direction of the façade ranged between 400 and 800 lx (Fig. 3). That is why during the experiments the white translucent shading screens (Fig. 2) in the room were positioned to keep out direct sunlight. During the experiments staff was instructed not to use these screens unless there was much direct sunlight. Additional notes were placed next to the controls of the screen, and black tape was placed on the window panes to indicate the maximum opening height of the screens.

Fig. 2. Experimental luminaire as installed in the day care centre.

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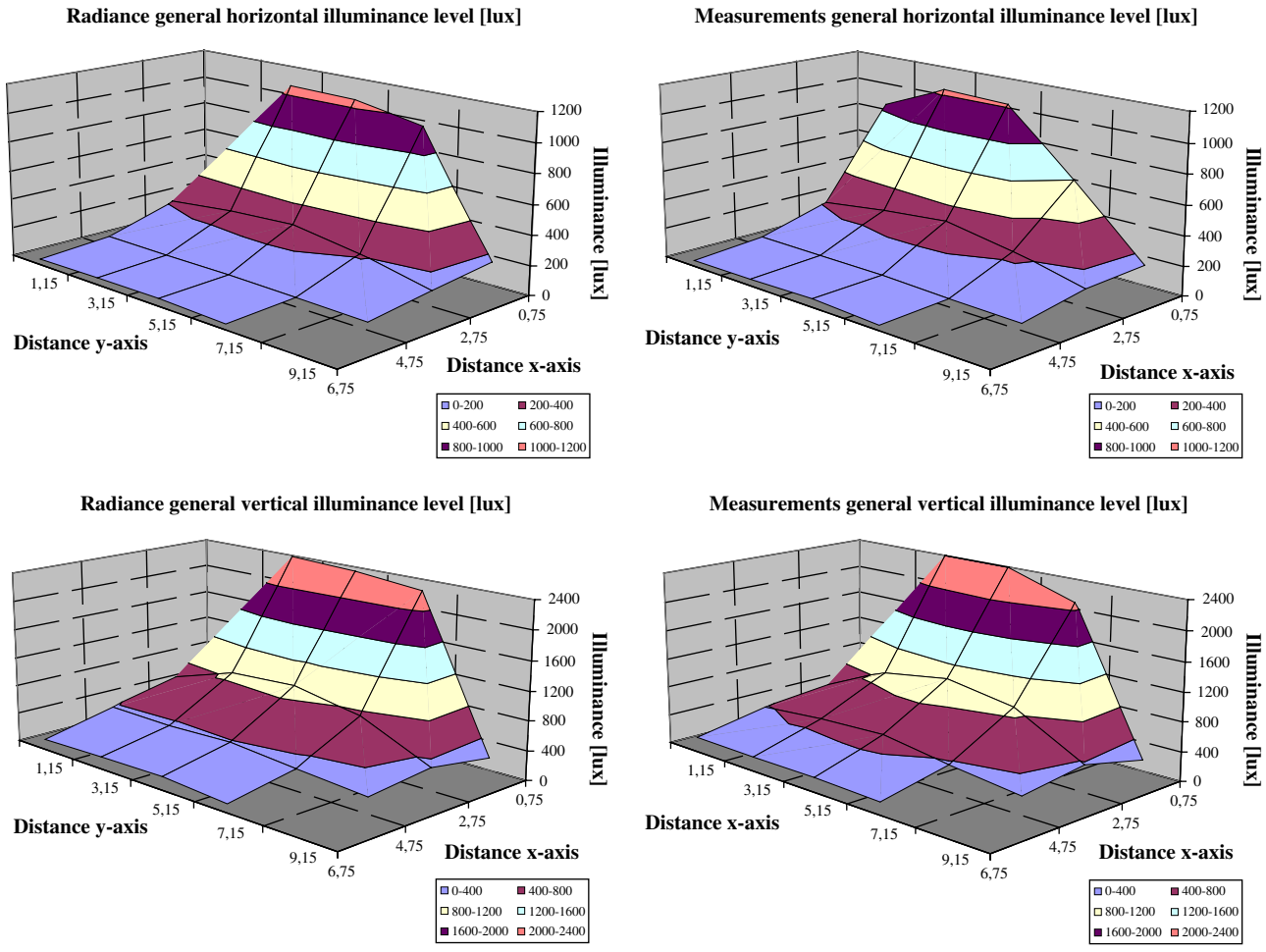

Fig. 3. Four scenarios of illuminance in Room B of the day care centre. The upper row shows horizontal illuminance levels, the lower row vertical illuminance levels. The first column shows results of the simulations in Radiance, the second column results of field measurements. Measurements were taken at a height of 1.2 m (for E_{vert}, measurements the instrument was facing towards the window).

Mean air temperature in the living room was kept at room temperature, i.e., 25 °C, which was verified by daily measurements around 14:00 h. 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 present from 07:30 h to 22:15 h in room A (14:45 h in total) and from 08:00 h to 19:00 h in room B (10:30 h in total). Occupants of room B had a somewhat more independent lifestyle, and went to their own living quarters in the evening hours. Occupants of room A, however, had more supervision. This is a reason why a cross-over design was chosen.

2.2. Subjects

Informed consent was signed by 23 subjects and/or their responsible relatives. One person was excluded because of a non-dementia-related psychogeriatric disorder. The 22 participants with a mean age of 88.2 years were randomly divided over two groups of 10 (group A) and 12 people (group B) respectively. All participants were clinically diagnosed by the medical staff, resulting in diagnoses of probable Alzheimer's disease (AD), vascular dementia (VD), mixed Alzheimer's disease and vascular dementia (MX), or Lewy Body dementia (Table 1). The majority of persons were diagnosed with vascular dementia. 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 disturbances as well as in the response to bright light therapy [24].

The residents spent most of their day in one of the rooms they had been assigned to. The interior design and type of furniture were of the same type for both rooms. The residents had been living institutionally for 45 ± 37 (mean, SD) months.

2.3. Study design

The intervention study was performed in May and June 2008 (Table 2). Pre-, mid-, and post-trial assessments of various parameters/scales were taken on 9 assessment days to investigate any generalisation of effects on behaviour and circadian rhythmicity on the ward. In the weeks prior to the light intervention, GIP scores, light conditions, and tympanic temperature were assessed and measured 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 lighting equipment was switched on for several consecutive days to find possible short-term effects. After these days, a short period of baseline lighting conditions was established once more. Both groups followed the same experimental protocol until

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Table 1
Population of the wards.

	Gender		Age [years]		Number of months living institutionally		Clinical diagnosis				Presence in the room
	Male	Female	Mean	SD	Mean	SD	AD	VD	MX	Lewy Body	
Group A	2	8	87.9	5.5	43.1	37.3	3	5	2	0	7 days per week ($n = 10$)
Group B	3	9	88.4	5.8	46.9	39.1	2	7	2	1	7 days per week ($n = 6$); 7 half days per week ($n = 3$); 5 days per week ($n = 1$); 2 days plus 5 half days per week ($n = 1$); 2 days plus 3 half days per week ($n = 1$)
Total	5	17	88.2	5.5	45.2	37.4	5	12	4	1	

May 26th. Thereafter, the design of a cluster-unit cross-over intervention trial was chosen. The two methods are a combination of previous designs chosen by van Hoof et al. [5] and Sloane et al. [26]. The protocol was stopped after June 24th. During each of the two lighting interventions, assessments of GIP scores, tympanic temperature, illumination levels and colour temperature took place. During the whole experimental period, logs were available to the care professionals to write down special or deviating events.

2.4. Behaviour

The Dutch Behaviour Observation Scale for Intramural Psychogeriatrics (GIP) [27] used in this study and by van Hoof et al. [5] for determining the behavioural conditions of the residents, is made up of fourteen subscales that can be used separately. Of the fourteen subscales, only five subscales for apathic behaviour, disturbances of consciousness, restless behaviour, depressive/sad behaviour, and anxious behaviour were used. Subscale scores range from 0 (not present) to a maximum of 21 (most frequent and severe); subscale scores are 0–18 for apathic behaviour, 0–21 for disturbances of consciousness, 0–15 for restless behaviour, 0–18 for depressive/sad behaviour, and 0–18 for anxious behaviour.

This part of the study could not be carried out blindly for two reasons: (i) the care professionals filling out the scoring lists make over-time observations and thus have to be familiar with the subject, and (ii) the type of lighting intervention is visible. Care professionals 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

This study used tympanic temperature as a marker of the 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 [28]. 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 [29]. In a study comprising 237 older adults with dementia, Sund-Levander and Wahren [30] have found that the variation in tympanic and rectal temperatures ranged from 33.8–38.4 °C and 35.6–38.0 °C, respectively. Dementia was significantly related to lower tympanic and rectal temperature. In this study, we were aware that temperatures found could be lower than expected in healthy older adults.

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 (1) at wake up (dark conditions in the private room), (2) 1 h after wake up, (3) 2 h after wake up, (4) approximately 5 h after wake up (around nap time), (5) approximately 8 h after wake up, (6) 3 h before going to bed, (7) 2 h before going to bed, (8) 1 h before going to bed, (9) bed time (dark conditions in room), (10) early night-time measurement, and (11) late night-time measurement (Table 3). During tympanic temperature measurements, illuminance measurements took place simultaneously at the eye level and viewing direction of the subjects. Data were reduced to single value for range of tympanic temperature (two times the amplitude), which were considered in further analysis.

2.6. Lighting equipment and measurements

In the rooms the subjects were cared for, the existing ceiling-mounted illumination above the table that the participants sat at, was replaced by 2 new luminaries (Fig. 2), type BioSun by Van Doorn B.V., Culemborg, the Netherlands. Each new fitting contained

Table 2
Study design.

Date	Lighting conditions ($E_{horizontal}$ [lx]/CCT [K])		Measurements and assessments
	Group A	Group B	
9 May 2008	(500/2700)		Tympanic temperature (11×), illumination at eye level (11×); GIP (1×)
13 May 2008			Tympanic temperature (11×), illumination at eye level (11×); GIP (1×)
17/18 May 2008			GIP (1×)
22 May 2008	(500/17,000)		Tympanic temperature (11×), illumination at eye level (11×); GIP (1×)
26 May 2008	(500/2700)		
30 May 2008	(500/2700)	(500/17,000)	Tympanic temperature (11×), illumination at eye level (11×); GIP (1×)
4 June 2008	(500/17,000)	(500/2700)	Tympanic temperature (11×), illumination at eye level (11×); GIP (1×)
19 June 2008	(500/17,000)		Tympanic temperature (11×), illumination at eye level (11×); GIP (1×)
24 June 2008			Tympanic temperature (11×), illumination at eye level (11×); GIP (1×)

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Table 3
Time line of activities in the day care centre. Sampling times are included by approximation to the activities.

Sampling times	Time	Activity
1	Morning	Residents come into the rooms after having received personal care, and have breakfast
	From 07:30	First people gather in the room of Group A
2	Around 08:00	
3	Between 09:15-09:45	
	Half-way during the morning	Coffee and tea break, activity
	Between 11:45 and 12:30	Warm meal
4	Between 12:45 and 13:45	Some residents of both groups return to apartment to have a rest. Others remain
	Half-way during the afternoon	Coffee and tea break, activity
5	Around 15:30	
	Between 17:00 and 18:00	Cold meal (bread)
	From 18:15 to 19:00	Some residents of group A return to apartment to have a rest. Most remain in the room
	From 18:15 to 19:00	Residents of group B are returned to their apartments. The living room closes.
6	About 19:00	Coffee and tea break. Some residents in Group A participate in an activity.
	About 19:30	First resident of Group A is returned to his/her apartment and put in bed.
7	20:00–21:00	
8	21:00–22:00	
9	About 22:00	Last person returns to his/her apartment
10	Around 01:00	
11	Around 05:00	

high-intensity fluorescent tubes by Philips Lighting (MASTER TL5 HO ActiViva Active 54 W 1SL for 17,000 K, and MASTER TL5 HO 54 W/827 UNP for 2700 K) – 6 tubes emitting 17,000 K light and 4 tubes emitting 2700 K light per luminaire. The spectra of the light emitted by the two types of tubes are shown in Figs. 4 and 5. The general colour rendering index (R_a) of the lighting was 82 for the 17,000 K lighting and 85 for the 2700 K lighting. For legibility, the paper mentions 2700 and 17,000 K lighting, whereas different values may be achieved in the field at eye level.

Based on simulations in the computer program DIALux 4.1 by DIAL GmbH (Fig. 6), an arrangement of luminaires was designed in order to obtain the largest illuminance level at the vertical eye level as possible without causing visual discomfort. The most efficient layout was a combination of two clusters of luminaires above the dining/work tables.

The lighting equipment was switched on from base-line conditions ($E_{horizontal}$ about 50 lx, added artificial light) each morning at 07:30 h, and allowed to gradually reach at least 500 lx $E_{horizontal}$ by 08:00 h. This level correspond to lighting recommendations for nursing homes

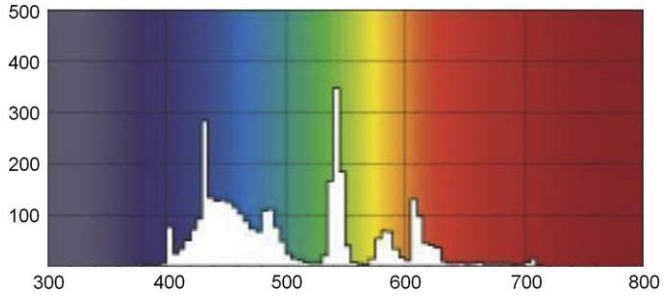

Fig. 4. Spectral distribution of the Philips Lighting MASTER TL5 HO ActiViva Active 54 W 1SL, shown for every 5 nm frequency band in μW/lm.

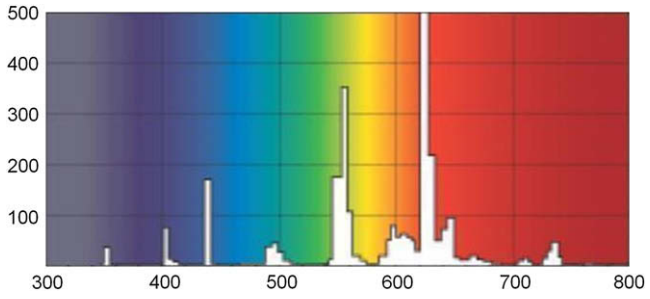

Fig. 5. Spectral distribution of the Philips Lighting MASTER TL5 HO 54 W/827 UNP, shown for every 5 nm frequency band in μW/lm.

in the Netherlands [31]. The amount of lighting was gradually lowered at 18:00 h in order to reach a level of 50 lx (added artificial light) at 18:30 h. The times correspond to the arrival and leaving of the majority of the residents, as can be seen in the time plan of a typical day (Table 3). The total exposure to the lighting intervention depended on the duration of the subjects' presence in the rooms (Table 1). Additional light sources in the room were not used during the experiments. The lighting installed during the first intervention had a CCT of 17,000 K, and 2700 K during the second intervention. The 17,000 K has a larger contribution of short-wavelength light in the light spectrum, whereas 2700 K largely lacks this part of the spectrum.

Since the direction of light at the retina plays an important role in non-visual effects of lighting, the illuminance as well as the colour temperature at the position of the eye were measured using a Minolta Chroma Meter XY-DC simultaneously with tympanic temperature; taking into account the participants' viewing direction and angle. The instruments' colour temperature range is from 1600 to 40,000 K. The daytime light measurements all included the contribution of daylight to illuminance levels and colour temperature, as the study is field study and environmental exposures are relevant exposures in practice.

According to the Kruithof diagram of the relation between colour temperature and illuminance and the perceived ambience [32], the 2700 K scenario is perceived as a warm ambience, while extrapolation of the current diagram shows that the 17,000 K might be just within the limits of being perceived as a cold ambience (threshold limit for satisfactory ambience). According to Berman [33], the intrinsically photosensitive retinal ganglion cells might explain the effects of light spectrum on spatial brightness perception. Górnicka [34] calculated the non-image forming (NIF) effects of 17,000 K lamps based on data provided by Philips Lighting, Eindhoven, the Netherlands, for office situations. She found that the lighting condition of 17,000 K would give 3.4 times more NIF output than the condition of 2700 K (Fig. 7). Due to the aforementioned opacification and yellowing of the vitreous and the lens, and thus increased filtering of the short-wavelength light emitted by the 17,000 K light source, this ratio might be different.

2.7. Statistical analyses

During each of the two light interventions, assessments of GIP scores, tympanic temperature and illumination levels took place. All the data were aggregated into average values for the two groups. These new data were in turn used for 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 0.05 for between-group comparisons of behaviour and tympanic temperature at baseline. Non-parametric statistics for independent and related samples were employed to test whether observed behaviour (GIP) differed between the two groups, and within-groups, for the various

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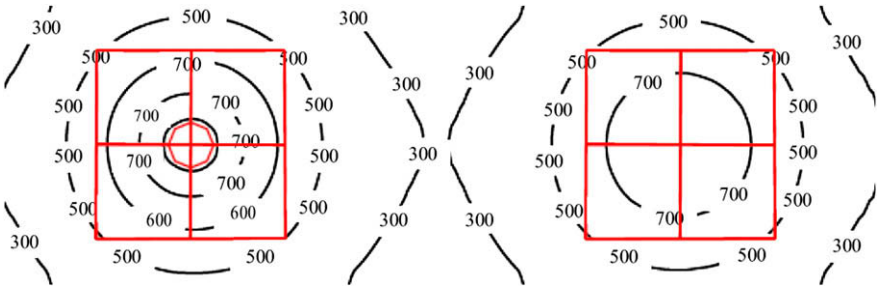

Fig. 6. Luminaire layout simulated in DIALux, showing isographs for horizontal illuminance levels at a height of 1.2 m.

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.

3. Results

3.1. Light

Light measurements showed that the illuminance at eye level in the two rooms was quite low (Table 4, Figs. 8 and 9), on average between 120 and 220 lx (mean value of the 11 measurement periods). When taking a closer look at measurement periods 3 and 5 when people are fully exposed to the light emitted by the experimental luminaire, the mean illuminance at eye level was much higher, ranging from 375 to 470 lx. The luminaire was designed to provide horizontal illuminance levels of up to 500 lx. The levels differ per individual, as not all subjects had the same viewing direction. Some looked at an interior wall, whereas others looked towards the window. Also, not all subjects had the same distance to the window. At measurement point 4 in Figs. 8 and 9, there is a distinctly lower illuminance level. This is due to the afternoon nap of some of the subjects. They were no longer exposed to the experimental conditions, but returned to their own apartment.

Table 4 shows that when assessing the mean value of the colour temperature during the day, these range from 2700 to 3250 K for the 2700 K scenario, and are between 4200 and 4700 K for the 17,000 K scenario. There seems to be a good match between the installed and realised colour temperature for the 2700 K scenario, but a large mismatch for the 17,000 K scenario. Figs. 10 and 11 show the measured colour temperature at eye level over the day, which varies considerably over the day, as people did not constantly stay in the rooms. When taking a closer look at measurement periods 3 and 5, the mean colour temperature is much higher, in both lighting scenarios. Means for the 2700 K scenario range from 2800 to 3460 K, with considerable peaks up to well over 8000 K, and for the 17,000 K scenario means range from 7400 to 8400 K, with maximum values of 11,500 and 12,500 K. The CCT installed thus does not match the colour temperatures found in the field, possibly due to interactions with daylight and the environment.

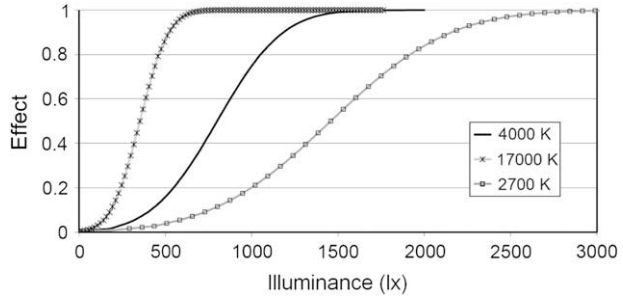

Fig. 7. Hypothesised size of non-visual effects of light during daytime for different illuminance levels at the eye and different colour temperatures, taken and adapted from Górnicka [34].

3.2. Behaviour

The median values of the five researched GIP subscales are given in Table 5. To allow for comparison, hypothetical means (ordinal scale) are given in Table 5 as well. The data for the 2700 K scenario are composed of the values of 5 assessments; the 17,000 K scenario out of 4 assessments. There were no differences in behavioural aspects between the groups at baseline.

Ideally, the 17,000 K scenario would result in improved behaviour. This is not the case. In group A, the scores for depressive/sad behaviour and anxious behaviour increase, i.e., behaviour deteriorates (Table 6). These within-group changes are significant ($p = 0.028$ and $p = 0.015$). Between-group comparisons show no differences. In the 17,000 K scenario, there is a between-group's difference for disturbances of consciousness, and the scores of Group B have increased, i.e., more disturbances were observed. Within-group comparisons for group B, show this difference is not significant ($p = 0.065$).

3.3. Tympanic temperature

The mean range of tympanic temperature and their standard deviation is given in Table 5. Independent *t*-tests (Table 5) showed that the tympanic temperature parameters did not differ from each other significantly, and can therefore be used for further analyses. There are no within-group differences in the two groups, implying that the 17,000 K scenario does not have circadian effects. In the 17,000 K scenario, the range in tympanic temperature has slightly declined (not significantly), whereas it should increase if any circadian effects were present.

Table 4
Illuminance levels at eye level and colour temperature at the eye in the two groups, average values over the day, and average values of measurement periods 3 and 5.

Measurements		2700 K scenario		17,000 K scenario	
		Group A	Group B	Group A	Group B
E_{eye} [lx]	Mean	201	219	119	162
	SD	42	55	40	46
	Mean (periods 3 & 5)	469	427	375	433
	SD (periods 3 & 5)	187	222	233	224
	Max (periods 3 & 5)	810	895	1170	910
Colour temperature [K]	Mean	2691	3254	4182	4716
	SD	300	328	367	646
	Mean (periods 3 & 5)	2823	3461	7364	8358
	SD (periods 3 & 5)	814	1290	2439	3043
	Max (periods 3 & 5)	7750	8850	11,500	12,500

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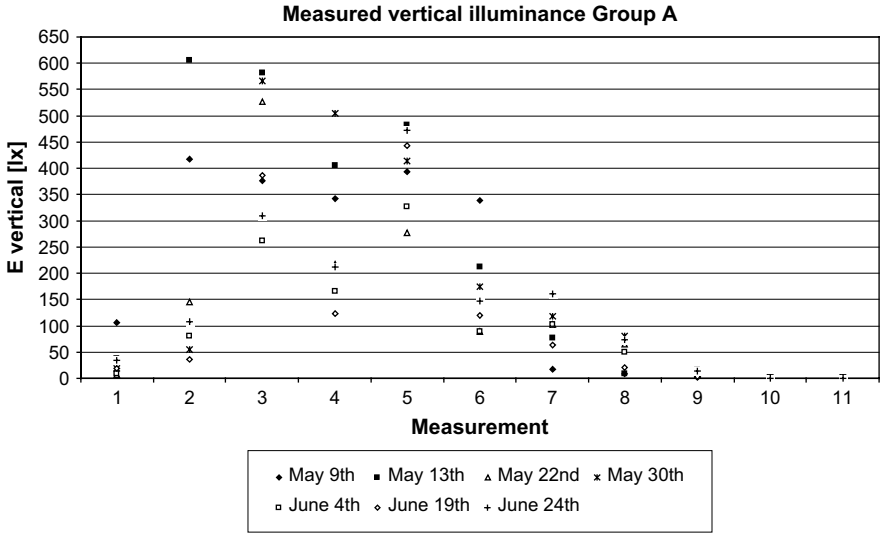

Fig. 8. Overview of average measured vertical illuminance at eye level for Group A shown per measurement day.

4. Discussion

4.1. Light

The light parameters considered in this study, illuminance and colour temperature, deviate in the field from what has been installed. The illuminance levels at eye level during the day are around 400 lx, with maximum values ranging between 810 and 1170 lx. The somewhat higher levels are probably due to daylight contribution through windows. Also, illuminance levels are higher in the 2700 K scenario as compared to the 17,000 K scenario. This difference cannot be attributed to luminous fluxes of the tubes (at 25 °C), which is 3800 lm for the MASTER TL5 HO ActiViva Active 54 W 1SL tube (17,000 K), and 4450 lm for the MASTER TL5 HO 54 W/827 UNP tube (2700 K). Given the installation of six versus four tubes of the two types, this could correspond to a 28% difference. Still, lighting was controlled at the same pre-set levels for both scenarios. There might have been a larger contribution of daylight.

In low colour temperature lighting, the low illuminance levels measured are not expected to cause any NIF effects. Differences in realised colour temperature between the two scenarios are more outspoken and might show different outcomes. The 17,000 K scenario does not expose people to 17,000 K at the eye level, and the 2700 K scenario does not automatically lead to continuous lighting conditions with a matching colour temperature. There are some explanations for these findings.

First of all, there is a contribution of daylight during the day, which influences the colour temperature of the light. In case of the low colour temperature intervention, daylight may increase the colour temperature by a factor 3 on average during the day (Table 4), particularly when subjects are facing towards the windows. The viewing direction, and the seating position of the subjects are thus of great importance. At the same time, figures show that the realised colour temperature in the 17,000 K scenario is much lower, with maximum values of 12,500 K. Here, daylight may also play a role, as well as interactions between the building, the furniture and interior design features. This is a direct result of conducting field studies in a non-uniform environment. Possibly, there might be a filtering effect of the luminaires too, which might absorb some of the short-wavelength part of the visible spectrum. During the

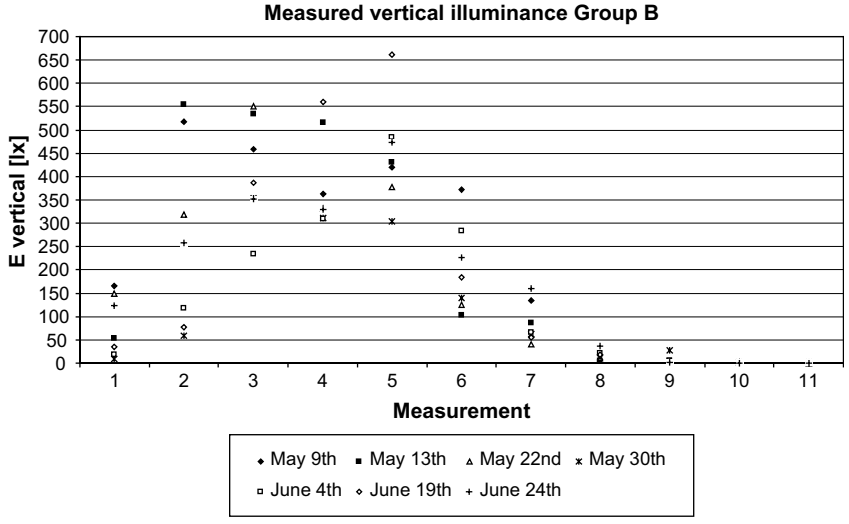

Fig. 9. Overview of average measured vertical illuminance at eye level for Group B shown per measurement day.

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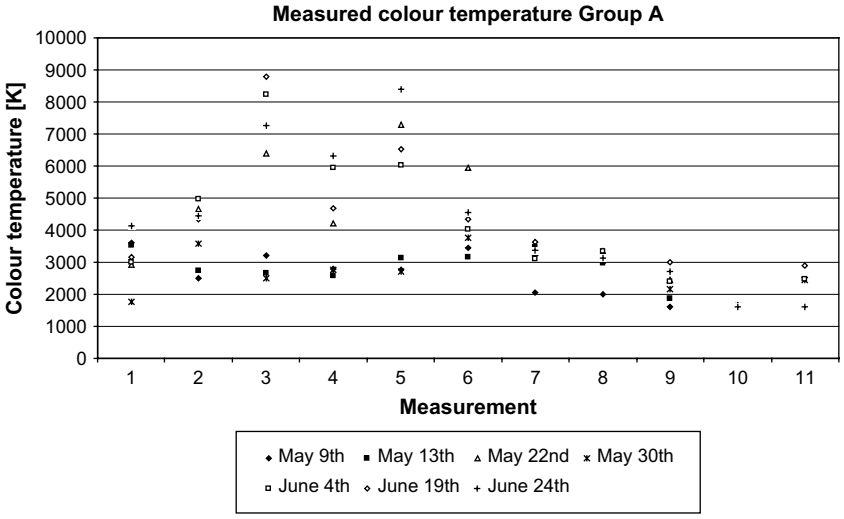

Fig. 10. Overview of average measured colour temperature at eye level for Group A, shown per measurement day.

evening hours, when curtains are closed, colour temperature ranges between 2000 and 3000 K for both lighting scenarios.

Also, ambient temperature may play a role. According to Philips Lighting, the correlated colour temperature of the lighting was determined at a temperature of 25 °C, which corresponds to the temperature of the rooms in the day care centre. When temperature alters, this soon causes a deviation of 0.005 in CIE XY coordinates. In case of the 17,000 K lighting, this can mean a shift of 2000 K in realised colour temperature.

One of the implications of lower achieved light levels and colour temperature can be a reduction of the aforementioned NIF effects. Based on Górnicka [34], the lighting condition of 17,000 K would give 3.4 times more NIF output than the condition of 2700 K. If in practice, the differences between colour temperature exposure of the 2700 and 17,000 K scenarios are smaller than 14,300 K, the differences in behavioural and circadian output would be much smaller too, smaller than the claimed 3.4 times in laboratory studies.

Given the measured situation, it might be that the current interventions do not cause any NIF effects at all. In combination with the lower illuminance levels, it might be that the lighting conditions do not reach the threshold levels (for long enough), for instance, the aforementioned 1000 lx. Still, the low illuminance levels found in the two rooms comply with lighting recommendations for nursing homes in the Netherlands, which seem to be insufficient for NIF effects to take place. Perhaps, positive effects could have been found in a controlled laboratory setting with an 'ambient' colour temperature of 17,000 K, whereas the same lighting equipment does not yield the same results due to interactions with the environment and daylight. The actual threshold may even be in between.

Another explanation may be that as illuminance levels are somewhat higher in the 2700 K scenario, and as colour temperature differences are not as large as suggested, the 17,000 K may even have a lower NIF effect than the 2700 K scenario. If one takes a closer look at daytime light conditions during measurement periods 3 and 5, the conditions are 450 lx and 3,140 K on average for the 2700 K scenario, versus 400 lx and 7860 K. Extrapolation of Fig. 7 [34] shows that the hypothesised effects of the realised light conditions in the 17,000 K scenario should still be about 30% larger than those of the 2700 K scenario. Still, illuminance levels were very low, perhaps too low to cause any

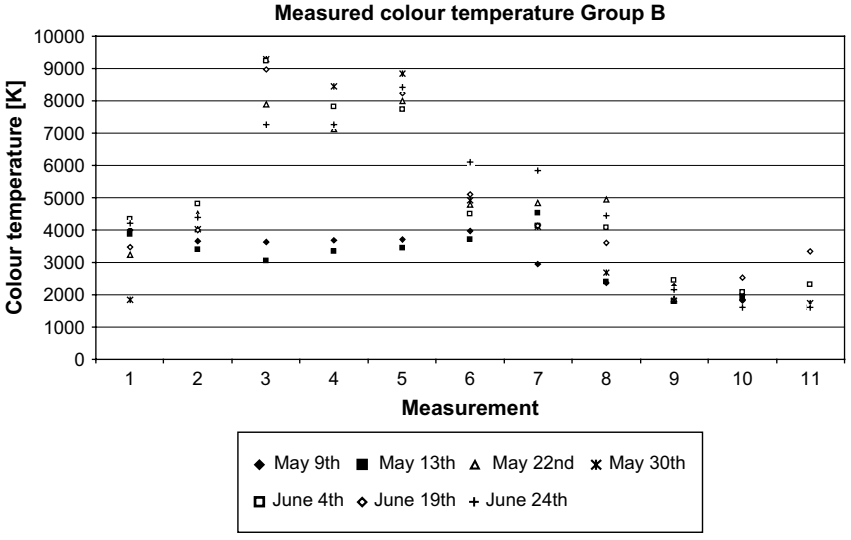

Fig. 11. Overview of average measured colour temperature at eye level for Group B, shown per measurement day.

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Table 5
Median scores of GIP subscales and mean range of tympanic temperature of the two groups, and results (*p*-values) of Mann–Whitney *U*-tests (GIP) and independent-samples *t*-tests (T_{tymp}) for between-group differences for the two lighting conditions.

	500–2700			500–17,000		
	Group A	Group B	*p*-value	Group A	Group B	p-value
GIP subscale[a,b,c]						
Apathic behaviour	8.5 (8.6)	9 (8.8)	0.974	8 (8.1)	10 (9.5)	0.254
Disturbances of consciousness	3 (3.7)	6.5 (6.1)	0.123	3 (3.5)	7.5 (7.1)	**0.000**
Restless behaviour	2 (2.4)	2 (2.9)	0.456	2 (2.5)	4 (3.5)	0.283
Depressive/sad behaviour	2 (3.1)	4 (4.4)	0.069	4 (4.2)	5 (4.4)	0.872
Anxious behaviour	0 (2.6)	2 (2.3)	0.923	2.5 (3.4)	1 (2.3)	0.456
T_{tymp}[d]						
Mean range [K]	1.17	1.15	0.818	1.12	0.94	0.085
SD	0.26	0.22		0.27	0.18	

[a] Exact significant differences (2-tailed, $\alpha = 0.05$) marked bold.
[b] The 0.5 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.
[c] Hypothetical mean values of GIP subscale scores are given between brackets.
[d] Significant differences (2-tailed, $\alpha = 0.05$) marked bold.

significant NIF effects. Also, the biological ageing of the eye has a yet unknown impact on this new ratio, as no short-wavelength light penetrates the eye in order to reach the retina. Even so, these findings may have a great impact on the expected effects of lighting interventions in practice, which may be not as large as anticipated.

4.2. Behaviour and physical symptoms

The 17,000 K lighting scenario did not bring about the effects hypothesised, partly because of reasons discussed in the previous section. In contrary, it even resulted in worsened observed behaviour. The lighting itself may be perceived as less natural, less comfortable, and therefore, it might contribute negatively to behavioural scores. Even though the colour temperature at eye level was much lower, people may at time look at the lighting equipment, or notice the higher amount of blue in the emitted light. In Group A, there is an increase in anxious and depressive/sad behaviour. The type of lighting and perceived colours may be a cause of the results found. People with dementia may not have the communicative skills to complain about the lighting, and express their discomfort in an indirect manner. Staff in day care centres and nursing wards might play an important role in signalling discomfort. Also, people with dementia have an altered sensitivity for indoor environmental conditions, which can induce problematic behaviour [35].

Some clues as to why people with dementia may respond negatively to the 17,000 K light tubes come from a study by Górnicka [34], who studied the effects of 17,000 K and 2700 K lighting in office situations (CCT of installed lighting). She has described the visual comfort remarks of the 17,000 K at a 430 lx situation of 12 subjects. The feedback on the lighting is very critical. Some of the remarks are the light is too bright, and too white, and that the visual comfort is bad. Also, there is a lot of reflection of light, resulting in a feeling of dizziness or 'moving' light. Another person described the light as being very bluish, which bleaches warm colours and the skin. Others state that when reading, the person gets a sensation of dizziness. Other important items mentioned are that the colour of the light is strange and not very natural, and that the light is too bright for a restful environment. The brightness of the light is said to take away a lot of the visual comfort. The perceptions reported by the subjects in this office study may be more outspoken in people with dementia.

Table 6
Results (*p*-values) of nonparametric Wilcoxon signed ranks tests (GIP), and results of parametric paired-samples *t*-tests (T_{tymp}), within-groups for both lighting scenarios.

	Group A	Group B
GIP subscale[a]		
Apathic behaviour	0.074	0.084
Disturbances of consciousness	0.553	0.065
Restless behaviour	0.812	0.098
Depressive/sad behaviour	**0.028**	0.694
Anxious behaviour	**0.015**	0.683
T_{tymp} parameter[b]		
Mean range	0.622	0.052

[a] Asymptotic significant differences ($\alpha = 0.05$) marked bold.
[b] Significant differences (2-tailed, $\alpha = 0.05$) marked bold.

At the same time, air temperature may affect psychological preferences for the colour temperature of light. In low temperatures, people seem to prefer lower colour temperatures, whereas in higher temperatures, higher colour temperatures are preferred [36]. The temperature in the day care centre was kept at room temperature. Ishi and Kakitsuba [37] mention that the preferences of colour temperatures according to the Kruithof diagrams [32] do not take seasonal changes or differences in age into account. Older people may have a preference for higher colour temperatures over lower colour temperatures. At the same time, dementia syndrome may undo age-related changes in colour temperature preference.

Sloane et al. [38] 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; eyestrain, seeing spots, problems with glare, eye burning or irritation, eye redness, jitteriness, skin rash on face or arms, severe agitation, headache, dizziness, and nausea, were not significantly experienced by residents (as reported by staff) and by staff. The intensity of light from the equipment is still much lower than outdoor light levels in summer. Possibly, the outcomes for higher CCT interventions (even at lower illuminance levels) are different and need to be studied in more detail.

Brawley [39] mentions that flickering of old-style magnetic ballasts may cause agitation and headaches and can even trigger seizures, and therefore need to be replaced with electronic ballasts. The system installed for the experiment was balanced with 24 kHz electronic ballasts.

One of the reasons for carrying out multiple GIP assessments in this study was the partially 'subjective' character of observations, as has been discussed by van Hoof et al. [5]. By averaging the scores found, a more stable judgment could be made about the behaviour observed. In future studies, other methods for observing behaviour

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or perceived quality of life, including dementia care mapping, can be used.

4.3. 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 [40]. As to the lighting intervention, the 17,000 K scenario had no effect on circadian rhythmicity. In our view, this is not due to the method chosen to assess circadian rhythmicity. Other methods, including the collection of melatonin from saliva and actigraphy, are available, but were not used in this study because these methods pose too much strain on the subjects or were not practical from a nursing point of view.

4.4. Implementation issues

The European Union is facing a boom in the number of older adults with dementia. Housing and care policies for older people with dementia include home modifications and services that lead to improved quality of life [41]. In both institutional settings and in the homes of community-dwelling older persons with dementia, lighting can be an important feature [42] that can be easily integrated into the design of new housing [35]. The benefits of lighting are manifold, including improved vision and the so-called biological or NIF effects [42]. Special ceiling-mounted luminaries are a non-invasive way of exposing people with dementia to pre-set ambient lighting conditions, without putting strains of health care professionals. Lighting systems should never be a compensation for going outdoors. It is of the utmost importance that older adults frequently go outdoors (for instance, [5,43]) for exposure to daylight. In a paper on environmental design for dementia, Brawley [44] asks herself: "Why are we not focusing on the reasons older adults in nursing homes do not get outside for valuable and much needed sunlight?" This, however, does not imply that residents are not entitled to have the best possible lighting equipment as an additional therapy [5].

4.5. Conclusive remarks

The dim lighting system with a high CCT of 17,000 K studied was not found to have any beneficial effects on circadian rhythmicity or behaviour in older persons with dementia in the field setting, compared to a dim lighting system with a low CCT of 2700 K. This might be an indication that high illuminance levels are a necessity in obtaining the aforementioned effects, or that a longer exposure to the lighting intervention was needed to obtain effects, as many people were only exposed during hours spent in the experimental rooms. Possibly, better results would have been achieved when using high-intensity lighting with the same colour temperatures. Also, the colour temperature realised in practice varied considerably from the correlated colour temperature of the lighting installed, and this raises serious questions when applying findings from controlled settings into practice. At the same time, the 17,000 K scenario may have an impact on behaviour, which might be caused by perception of the light source as being 'unnatural'. Similar experiments should be repeated in winter.

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