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Biodynamic lighting effects on the sleep pattern of people with dementia

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\textbf{ABSTRACT}

Dementia can disturb the circadian rhythm more than in normal ageing people. And their biological clock is often not enough stimulated by light. Sleep disturbances form a high burden for informal caregivers and is the main reason for institutionalization. The effect of biodynamic lighting with varying intensity and colour resembles a daylight curve has hardly been objectively researched. In this study, we evaluate the exposure to biodynamic lighting on circadian functioning of 13 patients with dementia admitted to a psychiatric hospital. Three biodynamic lighting armatures designed for home use were placed in the common area for a period of three weeks and then removed for the same period. These periods were intermittent in an AB-phase design. Objective data of the sleeping pattern were collected using a bed sensor. During exposure the average frequency of night-time bed wandering significantly decreased from 11 to 5 times (\(P = 0.002\)). The average frequency of daytime napping significantly decreased from 16 to 7 times (\(P = 0.004\)). The average total night-time sleep significantly increased from 408 to 495 min (\(P = 0.007\)). The average total time out of bed at night significantly decreased from 180 to 104 min (\(P = 0.006\)). This pilot study found promising evidence (effect sizes > 0.5) that biodynamic lighting, tailored to stimulate circadian entrainment, could be helpful in decreasing sleeping disturbances in patients with dementia. This biodynamic lighting setup could easily be used as a non-pharmacological intervention in a home situation.

1. Introduction

The number of people living with dementia worldwide is currently estimated at 35.6 million. This number will be doubled by 2030. Dementia is the leading psychiatric condition for people over 60 \cite{1}. It is of great importance that elderly people with dementia stay as healthy and vital as possible so that their quality of life remains high. In turn, it will also reduce the number of people going to care homes. Innovative care models for people living with dementia are promising to be effective in improving their health, quality of life and reducing care homes admission rates. One of these innovations is lighting \cite{2–4}.

Lighting has important visual but also non-visual aspects as light synchronizes physiological and behavioural rhythms in our body and influences the biological clock \cite{5} which is located in the suprachiasmatic nucleus (SCN) in the brain. The SCN stimulates the production of sleep-wake hormones (cortisol and melatonin) and follows a circadian rhythm. Warm colour temperatures are associated with stimulation of the secretion of melatonin, also known as sleep hormone. Cool colour temperatures are associated with the inhibition of melatonin and stimulation of the production of cortisol. This hormone is responsible for alertness and activity during the day \cite{8,10}. The effectiveness of light on the biological clock depends on several factors, such as light-intensity (\(\geq 1000\) lux) \cite{6}, colour temperature (> 4500 K) \cite{7}, colour rendering index (CRI) and the absorption spectrum of the lighting sources. Due to sensitivity for the light spectrum and a greater sensitivity for the blinding of light (due to degeneration of the ganglion cells) several light therapy methods are not suitable for nor appreciated by elderly \cite{8}. The elderly between 62 and 76 years of age best appreciate a lighting intensity level around 1000 lux \cite{9} and are more sensitive to indirect light.

Dementia can disturb the biological clock even more than in normal ageing. Several mechanisms have been postulated for this effect such as a more severe degeneration of the retinal ganglion cells and greater loss of functionality of the biological clock located in the suprachiasmatic nuclei. Therefore, people with dementia are at increased risk for a distortion of the circadian rhythm. In addition, people also tend to go less outside when they get older, especially people with dementia, so the biological clock is less stimulated by light. On the average young people spend five hours a day outside, older people 1 h and people with dementia in a nursing home only 1.6 min. In combination with the age-related optical changes to the eye, particularly smaller pupils and denser lenses, elderly people need far more light input than younger...
people [11,12]. They are actually double handicapped [13]. Furthermore, numerous studies show that the indoor light conditions in home or nursing care facilities for the elderly are not sufficient for the visual and the non-visual aspects of light [6,14–16].

All these together leads to a biological clock that is not stimulated enough by light, which can have huge consequences for the person with dementia and the informal carer. The disruptions of the circadian rhythm can lead to problems in the sleeping pattern manifested in symptoms such as nightly wandering, daytime sleepiness and daytime napping [17]. These symptoms form a high burden for caregivers and are among the main reasons for institutionalization. It increases the chance of hospitalization ten times [18–21].

Several studies have demonstrated that light is a promising non-pharmacological intervention to improve the sleeping pattern of elderly people with and without dementia. A review study of White et al. [22] including 18 cited articles of randomized controlled trial studies, concludes that dynamic lighting interventions may mitigate symptoms of circadian disruption in elderly people living in senior living environments.

Not all studies show a significant positive effect of light exposure in people with dementia. Forbes and colleagues [23] and Van Hoof and colleagues [24] both conclude in their review articles that there is limited statistical proof for the health effects of daylight. Fontana Gasio et al. [25] did not see an effect of a dawn simulator on circadian rhythm disturbances in people with dementia. Sloane et al. [26] also did not see a significant effect of a tailored lighting system on measures of sleep in people with dementia, however they did demonstrate a significant improvement in sleep quality in the caregivers. Both authors hypothesized that the used light sources did not seem to have a high enough light output to stimulate circadian entrainment. A field study of Aarts et al. [27] confirmed these hypotheses as they found a significant effect of high illuminance natural daylight exposure in summer on the sleep of healthy elderly but did not found an effect in winter.

Not only the illuminance quantity, but also the spectrum of visible light is an important factor in light exposure. The different wavelengths of the visible light spectrum are seen by the eye as different colours. The use of short-wavelength light (460–470 nm), also referred to as bluish light, lowers the threshold for circadian stimulation [28]. In addition to quantity and spectrum, the timing and duration of light exposure are also important. Light affects this system for the full 24 h in a day [29]. It is important to note that the authors of both review articles analyzed studies that used a variety of light therapy approaches and it is not clear how the light doses received by the participants were measured or monitored. Figueiro et al. [12] extends the studies by Sloane et al. [26] and Figueiro et al. [30]. They used light sources with a high short-wavelength (bluish) and high light output in the homes of people with dementia and found that this lighting intervention significantly increased sleep time and reduced depression and agitation scores. The authors then observed that people with dementia in nursing homes spend much time in the common area and tested the effectiveness of a light table and found positive effects on sleep quality and mood after four weeks of exposure [31]. Recently, Figueiro et al. [29] state that it is one of the biggest challenges to find a practical method for effectively delivering the lighting intervention to the eyes of people with dementia. Our study takes this into account by using a floor lamp that is designed for home use. This lamp exposes people to biodynamic lighting, lighting that follows a daylight curve in intensity, spectrum and temporal characteristics, to stimulating circadian entrainment. The lamp produces direct and indirect light with a high illuminance and bluish colour (high short-wavelength content) in the morning and lower levels in the evening. In order to make the robustness of the results of our study as optimal as possible, we have chosen a within subjects design and performed the study in an inpatient ward. Often results are obtained through subjective sleeping questionnaires or studies show lot of diversity in participants and used lighting programmes. In this study objective measures are used to obtain results.

The aim of this study is to investigate if biodynamic lighting, resembling a normal daylight curve in light intensity and colour in a fixed programme, objectively improves the sleeping pattern of institutionalized patients with dementia.

2. Materials and methods

2.1. Participants

The participants were recruited from a treatment facility for patients with neurocognitive disorders in psychiatric hospital GGzE in Eindhoven, the Netherlands within the period of January 2016 to January 2017. The attending physician and the formal caregivers working at the ward identified potential participants for the study. The inclusion criteria for the study were a primary diagnosis of dementia diagnosed by a geriatrician, neurologist or psychiatrist, based on the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) [32] criteria. We excluded patients from participation in the study if diagnosed with any other neurological disorder, including narcolepsy, sleep apnoea or restless legs syndrome or a serious eye disease incompatible with light therapy, such as retinitis pigmentosa. Patients were also excluded if they were physically disabled or if their acute psychiatric condition was not suitable for participation, like a manic episode, addiction or severe aggression in a psychotic episode. No restrictions are made for medication use. During the study medication was monitored.

The study protocol was approved by the Institutional Review Board of the psychiatric hospital GGzE. All participants signed a written informed consent to participate in this study, accordance with the Declaration of Helsinki (Seoul Revision, 2008) and the General Data Protection Regulation (AVG) www.eugdpr.org. Applies at 2018.

2.2. Procedure

2.2.1. Lighting intervention

Three biodynamic lighting armatures were placed in the common room of the ward. In biodynamic lighting the illuminance level and the colour temperature are combined in the right proportion and varied throughout the whole day from 7:30 a.m. to 10:30 p.m. resembling a daylight curve. All these aspects are accounted for in the designation of the Sparckel, type Bright Brenda [33]. This lamp has been developed after extensive research in a co-production with lighting specialists and users. A fixed daycurve programme was installed and used in our study. Fig. 1 illustrates the situation in a clinical ward of GGzE and Fig. 2 shows the floorplan of the used common room with the location of the three biodynamic lighting armatures.

One lamp can produce to 7500 lumen, five times more than usual in respectively an office or living room. It also produces a colour temperature of 2700–6500 K (indirect-direct) and the spectrum of the biodynamic lighting simulates a regular daylight curve by following

Fig. 1. Patient exposed to biodynamic lighting.
In order to have objective measurements of the received amount of lighting by the participants, lighting measures were collected. In each condition, the amount of lux was measured manually at least three times a week at three fixed locations in the common room at three fixed moments a day (9:00 a.m., 1:00 p.m. and 5:00 p.m.). Vertical measurements were obtained at eye level because they approach the real life situation of light collected by the ganglion cells in the eye the most. The lighting measurements were collected with a Voltcraft MS-200LEDluximeter. According to the European standards, 500 lux is recommended for adult people, not elderly, to be able to type, read and write [35].

### 2.2.3. Design

The design of this study focused on a within subjects design. The advantage of a within subjects design is that individual differences between participants have no influence as participants are their own control. Participants start in the condition that is present at the moment of admittance. Conditions of exposure to biodynamic lighting (condition A) and no exposure to biodynamic lighting (condition B) are intermittent during a study period of 12 months. All participants will minimal undergo a condition A and B.

The study design is shown in Fig. 6. Condition A represents exposure to biodynamic lighting and condition B represents no exposure to biodynamic lighting, both for the duration of 3 consecutive weeks. It takes about 2 weeks to adjust the biological clock in people with dementia. A recent study of Sekiguchi et al. [36] shows effects of bright light therapy within 2 weeks. To minimize carry-over effects the first two weeks of each condition were marked as wash-out and adjustment period and the last week (3rd week) is used for data collection [37].

The quality of sleep is determined by outcome measures of the time in bed during day and night, and the frequencies of daytime napping and night-time bed wandering. For this purpose, 6 variables are objectively measured in each condition by the Caremonitor (see Fig. 7). These variables are 1) frequency of night-time bed leave moments, 2) frequency of daytime moments in bed, 3) time in bed during the night (min), 4) time out of bed during the night (min), 5) time in bed during the day (min), 6) time out of bed during the day (min).

### 2.2.4. Sleep pattern measurements

The sleeping pattern is measured with the Caremonitor [38]. The Caremonitor is a thin matrass with sensors that is placed under the normal matrass of the participant. An example is shown in Fig. 7. The Caremonitor, produced by Caredon, is CE-certified and available for five years now for health care facilities in different countries. It is a reliable (99,5%) bed exit and wandering detection system developed for the Caremonitor platform. Via a high-tech sensor, discretely placed under the conventional mattress, it is being registered whether a client has left the bed, or hasn’t returned to the bed within 5 min. Daytime is defined as 7:30 a.m. to 10:30 p.m. and night-time is defined as 10:30 p.m. to 7:30 a.m. It manages to measure the exact frequency and duration of the participant leaving the bed or going to bed by a monitor or pdf-function (Bedleave and Wandering module). A bed leave is registered when a patient leaves the bed for more than 5 min. A nap is registered when a patient goes to bed for more than 5 min. It should be noted that the sensor does not registrate if the patient is actually sleeping when lying in bed.

Data are used of five subsequent days and nights in the last week of each condition (Monday-Monday). Medication use and dosage is registered at the beginning and end of participation in the study.

### Table 1

Measurement data of one lamp from Olino measurement report.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lamp measurement</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour temperature</td>
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<td>Direct light</td>
</tr>
<tr>
<td></td>
<td>4750K</td>
<td>Indirect light</td>
</tr>
<tr>
<td>Light intensity</td>
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<td>0.1 m distance</td>
</tr>
<tr>
<td>Colour Rendering Index</td>
<td>87</td>
<td>CRI,Ra</td>
</tr>
<tr>
<td>S/P ratio</td>
<td>2.0</td>
<td>1 m distance</td>
</tr>
<tr>
<td>Melanopic Effect Factor</td>
<td>0.682</td>
<td>According to standard DIN</td>
</tr>
<tr>
<td></td>
<td>SPEC 5031-100:2015-08</td>
<td></td>
</tr>
<tr>
<td>Light spectrum</td>
<td>465-480 Nm</td>
<td>Melanopic lux</td>
</tr>
<tr>
<td>Luminous Flux</td>
<td>6818lm</td>
<td>1 m distance</td>
</tr>
<tr>
<td>Blue light hazard risk group</td>
<td>0</td>
<td>No risk</td>
</tr>
</tbody>
</table>

Fig. 2. Floorplan of the common room.

### A1 

A: No exposure (3 weeks)  B: Exposure (3 weeks)
2.2.5. Analyses

Sleep pattern measurements and lighting measurements Data were analysed using SPSS version 19 (SPSS, IBM, Armonk NY). When participants undergo one biodynamic lighting condition (A) and one normal lighting condition (B) a within subjects analysis can be performed. All variables were tested if they were normally distributed to be able to perform a t-test. As none of the variables were normally equated, the Wilcoxon non-parametric test was chosen (two related samples) to analyse the data. The Bonferroni method was used to correct for multiple testing. The significance threshold was set at 0.01. The data of four participants that completed more than two intermittent conditions were also analysed using the Wilcoxon non-parametric test and are separately described and visually displayed. Effect-sizes were calculated for all statistically significant results. Effect-sizes are considered small for $r < 0.1$, moderate for $0.1 < r < 0.3$ and large for $r > 0.5$. The effect sizes are calculated conform Cliff’s Delta and absolute values are used as

![Fig. 4. Biodynamic colour temperatures of the Sparckel, type Bright Brenda, during a day. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)](image)

![Fig. 5. Power spectrum, sensitivity curves and resulting night and day spectra (1 m distance).](image)
3. Results

3.1. Study population

Sixty-one patients and their informal caregivers received information about the research project and were invited to participate. Written consent was obtained from 39 patients, a response rate of 63.9%. Twenty-six patients did not complete two conditions due to discharge, transition to a specialized nursing home or on account of decease. We obtained complete data of 13 patients. The group includes 7 women and 6 men with a mean age of 74.77 years. Four patients completed more than two conditions. Seven participants started in condition B (no exposure to biodynamic lighting) and six in condition A (exposure to biodynamic lighting).

3.2. Outcome measures

The mean amount of lux in the ‘biodynamic lighting’ condition was 1145, 8 lx with a minimum of 385 lx and a maximum of 281, 2 lx with a minimum of 63,4 lux and a maximum of 1145, 8 lx. A two-tailed paired t-test did show a significant difference in the mean amount of lux in both conditions ($p < 0.001$). Results are shown in Table 2.

Data of five subsequent days and nights in the last week (Monday –Monday) of each condition were collected for each participant. Six sleep pattern variables were studied. Significance ($P < 0.01$) was reached in four out of six variables. Conform best practice, effect sizes of each significant result are calculated. The effect sizes of all significant results are $r > 0.5$. Results are shown in Table 2.

The frequency of bed leaves at night and the frequency of daytime napping both significantly decreased in the biodynamic lighting condition compared to the normal lighting condition.

The duration in bed at night significantly increased in the biodynamic lighting condition compared to the normal lighting condition and the duration out of bed during the night significantly decreased in the biodynamic lighting condition.

The boxplots below show a visual display of the significant results. In Fig. 8 the frequencies of bed leaves at night and daytime napping in normal (B) and biodynamic lighting (A) condition are shown. The frequency of bed leaves at night was significantly less in the biodynamic lighting condition ($p = 0.002$). In addition, the frequency of daytime napping was significantly less in the biodynamic lighting condition ($p = 0.004$)

In Fig. 9 the duration in and out of bed during the night is shown. Duration in bed at night was significantly greater in the biodynamic lighting condition ($p = 0.007$). Duration out of bed at night was significantly less in the biodynamic lighting condition ($p = 0.006$).

3.3. Completion of more intermittent conditions

Although this study focused on minimal one A and B condition, one participant was admitted to the ward during a longer time and completed six conditions during the pilot following an A1B1A2B1A3B3 order. This data is very interesting because with this data we could also investigate whether the hypothesized effect could be confirmed. The results of the participant that completed six conditions are shown in Fig. 10. A decrease is visible in bed leaves at night and napping during daytime in two biodynamic lighting conditions (A1, A2) compared to the normal lighting conditions (B1, B2).

The results of the participants that completed three conditions in an A1B1A2 or B1A2B2 order, are visually displayed in Figs. 11–13. In participant 1 and 3 the frequency of bed leaves decreases in the biodynamic lighting condition, increases in the normal lighting condition and decreases again when the biodynamic lighting returns. For participant 2 starting in the normal lighting condition, the frequency of bed leaves increases in the normal lighting condition, decreases in the biodynamic lighting condition and increases again when the normal lighting condition returns. The frequency of daytime napping shows the same pattern in all participants. This is a strong indication of the positive effect of biodynamic lighting on night-time bed leaves and daytime napping. In participant 1 and 2 the same positive effect is visible in the duration in and out bed at night. A decrease in time in bed at night is visible from the biodynamic lighting condition to the normal lighting condition and an increase again when the biodynamic lighting condition returns. An increase of minutes out of bed at night is visible from the biodynamic lighting condition to the normal lighting condition and a decrease again when the biodynamic lighting condition returns. In participant 2 the effect is reversed because as this participant starts in the normal lighting condition. The same effect, however very small, is visible in the time participant 1 spends in and out bed during daytime. Participant 2 shows no difference in time in and out of bed during daytime. Participant 3 shows only positive effects on bed leaves and napping and no positive effects on duration in and out of bed.

3.4. Medication

All participants used medication at start (i.e. antipsychotic medication, sedative medication, antidepressant medication, melatonin, vitamin D, and pain medication). The medication use and dosage intake was registered at the beginning and end of participation in the study.
In nine participants the medication did not change during the study. In two participants antipsychotic medication was removed at the end of the normal lighting condition. In one participant sedative medication was removed at the end of the normal lighting condition and in one participant antidepressive medication was added at the end of the normal lighting condition.

4. Discussion

The present study found positive effects of a fixed biodynamic lighting programme resembling a daylight curve on the sleeping pattern of 13 patients with dementia admitted in a clinical ward of a psychiatric hospital.

In this study three weeks of exposure to biodynamic lighting decreases the mean frequency of bed leave moments during the night from 11 to 5 times with a large effect size of 0.610. The mean frequency of daytime napping decreases from 16 naps a day to 7 naps a day. Positive effects were also found on the duration in and out bed during the night. The time in bed during the night increased 77 min and the time out of bed during the night decreased 76 min. This indicates that people are more active during the day improving their circadian rhythm.

These results are consistent with the conclusion of a review study of White et al. [22] including 18 cited articles of RCT studies that dynamic lighting interventions may mitigate symptoms of circadian disruption in elderly people living in senior living environments.

A recent study of Giménez et al. [40] showed that in 196 hospitalized patients the objective sleep improved after five days of exposure to dynamic lighting. The sleeping duration at night increases with 30 min. This is consistent with our finding that after 21 days of exposure the sleeping duration at night increases with 77 min.

It should further be noted that most previous studies did not specifically examine the biodynamic aspect of lighting. Previous studies, like the study from Riemersma-van der Lek [6] demonstrated the positive effects of the exposure to vertical bright light on the sleeping pattern of people with dementia.

In our study one participant even completed six conditions and showed positive effects in the first four conditions. In the last condition the effect is not reconfirmed. A possible explanation is that at that moment this participant was told that a transition to a care home was needed. It is well known that older people with dementia react to stress with more problem behaviour such as restlessness and nightly bed wandering due to declining coping skills [41]. Taken together, the results of this study indicate that it is possible to improve the sleeping pattern in people with dementia by exposure to biodynamic lighting. It is important to note that we used biodynamic floorlamps that are suitable for home use.

Some important methodological limitations should be considered in interpreting the present results. First, the study design included a within subjects design. This design is chosen to control for most of the possible non-specific treatment effects. But not every non-specific effect can be controlled for (like for instance seasonal impact). In addition, a significant difference between the amount of lux in both conditions (p < 0.001) can be seen, the exact amount of lux a specific participant received, has not been measured. A personalized lighting measurement device placed close to the eye of the participant could approach this more closely. Furthermore, the sample of this study is small mainly due to the fact that it is a vulnerable group (elderly with dementia in a crisis situation) to participate in long-term (max 6 weeks if they want to succeed in both conditions) research. Another limitation is the used duration of three weeks for each condition. Experienced light
researchers as Figueiro et al. [30] used 4 weeks to reset the biological clock. However, we were able to find significant results in three weeks. Furthermore, a wash-in or wash-out effect of the biodynamic lighting condition is not completely excludable. However, it is not likely as in four participants that completed more than two conditions, the effect of the biodynamic lighting is reversible.

Sleeping patterns were measured by a censored mattress in the bed. Participants possibly also napped in a chair in the common room. These naps were not registrated. Still we can assume that these naps in a chair are comparable in frequency and time in both conditions and despite these improvements in sleeping pattern are shown in the biodynamic lighting condition(s).

Medication is often used in psychiatric hospitals. Only four single medication changes were registrated in this study. No conclusions can be drawn from these medication changes, due to the often long insertion time of these types of medication (i.e. antipsychotic and antidepressive medication). Medication may have an impact on the sleeping pattern [42], but due to the study design, the offered

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**Fig. 10.** Results of the participant that completed six conditions A1 (biodynamic lighting), B1 (normal lighting), A2 (biodynamic lighting), B2 (normal lighting), A3 (biodynamic lighting), B3 (normal lighting).
treatment as usual" and the inclusion criteria, we may assume our study group is an accurate reflection of the general population.

4.1. Conclusions

In conclusion, the results of this study is promising to improve the sleeping pattern in people with dementia by exposure to biodynamic lighting. It supports the premise that biodynamic lighting could be a possible (early) intervention for people with dementia in at home situations. In at home situations biodynamic lighting could also result in less disturbances during the night for the (informal) caregivers. This night-time behaviour is one of the symptoms which causes a reason for the transition to a more controlled environment because of the impact on the primary caregiver [30,43].

Further research in this area is certainly needed. First of all, the current intervention effects have to be replicated in studies that control for possible non-specific treatment effects and expectancy effects. Future studies should explore the specific contribution of the duration of the exposure and the exact received amount of lux per participant. Future research is also needed to reveal which patients with dementia respond best to this type of intervention and light program. Finally, it could be a potentially valuable direction for future studies to investigate the exact effects of biodynamic lighting on other symptoms of dementia, like attention, concentration and behaviour. Given the present effects on the sleeping pattern, positive effects might possibly also be expected in other areas.

In closing, the present findings obviously have some important implications for clinical practice. Biodynamic lighting interventions directed at improving circadian functioning might be a valuable addition to more traditional interventions, like pharmacotherapy. Based on the current results, biodynamic lighting interventions suitable for home use should be considered a promising intervention to support circadian functioning in patients with dementia living at home, particularly for patients with sleeping disturbances.

Declarations of interest

None.

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during this study.

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