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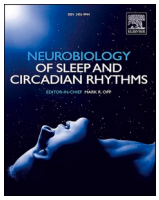

Effect of a dynamic lighting intervention on circadian rest-activity disturbances in cognitively impaired, older adults living in a nursing home: A proof-of-concept study

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ABSTRACT

Development of non-pharmacological interventions to improve disrupted rest-activity patterns and disturbed behavior in people with dementia is an important research goal. Here we report a proof-of-concept study which evaluates the effect and applicability of a dynamic light intervention to improve rest-activity patterns in cognitively impaired, institutionalized, older adults. The study was a randomized, open-label, proof-of-concept trial of limited sample size conducted at a nursing home for older adults in a non-metropolitan area in Denmark. Participants were 24 older nursing home residents with cognitive deficiencies. Equipment for delivery of a specialized dynamic light intervention was installed in the private apartments (within the nursing home) of the residents in the experimental group (N = 12). Study duration was four weeks. The control group (N = 12) was exposed to conventional lighting. We measured activity and rest using actigraphy, functional disability, behavioral disturbances, and time in bed We performed regression analyses to examine differences between the intervention groups. Participants in the experimental group partially improved on one of three diurnal rhythm variables, but otherwise no differences were observed between the two intervention groups. The improvement was found for the intradaily variability during the first part of the intervention period indicating a more stable and less fragmented 24-h rest-activity rhythm. However, availability of staff assistance in response to impaired physical mobility of the residents seemed to be a stronger determinant of activity level and pattern. The examined intervention showed promising results but did not consistently alter circadian rest-activity patterns in older nursing home residents given the current sample size. Future studies in the field need to consider real-life applicability of the experimental intervention and the interaction and importance of other important zeitgebers than light.

1. Introduction

Sleep and circadian rhythm disturbances comprise a frequently encountered and severe problem in older adults with dementia (Coogan et al., 2013). In close association with disturbed sleep-wake regulation, many patients with dementia develop behavioral disturbances with agitation and aggression especially occurring during the late afternoon and the early evening, so called 'sundowning' (Coogan et al., 2013). Fragmentation of circadian rhythmicity with sundowning is not compatible with most nursing home working schedules with reduced manpower during evening and night hours. These behavioral and organizational characteristics comprise the explanation of a high prevalence of psychotropic drug prescribing, especially hypnotics and sedating antipsychotics, in populations of older adults. Psychotropic drug use is associated with increased mortality rates in people with dementia and thus should be carefully used outside licensed recommendations (Jennum et al., 2015). Similar but less pronounced abnormalities in circadian rhythm are observed with normal aging including reduced amplitude and phase advance of circadian rhythmicity, and a disruption of nocturnal sleep (Arellanes-Licea et al., 2014; Kim and Duffy, 2018). The behavioral disturbances and the disrupted circadian sleep patterns in people with dementia may exacerbate further when

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placed in a nursing home or other long-term facility because these institutions tend to support inactivity and reduced daylight exposure. Several studies have documented insufficient levels of light exposure and association with reduced activity level and more pronounced circadian disruption in people with dementia and other nursing home residents (Figueiro et al., 2012; Shochat et al., 2000).

Circadian abnormalities in patients with dementia have been addressed by several chronotherapeutic intervention approaches. A Cochrane review investigating the effectiveness of light therapy to improve cognition, activities of daily living, sleep, challenging behavior, and psychiatric symptoms associated with dementia found insufficient evidence to justify the use of bright light therapy in dementia (Forbes et al., 2014). However, the experimental light interventions in the reviewed studies were mostly static of nature and comprised of a light box active for one to 2 h in the morning or in the evening. A non-controlled pilot study of a tailored lighting intervention in 14 nursing home residents for four weeks showed promising results in terms of subjective sleep quality, circadian entrainment and depression and agitation scores (Figueiro et al., 2014).

We hypothesized that an experimental intervention using dynamically adjusted light might improve and stabilize circadian rhythm, daytime activity, symptom intensity and in addition diminish nighttime activity in cognitively impaired people living in a nursing home. To pretest the applicability and efficacy of this technical solution we evaluated the set-up and equipment in a proof-of-concept design.

2. Material and methods

2.1. Design

We conducted a randomized, open-label, controlled trial where each included subject was randomized to the experimental light intervention or a control group exposed to conventional lighting The randomization was stratified according to score on the Mini Mental State Examination (MMSE) ensuring that participants with a MMSE score $\leq$ 17 were equally allocated between the two intervention groups.

2.2. Study population

The following subjects were eligible for inclusion in the study: residents at a specific town area nursing home (*Elmelunden*, Region Zealand, Denmark) with a MMSE score $\leq$ 24 and presence at the nursing home for a minimum of four days per week during the intervention period. Subjects were excluded from participation if they were medically unstable, were in the terminal phase of life, were blind, had hemiplegia, had aggressive behavior, or if they declined to have the specialized light equipment installed.

2.3. Statement of informed consent

All included subjects or, in the case of persons severely affected by dementia, a close relative gave written informed consent to participate in the study. If written consent was given by a relative it was ensured that the participant gave oral informed consent. To comply with national regulations regarding inclusion of subjects with severe dementia, written informed consent was also given by a third party, in this case the general practitioner. The study was approved by the local ethics committee (H-15016662). The study was carried out in accordance with the Code of Ethics of the World Medical Association.

2.4. Experimental intervention

The nursing home residents each lived in their private, small apartment (within the nursing home) where they slept and spent time on their own. During the daytime they also spent time, to a variable degree, in a common living room and other shared facilities supervised by caregivers. The specialized light equipment was installed in the private apartment meaning that the experimental intervention was delivered in the apartment and thus exclusively to the participants in the experimental group. Each apartment covered an area of 30 m^2 divided into a living room with a small tea kitchen and a bedroom with access to a bathroom. The nursing home contained a total of 30 apartments.

Seven specially constructed lamps controlled by an intelligent lighting system were installed in each participant's apartment. The placement of the lightning equipment was standardized as follows: one pendant lamp in the living room (large) and one in the kitchen (smaller), three floor lamps (two in the bedroom and one in the living room), one lamp hanging on the wall in the bathroom, and one table lamp in the living room. Existing light sources in the apartments were deactivated during the study period. The lamps were able to emit RGBW LED light, 2000–6500 K, 30–3000 lumen, which equals 300 lux at a 1 m distance. The 24-h controlled lighting system was designed to support high circadian stimulation during the day, good visual conditions during the waking hours, and nighttime lighting that was safe for both residents and staff and at the same time minimized disturbance to sleep. The light equipment emitted light which could be adjusted in color and intensity. Individual characteristics (gender, age, chronotype as measured by actigraphy at baseline, data on bedtime and rise time as documented by the staff, and clinical data, eg visual deficits, severity of dementia) were added to a controller app in order to personalize the emitted light. The equipment was able to adjust the light automatically as to mimic a sunny summer day. The simulated daylight was automatically turned on at 7 a.m. in a dim, warm, red color; it changed during the day to a stronger more white/blue color at midday; changed back again to the dim, red color, to turn off at 10 p.m. Each participant received individual activating light boosts (strong blue spectrum white light, min. 400 lux at the eye) 30–60 min each during the day. The light boosts were delivered individually during the day planned according to chronotype and individual habits to avoid that the boosts of light were delivered during nap time or when the participants were joining social activities in the shared areas. These boosts were thus delivered in the individuals' homes, but the participants were still able to freely move around in their homes or in shared areas in the nursing home. The participants were able to turn off some but not all the devices during the day. At nighttime, it was only possible for the participants to turn on one lamp with a dim, warm red color (maximum of 1500 K) in the apartment and the bathroom light was dim. The staff had been instructed to turn off other light sources as for example the television, so the apartment was as dark as possible at night. The staff could at any moment turn on all lights in case of an emergency. The light in the shared areas of the nursing home were dimmed during evening and nighttime.

Participants in the control group did not have any change to the lighting in their apartment.

2.5. Daily rhythm of activities for the nursing home residents

The residents woke up between 6 and 8.30 a.m. Some residents rose themselves and others needed help and awaited a little while in the bed after waking up. Breakfast was served between 6 and 9 a.m., lunch between 11.30 a.m. and 1 p.m., coffee at 3 p.m., and dinner between 5.30 and 7 p.m. The following activities were offered during the day: physical exercise, reading sessions, music, religious sessions and outdoor activities. Some residents very seldom participated in the activities and stayed in their private apartment for most of the day. After lunch most of the residents rested or napped for approximately 1 h. The residents could eat their meals in the common dining hall or in their own apartment as they preferred. Most of the residents spent much of the day in their apartment which often included watching TV in the afternoon and/or in the evening.

2.6. Actigraphy

All the participants wore an actigraph (Actiwatch Spectrum Pro, Philips Respironics) during the week preceding the intervention (baseline) and during the four weeks intervention period. An actigraph is a small wrist-worn device that measures activity using an accelerometer (Ancoli-Israel et al., 2003). We used the raw data to describe the activity pattern as a measure of the circadian rhythm.

2.7. Outcome measures for the circadian rest-activity pattern

Actigraphically assessed circadian rest-activity cycle parameters included the interdaily stability (IS), the intradaily variability (IV), and the relative amplitude (RA) (Van Someren et al., 1999). These 24-h actigraphy-derived variables reflect activity and rest expressed as circadian patterns. These non-parametric circadian rhythm parameters have been reported to be more sensitive to change compared with alternative statistical procedures (Van Someren et al., 1999). The IS quantifies the invariability from day to day, ie, how closely the 24-h rest-activity pattern follows the 24-h light-dark cycle (Feliciano et al., 2017). This index will be 1 for perfect IS, ie good synchronization to light and other environmental zeitgebers, whereas lower values reflect higher variability between observed days (Van Someren et al., 1999; Feliciano et al., 2017). The IV reflects the fragmentation of the 24-h rest-activity pattern, ie the frequency and extent of transitions between rest and activity. Thus, higher values of IV reflect higher degree of fragmentation and more frequent shifts between rest and activity (Van Someren et al., 1999), eg individuals who often nap during the day (Feliciano et al., 2017). The RA is calculated from the ratio of the most active 10 h period to the least active 5 h period in the average 24-h pattern, meaning that higher values indicate a more robust 24-h rest-activity pattern, reflecting more pronounced differences between periods of rest and activity (Van Someren et al., 1999; Feliciano et al., 2017). In this study, we did not rely on algorithm derived measures of sleep continuity variables (such as sleep latency and total sleep time) but used only the raw activity counts for calculation of the circadian rhythm parameters as described above.

2.8. Secondary outcome measures

To evaluate if the intervention had any effect on symptom severity, we assessed the participants using The Disability Assessment for Dementia (DAD) (Gélinas et al., 1999) and The Neuropsychiatric Inventory (NPI) (Cummings et al., 1994). These scales assess, respectively, functional disability and a range of behavioral disturbances occurring in patients with dementia. Nighttime ambulatory activity (time in bed) was measured using a small device (from 'Tunstall') that was placed in the bed of each participant. Longest duration of time in bed was observed as a proxy of nighttime ambulatory activity. We used the Tunstall device to monitor nocturnal wandering because the actigraph cannot distinguish location only activity versus rest.

2.9. Statistical analysis

Two-level mixed-effects linear regressions of IS, IV and RA were performed using STATA. This analysis is suited for repeated measurements from the same individual. All analyses were controlled for age and gender and the interaction between them. We did not control for connection to different groupings of staff because this variable was equally distributed among the two intervention groups. There was no difference in activity measures between weekdays and weekends and therefore we did not distinguish between these in the analyses. DAD and NPI were examined using regression analysis, and longest duration of time in bed was evaluated using *t*-test and median regression.

3. Results

We were able to include data from 24 participants, 12 in each intervention group. In the experimental group 8 (67%) participants were women and in the control group 7 (58%) participants were women. Mean age was 82.2 years in the experimental group and 85.7 years in the control group. Prescription of medication and other baseline characteristics are listed in Table 1. The duration of the intervention was four weeks (from March 21 to April 17, 2016). The intervention period was for analytic reasons divided into two periods, T1 (March 21 to April 3; 14 days) and T2 (April 7 to 17; 11 days). April 4 to 6 had to be excluded from analyses due to malfunctioning actigraphs and therefore no recorded data.

The participants in the intervention group were present in their apartments during the daily light boost in 69% of exposed days (range 18 to 100%), tracked by the caregivers. Only presence during light boosts was documented. We had no specific information on total exposure to the lighting intervention, i.e. the duration of exposure per day or the time per day spent in the private apartment, but time spent outside the nursing home would typically imply participating in outdoor activities and as such receiving outdoor light exposure.

The three primary outcome measures (IS, IV and RA) were close to normally distributed and thus the planned parametric statistical analysis was appropriate. Table 2 shows the results of the two-level mixed-effects linear regression analyses. The coefficients express the change in IS, IV and RA, respectively, in the intervention group compared with the control group, ie the intervention effect. We found no effect of the intervention on these circadian rhythm variables except for IV which was significantly lower (ie less fragmented) in the intervention group during the first intervention period (T1) but this did not persist to the end of the intervention (T2). Likewise, there was no difference between the intervention groups when looking at the absolute level of activity, ie activity counts/6 h.

For the applied symptom rating scales, we found no differences between the intervention groups. Longest duration of time in bed was observed as a proxy of nighttime ambulatory activity. For the whole sample there was no numerical nor statistically significant difference between the experimental and the control group. When excluding participants who were dependent on help from the nursing staff to get in and out from bed and analyzing only self-reliant nursing home residents, we found that the mean duration of the longest stay in bed was increased in the experimental group but not significantly so due to the even smaller number of participants included in this analysis.

4. Discussion

This randomized proof-of-concept study investigated if a specialized dynamic light intervention could improve circadian rhythmicity and day-night activity patterns in cognitively impaired, older adults living in

Table 1
Medication and other baseline characteristics of study participants.

	Experimental group (N = 12)	Control group (N = 12)
Antidepressants, N (%)	5 (42%)	2 (17%)
Antipsychotics, N (%)	2 (17%)	1 (8%)
Hypnotics, N (%)	1 (8%)	2 (17%)
Medication for dementia, N (%)	3 (25%)	1 (8%)
Opioids, N (%)	4 (33%)	5 (42%)
Other analgesics, N (%)	10 (83%)	12 (100%)
Cardiovascular medication, N (%)	10 (83%)	9 (75%)
Not capable of getting in and out of bed without help from staff, N (%)	8 (67%)	9 (75%)
Female gender, N (%)	8 (67%)	7 (58%)
Few symptoms of dementia, N (%)	6 (50%)	3 (25%)
Moderate symptoms of dementia, N (%)	2 (17%)	6 (50%)
Severe symptoms of dementia, N (%)	4 (33%)	3 (25%)

Table 2
Indicators of circadian rhythmicity across the intervention Two-level mixed-effects linear regression with IS, IV and RA as the dependent variables. The coefficients express how the dependent variable changes in the intervention group compared with the control group. All analyses were controlled for age and gender.

	Coefficient	SE	z	p
IS; T1	0.009	0.054	−0.17	0.863
IS; T2	0.043	0.054	0.80	0.424
IV; T1	−0.259	0.097	−2.66	0.008[a]
IV; T2	−0.045	0.097	−0.46	0.647
RA; T1	0.021	0.050	0.42	0.673
RA; T2	−0.010	0.050	−0.20	0.843

IS: Interdaily stability IV: Intradaily variability RA: Relative amplitude T1: Intervention period 1 T2: Intervention period 2.
[a] Statistically significant at the 0.05 level.

a nursing home. The intervention had no effect on the selected outcome measures except for a brief non-sustained beneficial effect of the intervention on IV. IV compares the activity each minute with the activity the preceding day and night and diminishes with increased stability in activity minute-to-minute. A reduced IV as in the first part of the intervention period thus indicates a short-lasting improvement in activity pattern and stability. Reasons for the only temporarily improved rest-activity stability are not readily observable but could be speculated to include tolerance to the light intervention or the basal circadian regulatory mechanisms being too disturbed (Kim and Duffy, 2018) to be ameliorated by the effect of light alone. Another possibility is that the intervention period was too short to allow for a possible effect to manifest itself. A recent 25-week study of an all-day lighting intervention in 47 persons with Alzheimer's disease in senior care facilities resulted in improved subjective sleep quality and reduced depression and agitation scores (Figueiro et al., 2020). Thus, a considerably longer study than the current one but associated with limitations because of lack of control group. From the same research group, a two times 4-week randomized cross-over trial (N = 46) with a control lighting intervention in persons with Alzheimer or related dementias (Figueiro et al., 2019) reported improved subjective sleep quality as well as significant improvement in IV, supporting the findings of the present study. Similar methodology was used in the two studies from Figueiro and colleagues which, in contrast to the present study, included only participants who had been identified as having sleep problems. This might partly explain the different overall results. Other differences compared with the present study include that data on each participant's exposure to the lighting intervention were collected by a participant-worn pendant device, and that the primary outcome was subjective sleep quality reported by the caregivers (Figueiro et al. 2019, 2020). The choice of a proxy self-reported sleep rating versus IS, IV and RA as objective measures might also explain differences in observed effectiveness between these studies and ours. The lighting intervention was comparable to the present study in that both emphasized high circadian stimulus. In another smaller (N = 15) and uncontrolled study where the dynamic lighting system was installed in the common room of a nursing home, no effect on circadian variables was detected (Wahnschaffe et al., 2017). However, a significant reduction in agitated behavior was reported. The amount of individual daily light exposure differentiated between good and poor response in a study of a dynamic lighting intervention in 89 severely demented patients (Munch et al., 2017). This indicates that further encouraging the level of exposure could have increased the effect in the current study.

Institutionalized people are subjects to reduced circadian light; the indoor light is significantly lower than light needed for circadian entrainment. Other zeitgebers including physical activity, social behavior and in part food intake may also be compromised. Furthermore, external factors like institutionalization, bedding, low social and physical activity may show significant effect on circadian expression. In addition, the circadian system shows lower circadian amplitude as determined by melatonin and cortisol secretion. Other – not yet understood – mechanisms (eg circadian gene expression) may be part of the disrupted circadian pattern associated with demented, older adults (Musiek, 2017).

4.1. Limitations of the present study

This was a pilot study with a limited sample size and without a dim-light or sham-light control intervention which does not allow any definite evaluation of the efficacy of the intervention. During the execution of this experimental light intervention we experienced that the most important challenge was the fact that the level of activity among the residents of the nursing home was highly influenced by the staff situation, the workflow and the work routines of the staff. Thus, the possibility of the residents to become active and maintain a stable level of activity during daytime was determined by the number of staff members at work and how busy they were. Many residents were dependent on staff assistance to get out of bed which is a clear determinant of level and timing of subsequent activity. This factor seemed to be a stronger determinant of activity level and pattern than the more subtle changes in rest-activity patterns that could be observed to result from the experimental light intervention. This impact of the nursing staff routines was also reflected in the analysis of longest time in bed where a numerical trend of improvement in the intervention group could be observed for self-reliant nursing home residents but not for the whole sample. Other limitations include the lack of objective measurement of light exposure for each individual resident which would have made it possible to control for the variability in the nursing home residents' actual exposure to the dynamic lighting intervention.

In conclusion, future studies in the field need to consider real-life applicability of the experimental intervention and the practical circumstances regarding the study participants' ability to increase and regulate their pattern of activity. Light is an important factor in circadian entrainment but other zeitgebers including level of institutionalization, bedding, social and physical activity (Kim and Duffy, 2018; Musiek, 2017) should be considered as part of a combined strategy when planning future interventions in this difficult to study population.

Credit author statement

LB and PJJ conceived the concept and the design of the study. LB and PJJ both participated in analysis and interpretation of data. LB wrote the manuscript and PJJ revised it. Both authors approved the final manuscript for submission.

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Declaration of competing interest

All authors declare no conflict of interest.

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