

**Blue-enriched Lighting for Older People Living in Care Homes: Effect on Activity, Actigraphic Sleep, Mood and Alertness**

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## **ABSTRACT**

Environmental (little outdoor light; low indoor lighting) and age-related physiological factors (reduced light transmission through the ocular lens, reduced mobility) contribute to a light-deprived environment for older people living in care homes. This study investigates the effect of increasing indoor light levels with blue-enriched white lighting on objective (rest-activity rhythms, performance) and self-reported (mood, sleep, alertness) measures in older people. Eighty residents (69 female), aged  $86 \pm 8$  yrs (mean  $\pm$  SD), participated (MMSE  $19 \pm 6$ ). Overhead fluorescent lighting was installed in communal rooms ( $n=20$ ) of seven care homes. Four weeks of blue-enriched white lighting (17000 K  $\cong$  900 lux) were compared with four weeks of control white lighting (4000 K  $\cong$  200 lux), separated by three weeks wash-out. Participants completed validated mood and sleep questionnaires, psychomotor vigilance task (PVT) and wore activity and light monitors (AWL). Rest-activity rhythms were assessed by cosinor, non-parametric circadian rhythm (NPCRA) and actigraphic sleep analysis. Blue-enriched (17000 K) light increased wake time and activity during sleep decreasing actual sleep time, sleep percentage and sleep efficiency ( $p < 0.05$ ) (actigraphic sleep). Compared to 4000 K lighting, blue-enriched 17000 K lighting significantly ( $p < 0.05$ ) advanced the timing of participants' rest-activity rhythm (cosinor), increased daytime and night-time activity (NPCRA), reduced subjective anxiety (HADA) and sleep quality (PSQI). There was no difference between the two light conditions in daytime alertness and performance (PVT). Blue-enriched lighting produced some positive (increased daytime activity, reduced anxiety) and negative (increased night-time activity, reduced sleep efficiency and quality) effects in older people.

**Keywords:** care home, light therapy; mood; elderly; rest-activity; sleep.

## Graphical Abstract



The effect of blue-enriched 17000 K lighting (right) on the rest-activity, sleep and mood of older people living in care homes has been investigated compared to control 4000 K lighting (middle) (left, original lighting)

## 1. Introduction

Age-related changes in sleep are widely reported in the literature [1-3]. Increasing age is associated with a decrease in sleep efficiency [4], early morning awakening [5; 6], nocturnal awakenings [1 ] and increased sleep latency [7]. Poor sleep in older people has been linked to cognitive decline [8], an increase in falls [9] and poorer physical and mental health [10] with a significant correlation between cognitive ratings and sleep fragmentation [11]. Sleep changes may be due to any number of factors including age-related effects on the homeostatic and/or circadian regulation of sleep [12-14].

Circadian systems are influenced by light and light exposure at set times can shift the timing of circadian rhythms [15] and increase circadian amplitude in older people [16] . Increased light levels have been shown to increase total sleep time [17] and to improve both alertness and mood at night and during the day [18; 19]. Non-visual effects of light on behaviour and physiology are dependent on its timing, duration, intensity and wavelength [15; 20-22], with short wavelength blue light (420 – 460 nm) having the greatest effect [22-25]. Short wavelength light has been shown to reduce accumulated sleep pressure and this effect was seen at light levels as low as 40 lux [26]. This blue-light sensitivity has led to the recent development and testing of both blue light and blue-enriched polychromatic light in a variety of populations [27-30].

Age-related ocular changes (reduced pupil size; accumulation of crystalline aggregates and light absorbing yellow chromophores in the lens) lead to a reduction in the amount of light, specifically short wavelength blue light, reaching the retina [31]. There is also a reduction in the classical photoreceptors, rods, S-cones and melanopsin photoreceptors with age [32; 33]. Controlled laboratory studies have shown that older people have a reduced responsiveness to light [22; 34], especially short wavelength blue light in some [22; 35] but not all studies [22; 36]. Therefore increasing the amount of blue light, e.g. using blue-enriched high colour temperature polychromatic lighting, may compensate for the reduced responsiveness to short wavelength light observed in older people.

Previous research into increasing light levels in residential care homes has shown a strengthening of the rest-activity rhythm and better sleep in older people [17; 37-38]. However, these studies have focused primarily on dementia sufferers with greater effects observed when combined with melatonin [38]. By contrast, some studies have seen little effect of light therapy on sleep of demented care home residents [39-42]. Bright light has also been shown to improve the sleep and cognitive performance of older people living in the community not suffering from dementia [43]. The 2002 Cochrane review [44] stated that there was an absence of light research in the area of older people not suffering from dementia. Light intervention has not, to our knowledge, been tested in older people without diagnosed dementia living in care home facilities.

The aim of the current study was to compare the effects of high colour temperature (17000 K) blue-enriched white light with low colour temperature (4000 K) white light on older peoples' subjective mood and alertness and objective rest-activity rhythms and sleep. It was hypothesised that the higher intensity blue-enriched 17000 K light ( $\approx$  900 lux) would have a greater effect than the control 4000 K light ( $\approx$  200 lux) condition.

## 2. Material and Methods

A favourable ethical opinion was obtained from the University of Surrey Ethics Committee and the care homes, whilst all research was carried out according to the Declaration of Helsinki 2008. Informed written consent was obtained from participants or their families where participants were unable to give consent themselves. Seven care homes in South East England (51° N) participated in the study. Each care home was assessed using the modified Therapeutic Environment Screening Survey for nursing homes (TESS-NH) [45], to ensure the environments were comparable.

The study was a randomised crossover design with two care homes studied concurrently (Figure. 1A) from September to December or January to April in 2008, 2009 and 2010. The 12-week study period began with a baseline week with the care homes' own lights followed by four weeks of each lighting condition (either 4000 K first or 17000 K first) separated by a three week wash-out period under the care homes' own lights.

Lights were installed in communal lounges and dining rooms ( $n = 20$ ) used frequently by the residents. The light luminaires were suspended overhead from free-standing Dexian frames, built specifically for each room (see graphic abstract). Light fitments were 11556 mm x 191 mm x 82 mm containing fluorescent tubes 58W TL-D Activiva (Philips TCS097 2 x TL-D58W HF O) for the blue-enriched 17000 K lighting and 58W TL-D lamps (Philips TCS097 2 x TL-D58W/451 HF O) for the control 4000 K lighting. The two light conditions differing in colour temperature (17000 K or 4000 K) and spectral power distribution (Figure 1B). The intensity of the 17000 K and 4000 K lighting was set to provide approximately 900 and 200 lux, respectively, at 1.6 m in the direction of gaze throughout the rooms. The irradiance and photon density was  $644 \mu\text{W}/\text{cm}^2$  and  $1.77 \times 10^{15}$  photons/ $\text{cm}^2/\text{s}$  for the 4000 K lighting and  $3422 \mu\text{W}/\text{cm}^2$  and  $8.73 \times 10^{15}$  photons/ $\text{cm}^2/\text{s}$  for the 17000 K lighting.

Only residents who regularly spent time in the communal rooms were eligible to take part. Across the seven care homes 285 people were assessed for eligibility, of these 169 did not meet the inclusion criteria (over 60 years of age, willing and able to give written informed consent themselves or their family, spend time each day in communal rooms where lights were installed) and 36 declined participation, leaving 80 residents willing and able to take part of which 69 were female.

### Study Protocol

The study design had different levels of participation that allowed residents to complete as much as they wished or were capable of. Subgroups of participants answered more in depth questions about their mood, alertness and sleep, wore activity monitors and carried out a visual psychomotor vigilance task (PVT). Participation levels are presented in Figure 2. A general health questionnaire was completed (vision, mobility) and medications noted for each participant at the beginning of the study.

Data were collected over the same two days each week in each care home. Once a week the location of each participant ( $n = 80$ ) and what they were doing was recorded at 09:00, 11:00, 14:00 and 16:00 h. At baseline, end of the wash-out (week 7) and end of each light condition (weeks 4 and 11), the mini mental state exam (MMSE) was administered ( $n = 53$ ) [46]. Subjective sleepiness ( $n = 63$ ) was assessed with the Karolinska sleepiness scale (KSS) [47], and a nine-point scale ranging from 1 = very alert to 9 = very sleepy [22;48]. Three nine-

point mood scales (calm to tense, cheerful to miserable and depressed to elated) assessed subjective mood (n = 42) [22; 48]. These questions were asked in the same order after breakfast (09:00-11:00 h), before lunch (11:00-13:00 h), after lunch (14:00-16:00 h) and before supper (16:00-18:00 h). To assess anxiety and depression a subset of participants (n = 21) were administered the hospital anxiety and depression (HAD) scale every week giving a score for anxiety (HADA) and depression (HADD) [49]. At the end of each light treatment and wash-out a subset of the study group were administered the geriatric depression scale (GDS) (n = 56) [50], and completed the Pittsburgh sleep quality index (PSQI) (n = 20) [51].

Seventy-three participants wore the same activity and light monitor (Actiwatch L (AWL) Cambridge Neurotechnology Ltd, Cambridge, UK) for the duration of the study. AWLs collected data at 1 minute epochs. All AWLs were calibrated for activity using equipment from the manufacturer and the light intensity lux readings were corrected against a calibrated powermeter (Macam Photometrics Ltd, Livingstone, Scotland). Data were downloaded and checked weekly and edited prior to analysis removing periods where the AWL was not worn. Eleven activity variables were created for each person using parametric cosinor analysis [52; 53] and non-parametric circadian rhythm analysis (NPCRA) [54]. Cosinor analysis provided values for amplitude, mesor and acrophase (peak time) of the rest-activity rhythm. The NPCRA created a measure of interdaily stability (IS) indicating the day to day variation and the intradaily variability (IV) and the fragmentation of the rhythm. The NPCRA gave the mean activity in the 5 least active hours (L5), the time that this period commenced (L5onset), mean activity during the ten most active hours (M10) and when this activity started (M10onset). Measures of amplitude (AMP) and relative amplitude (RA) (L5/ M10), providing an indication of the strength of the rest-activity rhythm, were also calculated.

Objective sleep parameters were calculated using data collected by the AWL. Specific bed times and get up times provided by the care staff were determined for each participant and used to analyse all sleep episodes across the 12 week study period. All sleep periods were assessed using the Sleepwatch software from Cambridge Neurotechnology Ltd. Mean weekly values were calculated for the 27 variables supplied by the analysis which were then subjected to statistical analysis.

Psychomotor vigilance performance was measured using the visual PVT administered for 5 minutes [55], one day each week, three times a day: before lunch (~09:00-11:00 h), after lunch (~14:00-16:00 h) and before supper (~16:00-18:00 h). The primary outputs calculated were mean reciprocal reaction time (RRT); 10% fastest reaction time (%FRT) and number of lapses ( $\geq 500$  ms).

An estimation of the time spent in the rooms with the experimental lights each week was made using two methods: observational data or light levels recorded by the AWL light monitors. Participants were observed at 09:00, 11:00, 14:00 and 16:00 h on the same day each week and the percentage of occasions each participant was observed in the rooms with the experimental lights calculated. The average time spent each day in light levels above a 100 lux threshold was calculated for each participant each week using the AWL data and the manufacturer's software.

### Statistical analysis

Comparison of the light treatment regimes, 17000 K and 4000 K, was conducted for the outcome variables (Table 2) using SAS 9.2 (SAS Institute, Inc., Cary, NC). Linear iterative model fitting was performed, resulting in the use of a mixed model (PROC MIXED), without a random intercept; a repeated measures model was fitted with a compound symmetry covariance structure. Design variables entered were; light sequence (17000 K first, 4000 K first) and a nominal week identifier (#1, #2, #3, #4) for weekly measured outcome variables.

Demographic variables considered to affect the outcome measurements were entered as covariates: age (years), mobility (1= fully mobile, 2 = walking stick, 3 = walking frame, 4 = wheelchair) and certain medications (antidepressants, antipsychotics, hypnotics, glaucoma: 1 = yes, 0 = no). Baseline scores for the relevant outcome variables were entered in preference to calculating and modelling changes from baseline. Two models were created, the only difference between them being the way the participants' light exposure was estimated. The first model used the weekly observational data of their time in rooms with the lights (%) (m1 model) and the second used time spent above a 100 lux threshold (m2 model).

Statistically significant differences at the 5% level ( $p < 0.05$ ) were reported for light treatment regime, treatment week and (light treatment regime) x (treatment week) interaction.

### 3. Results

The care home environments were similar according to the TESS-NH (score  $44.4 \pm 7.0$ , mean  $\pm$  SD; range 33 – 52). Demographic data for the participants in each care home studied and the total participants ( $n = 80$ ) are presented in Table 1. Forty five participants received the 4000 K lights first and 35 received the 17000 K lights first. Of the 80 participants, 40% were taking antidepressants, 16.3% were taking hypnotics, 12.5% were taking anti-psychotics and 12.5% were taking glaucoma medication. During the 12-week study eleven participants (13.8%) were lost to follow up (seven withdrew, one was withdrawn by the investigators and three died). The mean ( $\pm$  SD) baseline MMSE scores of the study population was  $19 \pm 6$  ( $n = 62$ , 6.5% severe  $< 10$ ; 54.8% moderate  $10 - 20$ ; 25.8% mild  $21 - 26$ ; 12.9% normal  $> 27$ ). The number and demographics of participants answering each set of questions varied in size from  $n = 63$  for the KSS to  $n = 17$  for the PVT (Table 2; Figure 2).

None of the covariates (% time in rooms with lights (m1), time spent above 100 lux (m2), age, mobility and medications) were statistically significant in the modelling of the outcome variables. The two models tested, m1 ( $n = 45$ ) and m2 ( $n = 43$ ), produced the same results except in one outcome: the NPCRA M10 measure. Whereas the m1 model showed a non-significant increase in M10 ( $p = 0.12$ ), the m2 model showed a significant increase in daytime M10 activity during the 17000 K light condition ( $130 \pm 80$ , mean  $\pm$  SD) compared with the 4000 K light condition ( $126 \pm 77$ ,  $p = 0.03$ ). For all the other variables both the m1 and m2 model results were the same. The results from the m1 model are reported in Table 3.

From objective actigraphic sleep analysis the blue-enriched 17000 K lights significantly increased actual wake time (amount of time between sleep onset and sleep offset classed as wake), actual wake percentage, activity score (across the whole sleep period) and activity score in wake periods with an increase in the length of the wake bouts ( $p < 0.05$ ) thus decreasing actual sleep time, actual sleep percentage and sleep efficiency ( $p < 0.05$ ). There were no statistically significant differences in sleep latency or fragmentation index between the light conditions.

The 17000 K blue-enriched light significantly advanced the peak time (acrophase) of the rest-activity rhythm (0.5 h) compared to the control 4000 K lights ( $p < 0.05$ ) using cosinor analysis. By contrast, the onset time of the ten most active hours (M10 onset) showed a non-significant trend to delay (0.4 h) under the 17000 K lights ( $p = 0.054$ ). The participants showed significantly higher night-time activity in the five least active hours (L5) during the 17000 K lights compared to the 4000 K lights ( $p < 0.05$ ). There was a significant effect of treatment week on daytime activity (M10) with greater activity in the last two weeks of light treatment (weeks three and four) compared to week two ( $p = 0.02$ ) from the non-parametric circadian rhythm analysis.

Subjective sleep quality as measured by the PSQI was worse after the 17000 K lights, with participants exhibiting a higher PSQI score compared to after the 4000 K lights ( $p = 0.04$ ). Statistically significant differences were seen in the HADA score with the participants showing lower daytime anxiety levels during the 17000 K blue-enriched white light compared to during the 4000 K light ( $p < 0.005$ ).

There were few statistically significant interactions between light treatment week and light condition for the outcome measures except for the calm/tense scale (light treatment week x light condition interaction,  $p < 0.05$ ), the actual sleep and wake percentage and the mean wake score with increased wake in week 4 of the light treatments ( $p < 0.05$ ). Participants' self-rated calmness was significantly different in the light conditions between weeks two and three (more calm in week 3) and participants under the 4000 K condition were more tense during week three compared to week four.

No significant differences were seen between the light conditions for the PVT variables: reciprocal reaction time (RRT); 10% fastest reaction time and lapses ( $\geq 500$  msec) (Table 3). The time of day that the PVT was administered significantly affected the mean RRT and the number of lapses ( $p < 0.05$ ); participants ( $n = 17$ ) had fewest lapses in the morning ( $12.0 \pm 10.3$ ), and most lapses after lunch ( $13.7 \pm 11$ ) with slower reaction times in the morning (RRT  $2.5 \pm 0.9$ ) and faster reaction times in the afternoon (RRT  $2.4 \pm 0.9$ ).

#### **4. Discussion**

The current study investigated the effect of overhead blue-enriched white lighting on older people, without diagnosed dementia, living in care homes, the majority (65%) of those classified as having moderate cognitive impairment giving MMSE scores of 15 and above. Unlike previous studies [40; 56-58], participants in the current study were free to enter and leave the communal areas housing the experimental lights whenever they wished allowing for the natural behaviour of residents. Moreover, the participants were independently living and free to leave and enter the care home. Some, but not all, previous studies have reported that increasing light

levels in residential care homes can lead to strengthening of the rest-activity rhythm and better sleep in older people [17;37; 38; 40; 58-60]. The participants in these studies were diagnosed as suffering from dementia and the study protocols required individuals to either sit in front of bright white light boxes, of varying colour temperatures, for set hours of the day or under bright overhead lighting switched on for different periods of the day. Owing to the different nature of each care home setting and how our study was arranged to allow the residents to be able to carry on their normal day to day lives, we recognise that there are limitations to this study. However, these limitations are important to acknowledge and address as the previous studies controlling participants' behaviour are less practical to instigate in a normal care home setting.

Indoor lighting levels in care homes for older people are reported to be low and considered insufficient to meet the European standard [61; 62]. In agreement with these reports, existing lighting levels in the care homes participating in the current study were also low ( $51 \pm 9$  lux) [63].

Residents exhibited increased activity in the 17000K lights during both the day and night (M10, L5 and mean activity score). This activating effect of light on activity levels is in agreement with some of the previous studies in demented subjects [40; 42; 54; 64]. Night-time activity, assessed during the five least active hours (NPCRA L5), was significantly higher and sleep efficiency and actual sleep time significantly lower during the 17000 K light condition. This finding implies increased night-time agitation during the 17000 K light period. Previous light studies have also reported increased agitation at night from caregivers' observational data [65], although specific effects on objective night-time activity (L5) have not previously been reported. Blue-enriched or white light have shown no effect on sleep efficiency of older people [66]. The well-known alerting effects of light [18] especially blue light, may explain the increased activity measured during the day and night in the 17000 K blue-enriched light condition.

The acrophase (peak time) of the rest-activity rhythm occurred significantly earlier under the 17000 K lights than under the 4000 K lights which could be explained by the participants receiving extra brighter blue-enriched light in the earlier part of the day corresponding to the phase-advance portion of the phase response curve for light [15; 67]. Care home routines meant that participants usually retired to their own bedrooms (with no experimental lights) after the evening meal thus reducing their bright light exposure in the later (phase-delaying) part of the day. From NPCRA analysis the beginning of the 10 h with greatest activity (M10 onset) occurred slightly, but not significantly, later with the 17000 K light ( $10.00 \text{ h} \pm 2.5$ ) compared to the 4000 K light ( $9.6 \text{ h} \pm 2.7$ ). This finding would appear to contradict the observed advance in the acrophase of the rest-activity rhythm, however, this could be due to an overall increase in activity levels across the whole day thus extending the active period whilst acrophase cosinor analysis is restricted to identifying the time of maximum activity levels.

Subjective sleep quality as measured by the PSQI was poorer after four weeks of 17000 K light than after 4000 K lighting. This finding may be related to the objective findings of increased night-time activity, lower sleep efficiency and lower actual sleep time during the 17000 K light condition. A positive effect of 10000 lux light for 30 minutes a day for 30 days was seen in PSQI scores of care home residents with mean PSQI scores changing from  $12.8 \pm 4.26$  at baseline to  $3.95 \pm 1.75$  after treatment [68]. Unfortunately in the current study the

number of participants who completed the PSQI was relatively low (25%) owing to the complexity of the questionnaire for these older care home residents. The use of the PSQI questionnaire in this study population may not be appropriate and use of a simpler sleep scale is recommended for future studies. A previous study investigating the effect of light on sleep in older people living in the community found that the PSQI and the objective sleep measures did not correlate [69].

Self-rated anxiety (HADA) was significantly different between the lighting conditions with reduced anxiety in the daytime during the 17000 K light intervention. This finding is in agreement with a study by Kobayashi et al.[70] in which lower anxiety was reported in healthy older people during bright light treatment. Further work looking at additional anxiety measurements during light studies would be useful to confirm our finding.

Apart from an effect on self-rated anxiety, bright blue-enriched light had no significant effect on other self-rated mood parameters (depression, cheerfulness, calmness, alertness) or performance (PVT). It should be noted that in the current study participants were not forced to be exposed to the experimental lights during the mood and alertness assessments thus the well-known acute effect of lighting on mood and alertness [18; 19; 22; 25; 27; 66; 71], may not have been captured. The subjective mood and sleep questionnaires used in the current study may also have been too blunt an instrument to discriminate small changes in mood, alertness and sleep quality in this older study population, although changes were seen in office workers [27], and in a population of nursing home residents with [38] and without dementia [72]. In the former study, however, care givers evaluated the participants' mood and behaviour, whereas in the current study participants responded themselves which may well account for the discrepant results.

Although the performance measures (PVT) showed no difference between the lighting conditions, a time of day effect was observed in reaction time and number of lapses, as has been previously reported [73]. It is possible that with the current study population reaction time was slow due to physical constraints which allowed no measurable improvement during the different light conditions. A previous study of older people suggested that this study population is less likely to show a change in PVT performance with different amounts of sleep [74].

It is not known whether light may impact differentially in men and women. In this study the gender imbalance (69 female, 11 male) makes gender comparison impractical. However, it is reflective of the older population as women live on average longer than men, and although the differential is decreasing, it is inevitable that residential care homes for older individuals will have a preponderance of females.

Installation of the same high colour temperature (17000 K) blue-enriched light sources in the workplace has been reported to improve self-reported alertness, mood and irritability in office workers compared to 4000 K white light [27; 30]. In Antarctica 17000 K blue-enriched light throughout the wake period advanced the circadian system (as assessed by the urinary melatonin metabolite, 6-sulphatoxymelatonin) accompanied by earlier actigraphic sleep onset and shorter sleep latency during the winter [28]. Also in Antarctica normal fluorescent light of 100-300 lux showed a significant delay in melatonin onset compared to blue-enriched white light with no difference in rest-activity rhythms by NCPRA under the two light conditions [29]. Similarly, a

recent study reported cognitive improvements using an assessment of cognitive function and a profile of mood states with 30 minutes of blue LED light (400 lux) each day compared to red light in older people in long term care [75]. Despite these positive effects of blue or blue-enriched light, in the current study only one of the mood variables showed a significant difference between the two light conditions. There are several possible explanations for this. Firstly the experimental light was set at around 900 lux which may have been too low to observe an effect whereas other studies have used higher light intensities (e.g. 3000 lux [69]). The light interventions were only for 4 weeks which may not be sufficient time to elicit a permanent change in behaviour in this study population. Based on a previous study [38], use of bright light over a longer time (2-3 years) might have given more substantive results. Finally, the questionnaires and tests used in the current study may be inappropriate to identify small changes in mood and behaviour given the age-related reduced cognitive ability of the participants.

For future work in order to increase the effectiveness of the lights, installing lights in the participants' bedrooms could be considered if ethical considerations and cost would allow, however, this needs to be balanced against light's ability to increase alertness before bedtime and delay sleep time [76; 77].

Blue-enriched polychromatic light has now been tested in a number of settings [27-30], but caution should be applied to the findings, as in some cases, such as the study of older people reported here, the effects appear small and mixed. Based on this work it is important to further characterise the risks and benefits of 17000 K blue-enriched light prior to this lighting being applied permanently in care homes for older people.

**Conflict of interest:** There are no financial, personal, potential conflicts of interest in the conduct of the study or in the manuscript development. Although Philips Lighting supplied the light fittings, they had no part in the design of the protocol nor in the analysis of the data.

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**Table 1. Baseline Demographics for All Participants**

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<b>Care home</b>	<b>n</b>	<b>Time of year</b>	<b>Owner of care home</b>	<b>Number of beds in care home</b>	<b>Age (yrs) (mean <math>\pm</math> SD)</b>	<b>male: female</b>
1	11	Sept. 2008	Local authority	38	84.9 (6.0)	1:10
2	9	Sept. 2008	Local authority	38	84.6 (9.9)	2:7
4	13	Jan. 2009	Private company	43	87.6 (5.9)	0:13
5	19	Sept. 2009	Private company	76	84.1 (7.2)	5:14
6	10	Sept. 2009	Private company	78	87.2 (4.5)	0:10
7	7	Jan. 2010	Private company	58	85.4 (7.5)	1:6
8	11	Jan. 2010	Private company	28	87.4 (11.3)	2:9
<b>Total</b>	<b>80</b>				<b>85.8 (7.5)</b>	<b>11:69</b>

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**Table 2. Demographics of the Participants Included at Completion of Each Outcome Measure**

<b>Outcome measure</b>	<b>Number of participants</b>	<b>Age (mean years <math>\pm</math> SD)</b>	<b>Male: female</b>	<b>Mean MMSE score (mean <math>\pm</math> SD) (n)</b>
<b>Rest-activity</b>				
Cosinor amplitude, acrophase, mesor	34	84.8 $\pm$ 8.1	5:29	19.3 $\pm$ 6.8 (30)
NPCRA	45	84.8 $\pm$ 7.6	5:40	19.6 $\pm$ 6.6 (38)
All parameters				
<b>Actigraphic sleep analysis</b>				
All parameters	47	85.2 $\pm$ 7.7	5:42	19.6 $\pm$ 6.5 (40)
<b>Mood and sleep</b>				
Alert / Sleepy				
Calm / Tense	42	86.6 $\pm$ 7.4	4:38	18.9 $\pm$ 5.6 (36)
Cheerful / Miserable				
Depressed / Elated				
KSS	63	86.0 $\pm$ 7.4	7:56	19.0 $\pm$ 5.7 (57)
GDS	56	86.6 $\pm$ 6.6	7:49	19.3 $\pm$ 5.7 (52)
HAD	21	86.2 $\pm$ 7.4	4:17	23.9 $\pm$ 4.6 (19)
PSQI	20	86.5 $\pm$ 7.7	3:17	23.8 $\pm$ 4.6 (17)
<b>Performance</b>				
PVT lapses, mean RRT, 10% F RT	17	85.2 $\pm$ 7.8	3:14	23.6 $\pm$ 5.7 (17)

GDS = Geriatric Depression Scale; HAD = Hospital Anxiety & Depression Scale; KSS = Karolinska Sleepiness Scale; NPCRA = Non parametric circadian rhythm analysis; PSQI = Pittsburgh Sleep Quality Index; PVT = Psychomotor Vigilance Task; RRT = Reciprocal Reaction Time; 10% FRT = 10% Fastest Reaction Time.

**Table 3. Outcome Measures Estimated from the Repeated Measures Analysis of Variance m1 Model (mean  $\pm$  SD).**

Outcome measure	n	Light Condition		P
		17000 K	4000 K	
<b>Rest-activity</b>				
Cosinor amplitude	34	2955 $\pm$ 1844	2924 $\pm$ 1821	0.58
Cosinor acrophase (dec. h)	34	14.7 $\pm$ 2.5	15.2 $\pm$ 2.6	0.04*
Cosinor mesor	34	4490 $\pm$ 2539	4416 $\pm$ 2397	0.9
IS	45	0.5 $\pm$ 0.1	0.5 $\pm$ 0.1	0.61
IV	45	1.3 $\pm$ 0.3	1.3 $\pm$ 0.3	0.95
L5	45	27.4 $\pm$ 30.1	24.9 $\pm$ 23.4	0.04*
L5 onset (h)	45	24.3 $\pm$ 2.1	24.0 $\pm$ 1.9	0.13
M10	45	132 $\pm$ 81	128 $\pm$ 76	0.12
M10 onset (h)	45	10.0 $\pm$ 2.5	9.6 $\pm$ 2.7	0.05
Amplitude	45	105 $\pm$ 63	103 $\pm$ 63	0.43
Relative amplitude	45	0.7 $\pm$ 0.2	0.7 $\pm$ 0.2	0.63
<b>Actigraphic sleep analysis</b>				
Actual sleep time (dec h)	47	8.1 $\pm$ 0.2	8.3 $\pm$ 0.2	0.04*
Actual sleep %	47	81.0 $\pm$ 2.0	82.1 $\pm$ 2.0	0.03*
Actual wake time (dec h)	47	1.8 $\pm$ 1.1	1.7 $\pm$ 0.9	0.02*
Actual wake %	47	19.0 $\pm$ 11.4	17.9 $\pm$ 9.8	0.03*
Sleep latency (dec h)	47	0.64 $\pm$ 0.43	0.61 $\pm$ 0.34	0.25
Sleep efficiency %	47	74.3 $\pm$ 12.9	75.6 $\pm$ 11.5	0.045*
Mean activity score	47	39.2 $\pm$ 42.4	34.5 $\pm$ 32.1	0.004**
Mean score in wake periods	47	131.8 $\pm$ 93.9	121 $\pm$ 81	0.002**
Mean wake bout time (dec h)	47	0.08 $\pm$ 0.05	0.07 $\pm$ 0.03	<0.001***
Mean wake score	47	119.0 $\pm$ 75.8	112.5 $\pm$ 68.7	0.007**
Fragmentation index	47	54.0 $\pm$ 17.0	52.7 $\pm$ 16.8	0.18
<b>Mood and Sleep</b>				
Alert/ Sleepy	42	4.4 $\pm$ 1.5	4.4 $\pm$ 1.3	0.66
Calm / Tense	42	3.7 $\pm$ 1.3	3.7 $\pm$ 1.2	0.62
Cheerful / Miserable	42	4.0 $\pm$ 1.3	3.9 $\pm$ 1.2	0.87
Depressed / Elated	42	5.7 $\pm$ 1.2	5.6 $\pm$ 1.2	0.26
KSS	63	4.0 $\pm$ 1.5	4.1 $\pm$ 1.4	0.69
GDS	56	4.4 $\pm$ 2.9	4.0 $\pm$ 3.3	0.42
HADA	21	4.5 $\pm$ 2.5	4.6 $\pm$ 2.7	0.004**
HADD	21	3.7 $\pm$ 2.4	4.0 $\pm$ 2.4	0.53
PSQI	20	6.6 $\pm$ 2.9	5.6 $\pm$ 2.5	0.04*
<b>Performance</b>				
PVT mean RRT	17	2.5 $\pm$ 0.9	2.5 $\pm$ 0.9	0.71
PVT lapses ( $\geq$ 500 ms)	17	12.3 $\pm$ 9.3	13.2 $\pm$ 10.0	0.25
PVT 10% FRT	17	308 $\pm$ 139.7	315.0 $\pm$ 12.7	0.25

Statistical significance set at  $p < 0.05$

GDS = Geriatric Depression Scale; HADA = Hospital Anxiety & Depression Scale Anxiety component; HADD = Hospital Anxiety & Depression Scale Depression component; IS = Interdaily Stability; IV = Intradaily Variability; KSS = Karolinska Sleepiness Scale; L5 = average activity during 5 h least active; L5 Onset = start time of 5 h with least activity; M10 = average activity in 10 consecutive most active hours; M10 Onset = start time of 10 h with most activity; NPCRA = Non parametric circadian rhythm analysis; PSQI = Pittsburgh Sleep Quality Index; PVT = Psychomotor Vigilance Task; RRT = Reciprocal Reaction Time; 10% FRT = 10% Fastest Reaction Time.

## Figure legends

### **Figure 1.**

**A.** Diagram of light intervention trial design with two care homes being studied concurrently. One baseline week (BL) was followed by four weeks of each light condition (either 4000 K first or 17000 K first) separated by three weeks washout. Light illuminance levels (lux, mean  $\pm$  SEM) were recorded at 1.6 m in the direction of gaze.

**B.** Spectral power distribution of the polychromatic fluorescent lighting installed in the care home communal rooms (17000 K lighting, solid dark line; 4000 K lighting, dotted line). Details of the lights (irradiance, photon density) are in the text.

### **Figure 2.**

Flow chart of the participants included in the study and the outcomes measured.

GDS = Geriatric Depression Scale; HAD = Hospital Anxiety & Depression Scale;

KSS = Karolinska Sleepiness Scale; NPCRA = Non parametric circadian rhythm analysis; PSQI = Pittsburgh Sleep Quality Index; PVT = Psychomotor Vigilance Task.

**Figure 1**

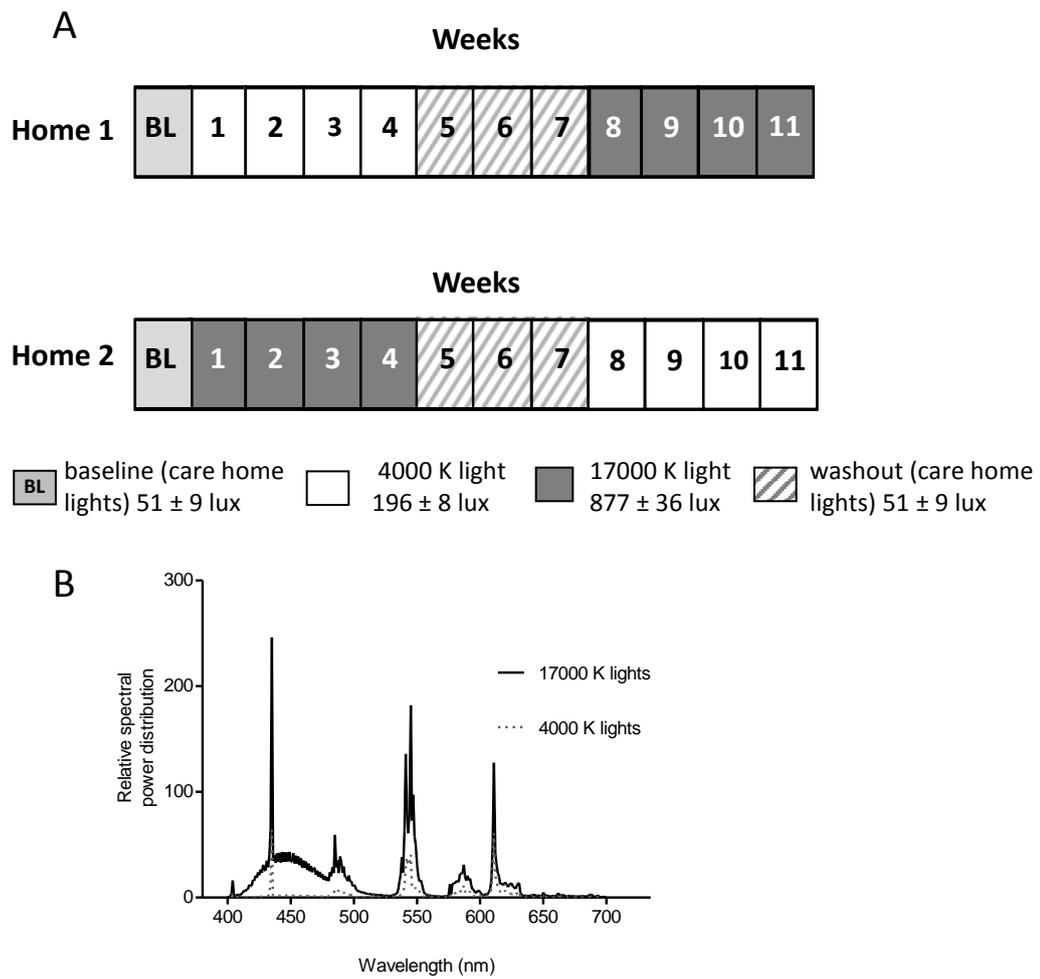


Figure 2

