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Amanda Nioi[1], Jenny Roe[2], Alan Gow[3], David McNair[4], Peter Aspinall[5]

[1] *School of Engineering and Physical Science, Heriot-Watt University, Edinburgh, United Kingdom*
[2]*Center for Design and Health, School of Architecture, University of Virginia, Charlottesville, United States of America*
[3]*School of Management and Languages, Heriot-Watt University and Centre for Cognitive Epidemiology, University of Edinburgh, Edinburgh, United Kingdom*
[4]*Dementia Centre, Hammond Care, Sydney, Australia*
[5]*School Energy, Geoscience, infrastructure and Society, Heriot-Watt University, Edinburgh, United Kingdom*

Abstract: This paper reports seasonal difference in light exposures and health and wellbeing indicators as well as predictors of sleep quality parameters in care home dwelling older adults. The quality of lighting in the indoor environment can impact upon the health and wellbeing of building occupants. For older adults in care homes poor light exposure has been attributed to disruptions in the sleep/wake cycles. The repeat measure design explored personal illuminance and blue spectral irradiance exposure and sleep/wake patterns in older adults in two seasons (n=16). The cohort was assessed across a suite of health and wellbeing indicators. Statistical analysis included a paired means test to detect changes over time and an exploratory analysis of predictors of sleep parameters. Light exposures and daytime physical activity were significantly different between seasons (i.e. these were higher in summer). Morning blue light exposure (a predictor of total night-time sleep), daytime activity level (a predictor of sleep efficiency) and visual function (a predictor of minutes awake during the night) may contribute to sleep quality. This paper presents insights into the limited amount of light exposure in older adults and architectural characteristics that that could serve to promote health and wellbeing.

Keywords: daylight, sleep/wake, circadian rhythms, physical activity, well-being

Background

Humans have evolved under a diurnal cycle of bright light from daylight to darkness, which keeps circadian rhythms in synchronicity. Adequate light exposure has been reported as the strongest cue in regulating and synchronising circadian rhythmicity (Foster, 2010). Exposure to light for circadian synchronisation is likely to differ with age. Turner and Mainster (2008) reported that a person at age 75 requires three times as much light as that of a 45 year old to elicit the same circadian response. Research investigating light exposures in a natural setting have suggested inconsistency in illuminance level and blue spectral irradiance, particularly across seasons and age groups (Thorne *et al.*, 2009). Evidence exists to suggest that older adults residing in residential care homes may be exposed to very low levels of illuminance and spend short durations exposed to bright light. This has been attributed as a cause of circadian misalignment (De Lepeleire *et al.*, 2007; Sinoo, van Hoof and Kort, 2011).

The architectural design and specifically the lighting requirements within the care home environment have been associated with changes in health parameters, such as sleep quality (Ancoli-Israel *et al.*, 1994; Espiritu *et al.*, 1994; Shochat *et al.*, 2000; Stone *et al.*, 2014). Poor light exposure and insufficient lighting design can add to the disruption of the sleep/wake cycle in older adults, in particular those living with cognitive impairments (Shochat *et al.*, 2000; Sinoo, van Hoof and Kort, 2011). Natural changes in light may also be responsible for alterations in sleep patterns – for example seasonal changes is light from long bright summer days to dark short winter days in northern latitudes countries (Paul *et al.*, 2015).

It is well documented that the human circadian system is most sensitive to short-wavelength light (450-500nm), i.e. the blue part of the visible spectrum, and that the eye facilitates the communication of light information to the area of the brain where the body clock oscillates (Lockley, Brainard and Czeisler, 2003; Brainard *et al.*, 2008; Gooley *et al.*, 2010). The human eye facilitates the 'non-visual' pathway to the circadian system in the brain and contains light-sensitive cells (intrinsically photosensitive retinal ganglion cells or ipRGC) (Hattar *et al.*, 2002). Research has demonstrated the eye changes with ageing, this is characterised by a narrowing pupil and yellowing lens (Hughes and Neer, 1981). As a consequence the transmission of light is impeded through the eye to vital non-image-forming light sensitive cells (Kessel *et al.*, 2010). What is also understood is the ability for yellow/orange-tinted lenses to block blue light wavelengths, which happens naturally with increasing age (Sasseville *et al.*, 2006; Turner and Mainster, 2008). Blocking these vital blue light wavelengths may hinder circadian entrainment and contribute to a fragmented sleep pattern. Therefore, reduced light stimulus to the circadian system would indicate that lighting requirements are likely to differ across the life span (Turner and Mainster, 2008).

This research is one of the first to present continuous objective measures of sleep/wake and light exposure patterns and measure visual function in older adults living in a residential care home setting. The aim of this research was to investigate, in two seasons, personal blue light exposure, illuminance levels and health variables (i.e. sleep/wake cycle, daytime physical activity level, cognitive ability and visual function). The following research questions were investigated (1) what are the seasonal differences in sleep/wake, activity, mental wellbeing and cognitive ability, (2) what are the seasonal differences in blue light irradiance, illuminance level and duration in thresholds, and (3) What are the potential predictors of sleep quality parameters, measured by total sleep time, sleep efficiency and wake after sleep onset?

Methods

Participants were recruited from six care homes across central Scotland. A visual aid was developed to communicate the study protocol and commitment required (Nioi, 2016). Each participant gave written consent with additional written consent acquired from next of kin. In total 20 participants in summer (male=3, female=17) and 16 participants repeated this in winter (male=3, female=13). The reduced participant numbers in winter were accounted for by 1 participant who passed away, 2 withdrew from the process, and a lost dataset for 1 further participant during download. For the purposes of the within group analysis the repeat 16 participants datasets were used.

Sleep/wake and physical activity

The sleep/wake cycle was monitored using the Philips Respironic Actiwatch. This is a wrist-mounted sensor, worn like a watch that records sleep/wake and activity movements (Nioi, 2016).

Health and wellbeing indicators

The following health and wellbeing indicators were assessed. A full description of these can be sourced in Nioi, 2016 and Nioi *et al.*, 2017.

1. *The Pittsburgh Sleep Quality Index (PSQI),* (Buysse *et al.*, 1989) evaluated the sleep status over the last month. This is a self-rated measure consisting of 19 items generating a 7 component score (i.e. duration of sleep, sleep disturbance, sleep efficiency, daytime dysfunction due to lack of sleep, medication, etc.). The sum of these scores yields 1 global score, i.e. total sleep quality. A score of <5 is classed as good sleep quality and a score of >5 is classed as poor sleep quality.
2. *The Mini Mental State Exam (MMSE),* (Folstein, Folstein and McHugh, 1975) was used as an initial screening for potential cognitive impairment.
3. *Deary-Liewald Cognitive Reaction Time test* (Deary, Liewald and Nissan, 2011). This is a computer-based assessment conducted on a laptop computer. Participants were instructed to press any key to start the test. The computer screen presents a white box in the centre, within which a black X appears. The aim was to press any key again when they saw the X appear to make it disappear. This was repeated for 20 counts and recorded in milliseconds.
4. *Warwick Edinburgh Mental Wellbeing Scale (WEMWBS),* (Tennant *et al.*, 2007). This is a 14-item scale that covers both hedonic (pleasure) and eudaimonic (meaning and self-realization) aspects of mental health.
5. *Visual function* - participants completed a set of visual function tests selected by ophthalmologists. The first assessment was the Bailey and Lovie LogMAR visual acuity test (Bailey and Lovie, 1976). This is a test of the sharpness of central vision and the ability to see fine details. The second measure was the Pelli-Robson test to measure contrast sensitivity (Pelli, Robson and Wilkins, 1988). Contrast sensitivity is the visual ability to see objects that may not be outlined clearly or that do not stand out from their background.

Light exposure

There are three key light variables under exploration, (1) mean illuminance levels and mean blue spectral irradiances over a time-period (morning (8:00-12:00), whole day (8:00-18:00) and evening (18:00-22:00), (2) durations spent in illuminance thresholds, and (3) durations spent in blue spectral irradiance thresholds (Nioi, 2016).

Protocol

A repeated measures design was used to explore sleep parameters and health and wellbeing outcomes in the sample between two seasons (summer and winter), in relation to environmental blue light exposure and illuminance levels. Sleep/wake and personal light exposure patterns were monitored for 4 days. Participants wore two body-mounted sensors, (1) wrist capturing sleep/wake and activity levels, and (2) lapel capturing light exposure on the vertical plane more representative of light incident at the eye.

Data analysis

Data analysis was carried out using SPSS 21. A within group Wilcoxon signed-rank test was used to detect changes over time. A new form of high dimensional regression modelling, known as Correlated Component Regression (CCR) (Magidson, 2013), was used to explore potential predictors of sleep quality parameters - i.e. could light exposure level, duration of exposure or health and wellbeing covariates predict sleep quality outcomes. CCR allows regression modelling to be carried out on small samples and, specifically, can be used when the number of predictors (*P*) exceeds the number of cases (n), thus addressing the problem of collinearity (i.e. predictor variables which have a moderate to high correlation with one another) with a focus on out of sample prediction (i.e. uses existing data to forecast future relationships).

Results

Results are illustrated in Figures 1-3 box plot and whisker diagrams. The box represents the range of scores, the dark line across the box is the median score and the whiskers represent the maximum and minimum scores.

Seasonal differences in sleep/wake, activity, mental wellbeing and cognitive ability

Daytime physical activity (Figure 1) was significantly higher in summer (mean=454 average active count) than in winter (mean=174 average active count) indicating participants were more active during the summer season (Z=-3.51, p<0.00). Results suggested a significant difference between visual acuity measured in the right eye between summer (mean=.39 logMAR) and winter (mean=.54 logMAR) indicating visual acuity decreased from the first measurement (Z=-2.44, p=0.05). No other health and wellbeing indicators were significantly different.

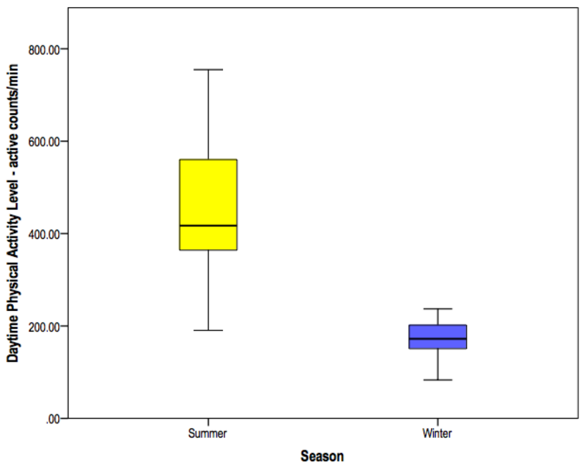

Figure 1. Daytime physical activity in two seasons
(Summer M=454 average active count and winter M=174 average active count)

Seasonal differences in blue light irradiance, illuminance level and duration in thresholds

Morning blue light exposure (Z=-3.00, p=0.03) and morning illuminance level (Z=-2.98, p=0.04) were both significantly higher in summer (Figures 2 and 3). Duration spent in bright light of >1000 lux was significantly longer in summer (mean=46 minutes) compared to winter (mean=3 minutes), (Z=-2.91, p=0.04). The corresponding blue light threshold of >100 μW/cm^2 was also significantly different between seasons (Z=-2.66, p<0.00). In summary, there was a significant difference in all light and threshold duration measures – including blue light – between seasons.

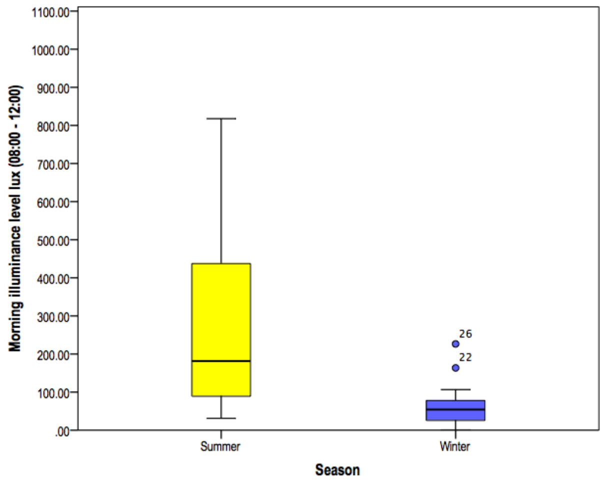

Figure 2. Morning (8:00-12:00) illuminance level (Summer M=466 lux and winter M=65 lux)

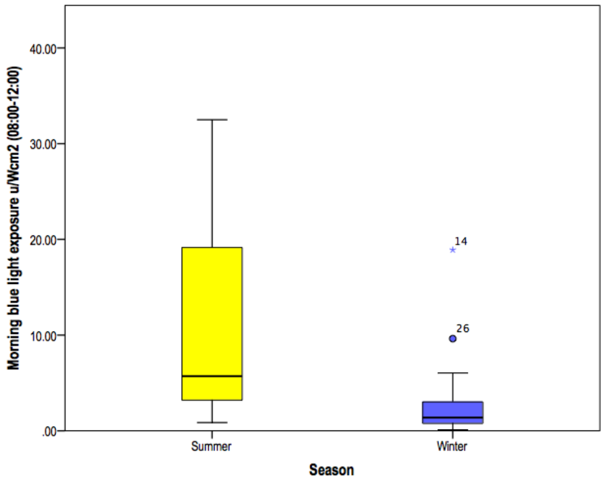

Figure 3. Morning (8:00-12:00) blue light exposure (Summer M=24 μW/cm^2 and winter M=3 μW/cm^2)

Predicting sleep quality parameters using high dimensional regression modelling

The CCR results are represented in Tables 1-3 and should be interpreted in the following way. In each table under 'fit' there is a report of the R^2 values, i.e. the total variance in the model. The standard coefficients for each tuning parameter of correlated component (K) are listed below. The predictors (P) and the corresponding standard coefficient for each are reported in rank order. The effect size quantifies the strength of the relationship between variables. Cohen (1988) suggests the following effects for standard coefficients, 0.2 is considered small, 0.5 moderate and 0.8 as large.

(1) Total sleep time (i.e. the total time within each rest interval scored as sleep) was best predicted by morning blue light exposure (0.02), with a small effect size of R^2=0.10 (Cohen 1988), for a sample of 20.

Table 1. Predictors of total sleep time

Fit	**Training**	**Cross-Validation**	**SE**
R^2	0.00	0.10	0.08
Std. Coefficient			0.02
Predictors	**Std. Coefficient**		**CC1**
Mean morning blue light exposure	0.02		1

(2) Sleep efficiency (i.e. the percentage of time in bed actually sleeping) was predicted by (in rank order) daytime physical activity (0.40) and visual acuity (-0.29), with a small effect size of R^2=0.04 (Cohen 1988).

Table 2. Predictors of sleep efficiency

Fit	**Training**	**Cross-Validation**	**SE**
R^2	0.20	0.04	0.02

Std. Coefficient		0.47	0.03
Predictors	**Std. Coefficient**	**CC1**	**CC2**
Daytime physical activity	0.40	0.92	-0.79
Visual acuity right eye	-0.29	0.57	0.49

(3) Wake after sleep onset (i.e. the number of minutes awake during the sleep cycle) was predicted by (in rank order), contrast sensitivity (-0.14) and visual acuity (0.27), with a small effect size of R^2=0.02 (Cohen 1988).

Table 3. Predictors of wake after sleep onset

Fit	**Training**	**Cross-Validation**	**SE**
R^2	0.24	0.02	0.01
Std. Coefficient		0.83	0.62
Predictors	**Std. Coefficient**	**CC1**	**CC2**
Contrast sensitivity left eye	-0.14	-0.06	-0.17
Visual acuity right eye	0.27	0.02	0.28

Discussion

These results indicated that older people had low blue light exposure and illuminance levels in both seasons, with this being markedly lower in winter. Similarly, participants spent significantly longer durations in bright light during summer compared to winter. This may be expected, as daylight is more plentiful in northern latitudes during the summer. However, intensity and durations in bright light were very short in both seasons. The findings here are consistent with previous work that indicated care homes may be poorly lit and time spent in bright light, particularly daylight, is curtailed in older people (De Lepeleire *et al.*, 2007). This has important implications for the wellbeing of older people, for building and lighting design and care policy.

The key findings were the low levels of physical activity in both summer and winter and low blue light exposure. Previous studies have categorised sedentary behaviour as an <100 physical activity counts (van Alphen *et al.*, 2016). The results in this current study suggest that activity levels in the winter sample were very low (174 active counts), indicating, on average, participants had reduced levels of daytime physical activity. This is further evidence of the growing need to boost physical activity in older adults (particularly in the winter period) with the potential to improve blue light exposure and sleep quality.

In estimating predictors of sleep quality parameters, this study provides evidence of key factors influencing sleep and the importance in determining light exposure levels as well as daily routine. In summary, these were (1) timing of light (i.e. morning light exposure, a crucial in regulating sleep), (2) daytime physical activity level and (3) the health of the visual system. A principal element in this study was reporting visual function as an influence upon sleep quality. It demonstrates that future research must explore the impact of the health of the visual system in relation to designing appropriate lighting environments for older people living in a care home setting.

Objective measures of sleep quality, as measured by the actiwatch (e.g. total sleep time, sleep onset latency, wake after sleep onset, sleep efficiency, wake up time and bedtime) did not differ significantly between seasons. Similarly, there were no statistical differences in cognitive function tests or mental wellbeing. Reasons why there were no observed statistical differences in sleep outcomes or other health and wellbeing measures could be due to the small sample size and exploratory nature of this research. Confounders that may have limited the study include, medication use, nursing routine, diet choices and/or life events (e.g. passing of other residents/family members). In future studies, with larger numbers, collecting this information would help better understand health and wellbeing indicators in older adults.

Analysing human biomarkers (such as circadian rhythmicity, hormonal concentration profiles etc.) and their association with the built environment will help create healthier indoor environments, in particular, for those with reduced mobility and limited time outdoors. The implications for practice are far reaching. For example, post-wake exposure to bright light helps synchronise the body clock and entrain the 24-hours circadian pattern. Therefore, it would be advantageous to maximise this in the daily routine of older adults – e.g. increasing time outdoors in the morning hours. Conversely, reducing light exposure at night-time will aid the production of melatonin (the sleep hormone). This can be achieved by fitting bedrooms with heavy curtains or blackout blinds to exclude light pollution from external sources (i.e. bright light in summer or excessive light from street lighting).

Spatial orientation of the building layout is crucial in achieving appropriate daylight exposure. Where possible rooms ought to face the required circadian direction - e.g. east or south/east bedrooms gaining morning light exposure. Similarly, the positioning of furniture towards windows with a stimulating view would be helpful for both circadian entrainment and for general wellbeing (Kaplan, 2001). Architectural designs should always facilitate easy access to outdoors, be these gardens, balconies or terraces. There is no substitute for time outside in daylight to help circadian entrainment. This brings additional health and wellbeing benefits, such as exposure to fresh air and is the primary source of Vitamin D synthesis (Humble, 2010). Beyond light as a synchroniser access to other environmental cues are vital. Time of day, ambient air temperature, noise and acoustic levels all play a role in entraining circadian rhythms. Creating light and view filled destinations in rooms would facilitate access to these.

In conclusion, the findings suggested that light exposure and health outcomes, such as physical activity and visual function could be responsible for sleep quality. This has implications for design and health interventions promoting wellbeing.

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