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Older adults' rest-activity and light exposure patterns in the home setting: a methodological case study

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Abstract

Background—This methodological case study describes light exposure and rest-activity patterns in an older adult with dementia and his caregiver spouse.

Methods—Two devices were used to measure rest-activity and light exposure data: a wrist-worn actigraph with a light sensor to record full spectrum light exposure data and an eye-level wavelength sensitive light meter (Daysimeter™). The wife wore both devices simultaneously; the husband wore only the actigraph.

Results—There were minimal feasibility issues in using the devices in the home setting. The wife's light exposure was considerably better than her husband's, but she spent little time in bright lighting. Her circadian stimulus (CS) and activity values suggest high level of circadian disruption.

Conclusion—This case study provides beginning support for the use of the Daysimeter in the home setting while also highlighting unrecognized circadian disturbances and very low light levels in an older couple's home.

INTRODUCTION

Among the many challenges of providing home-based care for older adults with dementia, nighttime sleep disturbances are some of the most bothersome, in part because they frequently trouble both the older adult and the caregiver. This methodology paper focuses on a case study of a husband-wife dyad (an older man with dementia and his wife-caregiver) in which we assessed sleep-wake rhythms and 24-hour light-dark patterns using the standard clinical diagnostic tool, the wrist actigraph with light sensor, and a new device, the Daysimeter™, which recorded the wife-caregiver's exposure to circadian-stimulating blue-white light. We chose the subjects and the setting because there is little information on older adults' light exposure in their own home environment and most sleep disruption research has focused on the older adult with dementia, not the caregiver. Additionally, there is no known research on older adults' exposure to blue-white light and its relationship to their sleep-wake cycles.

The Human Circadian Response to the 24-hour Light-Dark Cycle

All species on the planet are exposed to 24-hour patterns of light and dark. In response to these naturally occurring patterns, humans have evolved circadian (circa=about; dia=day) rhythms (e.g., core body temperature variations, melatonin synthesis, sleep-wake behavior) that repeat approximately every 24.2 hours¹ and are synchronized to the solar day by photic and non-photoc cues, with the light-dark cycle being the strongest²⁻⁴. Light-dark patterns affect the timing and magnitude of circadian rhythms and when exposures to light and dark are not in synchrony with socially accepted hours of wakefulness and sleep, individuals can

experience sleep deprivation, mood and eating disorders, and possibly immune system deficiencies^{5, 6}.

The sleep/wake pattern is directly driven by the timing signals generated by the suprachiasmatic nuclei (SCN), which is known to be compromised in older adults with dementia⁷. Since the 24-hour light-dark pattern incident on the retina is the most efficacious stimulus for entraining the circadian system in humans⁴, a potential cause of sleep disturbance in older adults with dementia is reduced level of retinal light exposure. Older adults spend much of their time in muted indoor lighting. One study found that residents in assisted living have 35 minutes/day of bright light exposure⁸ compared to approximately 58 minutes of bright light per day for middle-aged adults⁹. Reduced light exposure also may be due to physiologic changes such as senile meiosis, cataract formation, or increased light absorption by the crystalline lens^{10–12} and all of these factors may attenuate light exposure by more than 80% in normal older adults relative to young adults¹³.

Bright light therapy (BLT), which is recommended to be at least 1000 lux exposure of white (polychromatic) light to the eye, has been used as an intervention to increase light exposure of older adults and thus, improve sleep disturbances. Prior research on timed exposure to BLT has produced small-moderate results in older adults who are residents in a long-term care facility^{14, 15}, with two of the most recent studies showing that BLT increased nighttime sleep by approximately 15 minutes in nursing home patients with severe dementia¹⁶, and modestly slowed cognitive deterioration in older adults in assisted living facilities, 87% of whom were diagnosed with a dementia-related disorder¹⁷.

Along with these clinical studies, another line of research has revealed that the retinal receptors for the human visual system (rods and cones) are not the only ones used by the human circadian system. A novel photoreceptor, the intrinsically photosensitive retinal ganglion cell (ipRGC) was discovered in 2002¹⁸. Although the ipRGC receives input from rods and cones, it is now accepted that it is the primary photoreceptor for the circadian system. The overall spectral sensitivity of the circadian system peaks at shorter wavelengths of electromagnetic spectrum, typically found in blue-white light (450–480 nanometers)^{19–22}. This interaction is mathematically modeled²³ in the theory of human circadian phototransduction¹⁹. Four spectral sensitivity functions are used in the model: the scotopic luminous efficiency function, $V'(\lambda)$ ²⁴, based on rod sensitivity; $V_{10}(\lambda)$ based upon the cone fundamentals (short, medium, and long [S, M and L respectively])²⁵; the S-cone fundamental²⁶; and a standard photo-opsin emulating melanopsin contained within the intrinsically photosensitive retinal ganglion cell (ipRGC)¹⁸, which has a peak spectral response at 480 nanometers (nm) and a half-bandwidth of 95 nm. Briefly, in the model the cone fundamentals form a spectrally opponent input (blue vs. yellow²⁷) to the ipRGC which sends circadian light signals to the SCN. The modeled rod response suppresses output from the ipRGC when the blue-yellow opponent signal is positive, with diminishing suppression at higher irradiance levels as rods become more fully bleached. A negative blue-yellow opponent signal, however, produces a response determined solely by the ipRGC (no cone input and no rod suppression). The human circadian system response to light (CL_A), as measured by acute nocturnal melatonin suppression²⁸, follows a logistic function²⁹. Melatonin is a circulating hormone that is essential in regulating several biological functions including the sleep-wake cycle.³⁰ In the human circadian phototransduction model, this response function is used to transform the calculated CL_A values into circadian stimulus values (CSA). CSA is considered to be a better indicator of the effectiveness of the light stimulus for the human circadian system because it is defined in terms of the circadian system's input-output relationship, including both threshold and saturation.

The Daysimeter™: Measurement of the Human Circadian Response to Light

In order to obtain data for calculating circadian stimulus (CSA), the Daysimeter²⁰ was developed to measure circadian light-dark and activity-rest patterns. Designed to work in a clinical setting, the Daysimeter is a small and personalized photometer calibrated in terms of the spectral-spatial-intensity response of the human circadian system. Moreover, since light must be incident on the retina to be effective, the Daysimeter was designed to place the light sensors near the plane of one cornea.

The Daysimeter has been used in one previous ecological study, to assess circadian entrainment for 37 day-shift and 78 rotating-shift nurses³¹. Each nurse provided seven consecutive days of light and activity data and phasor analysis was used to quantify the level of entrainment, or conversely disruption, experienced by the nurses. Based upon examinations of a wide range of activity and light exposure profiles from the day-shift nurses, a “typical” day-shift person exhibits a delayed phasor angle of between one and two hours with a phasor magnitude between 0.5 and 0.6. “Typical” individuals tend to be consistently active throughout their waking period, but are exposed to relatively higher light levels in the early part of their activity period than toward the end. This asymmetry in relative light exposure from the early to the late part of their activity period, in fact, produces delayed phasor angles. Rotating-shift nurses, who are clearly more disrupted, had phasor magnitudes between 0.2 and 0.4.

Our program of research merges the human circadian phototransduction model with the clinically-based human response model³², which posits that humans continuously adapt to environmental stimuli (e.g., the 24-hour light-dark pattern) as indicated by biobehavioral responses (e.g., 24-hour sleep-wake pattern). The long-term goal of our program is an intervention that combines the promising results of BLT with the new knowledge of ipRGC responses, in order to test the effectiveness of a targeted, blue-white lighting intervention to improve sleep-wake cycles in older adults. The purpose of this case study, however, was to focus on a required first step: assessment of the feasibility and reliability of using the Daysimeter in a field setting and using the human circadian phototransduction model’s analyses to provide clinically relevant results. The findings from this study also provided intriguing data about the activity-rest rhythms and light exposure patterns of two people who share a living space and have closely linked 24-hour schedules.

METHODS

This descriptive 7-day case study was approved by the institution’s Human Subjects’ Review Board.

Participants

Mr. X, 80 years, and Mrs. X, 73 years, a married couple, were recruited from the clinical practice of the second author where Mr. X was diagnosed with probable vascular dementia three years previously. The couple had recently moved into an independent housing community for older adults. Neither member of the dyad reported visual problems and neither was taking sleep medications or anxiolytics. Mr. X, who was continent, needed assistance for bathing, dressing, transfer, toileting and feeding and all independent activities of daily living. His Mini Mental Status Exam, 25/30, was completed more than 3 years before the study and he resisted all repeat attempts at testing. Besides dementia syndrome, Mr. X had multiple co-morbidities including cerebrovascular accident with hemiparesis, diabetes mellitus, bilateral lens implants for cataracts, and a history of depression (in remission). Mrs. X rated her health as good and reported that she took medication for hypertension and hyperlipidemia. She provided all care for her husband.

Instruments

Sleepwatch-L®—The Sleepwatch-L is a factory calibrated actigraph from Ambulatory Monitoring Incorporated (AMI) that continuously records activity-rest data and is combined with a light sensor that records light exposure data in lux. Compared to polysomnography, wrist-worn actigraphs are valid and reliable devices, sensitive in detecting sleep (92–98%) and accurate in determining sleep efficiency ($r = 0.80$, Bonferroni $p < 0.00001$)³³. The proportional integration mode (PIM), which closely correlates with polysomnography³⁴, was used in this study to produce graphical and statistical data.

Daysimeter™—The Daysimeter is designed to be worn at eye level (attached to a headband or glasses) and employs two photosensors separately calibrated to record photopic and short-wavelength (blue) responses to optical radiation²⁰. Using data from the two photosensor channels, the model of circadian phototransduction¹⁹ is used to calculate CL_A .

Questionnaires—Mrs. X completed two questionnaires at the beginning of the study; both are used extensively in clinical and research applications with older adults and both have well documented reliability and validity data: 1) the Epworth Sleepiness Scale (ESS), a measure of daytime sleepiness with higher scores indicating more daytime sleepiness^{35, 36} and 2) the Pittsburgh Sleep Quality Index (PSQI), a measure of sleep behavior in the past month^{37, 38}. A third investigator-developed questionnaire was used in a daily interview with Mrs. X, to record the dyad's bed times, morning time out of bed, and number of times up in the night. Mrs. X also reported her number of naps and rated the quality of each night's sleep. Her husband was unable to provide reliable answers to this question and due to the low congruence between patient and surrogate subjective data³⁹, we did not ask her to evaluate the quality of her husband's sleep.

Data collection

After Mr. and Mrs. X provided written informed consent, they were instructed in the study protocol, the devices were applied, and caregiver questionnaires were completed. In a home visit on Day 3 of data collection, the first author conducted a visual assessment of the apartment's lighting and color schemes. The researchers also had daily phone contact with Mrs. X, who evaluated the acceptance and use of the devices, provided an assessment of her previous night's sleep quality, and reported sleep habits for both herself and her husband.

During the 7-day study, Mrs. X wore both devices simultaneously; Mr. X wore the Sleepwatch-L. At the initiation of the data collection period, all three devices were synchronized to identical times (to the minute). Mr. and Mrs. X were instructed to wear the waterproof Sleepwatch-L on their wrists at all times and attempt to keep the face of the 'watch' uncovered to facilitate light measurement; Mrs. X was instructed to remove the headband-mounted Daysimeter and place it nearby when bathing or sleeping. Identical times were used for all three devices at the end of the trial.

DATA ANALYSIS

Activity-rest

The caregiver's responses for "in-bed" and "out-of-bed" epochs were used to score the 7-day actigraph dataset and AMI software provided sleep estimates for nighttime sleep (number of minutes scored as sleeping), sleep latency (number of minutes until occurrence of sleep lasting 20 minute interval), wake after sleep onset (number of minutes scored as awake after sleep onset, to end of nighttime sleep), sleep efficiency (percent time scored as sleep starting with first sleep interval), and napping (number of minutes scored as sleeping while not in bed). There were no missing actigraph data for either participant.

Circadian disruption

Data from the Daysimeter were used to calculate phasor magnitude, a surrogate for circadian disruption. Phasor analysis, a technique based on signal processing techniques⁴⁰, then makes it possible to interpret the light and activity data, sampled together over consecutive multiple days, in terms of the phase and magnitude of the joint 24-hour patterns. The correlations between the periodic changes in light and in activity are first determined by calculating the circular correlation function of the light and activity time series. The circular correlation function reveals how the correlation (r , not r^2) between light and activity change as a function of the timing difference, or phase between them. The circular correlation function is then decomposed into its temporal frequencies and phase angles using Fourier analysis techniques, from which the 24-hour frequency component is selected as a measure of circadian rhythmicity. The 24-hour phasor magnitude is used as the metric for behavioral circadian entrainment/disruption; the greater the magnitude, the greater the level of behavioral circadian entrainment of activity to light. The phasor angle reflects the phase relationship between the periodic light-dark exposure pattern and the periodic activity-rest pattern in the correlations.

Data from the actigraph were used to calculate inter-daily stability (IS) and intra-daily variability (IV), two nonparametric tests used to estimate fragmentation of rest/activity rhythms⁴¹. Inter-daily stability (IS) (0.0–1.0) is an indication of the strength of the coupling between the 24-hour light-dark and rest-activity cycles, with higher scores indicating better day-to-day synchronization (i.e., over several days, a person's sleep and wake periods occur at approximately the same time during each 24 hour period). Intra-daily variability (IV) (0.0–2.0) is a measure of rest-activity fragmentation per 24 hours, with higher scores indicating more transitions between rest and activity states within the 24-hour period (i.e., a higher IV value indicates nighttime sleep is interrupted with periods of wakefulness and/or daytime wakefulness is interspersed with napping)⁴².

Caregiver perceptions of sleep

Questionnaires were scored according to standard directions with summative scores obtained for the Epworth Sleepiness Scale and the Pittsburgh Sleep Quality Index.

RESULTS

Architectural assessment

Measurements for the dyad's apartment (640 square feet) were available on a public website. The apartment had brown paneling and beige walls, standard fluorescent ceiling lighting in the bathroom and kitchen, and the usual floor and table lamps (with incandescent light sources) in the combined living room-dining room and separate bedroom. The bedroom had the only window; the living room had a double door opening to a screened-in patio. Both the window and door faced south and both had blinds and drapes.

Caregiver perception of sleep quality and rest-activity habits

At the onset of the study, Mrs. X's scored a 3 on the ESS (range 0–24), indicating that she rarely or never dozed during daytime activities such as sitting and reading or watching TV. While Mrs. X rated her sleep habits as good, her global score on the PSQI was 5, suggesting that she experienced sleep disturbances. During the 7-day trial, in daily phone calls, she reported that she did not take any daytime naps, regularly went to bed about 10 p.m., and got up once during the night to use the bathroom. In the mornings she was up and out of bed for the day between 7–8 a.m. In the daily telephone call, she evaluated her previous night's sleep quality as fair or very good with only 1 of 7 nights rated as fairly poor. She reported that Mr. X was up for the day between 8–8:30 a.m., spent most of the day in his recliner, and

that she considered him a “a good nighttime sleeper” who did not disturb her sleep even though he used the urinal once a night and she was always aware of when he was awake.

Caregiver perception of protocol and use of technology

Mrs. X reported that she did not have any problems with the protocol (daily phone call and one home visit) and neither she nor her husband had any difficulty wearing the wrist actigraphs. She also reported that she did not mind the headband-mounted Daysimeter although she also noted she did little socializing during the data collection. The Daysimeter’s position (level with her right eye) did not impede her vision or her ability to drive.

Rest-activity and ambient light exposure patterns

Figure 1 illustrates the closely aligned schedules of the husband and wife in one typical 24-hour period. Quantitative results, calculated from all seven days, are in Table 1. For each 24-hour period, actigraph data estimated that Mrs. X slept an average of 4.3 hours at night and one-half hour during the day; she required more than an hour to fall asleep and after initial sleep onset and she was awake almost two hours each night. Mr. X slept 7.4 hours at night and 1.6 hours during the day and fell asleep relatively quickly but also was awake almost two hours each night. For consistency and comparison, the dyad’s 24-hour ambient light exposure patterns were analyzed using data from the wrist-worn Sleepwatch-L. As indicated in the table, which reports all light exposure data in photopic lux, Mr. X experienced extremely limited light exposure, with most of his time calculated at >20 lux but less than 500 lux. There was no measured exposure to bright light (>1000 lux). Mrs. X’s data indicated she spent considerably more time in brighter light although she spent little time outside the apartment and consequently, most of her time (10.6 hours/24 hours) was spent in lighting of > 20 lux but less than 500 lux, and only 8 minutes/24 hours exposed to bright light.

Circadian disruption

CL_A and activity values obtained by the Daysimeter data were used to assess the level of entrainment between the caregiver’s rest-activity and the 24-hour light-dark cycle. Figure 2a shows the cyclical correlation function for the caregiver and Figure 2b shows the phasor. As seen in Figure 2a, her pattern is aperiodic and exhibits minor correlation peaks at times other than at the 24-hour phase markers. As a diurnal person, Mrs. X has the expected phasor direction to the right, seems to exhibit greater activity near the onset of CL_A (i.e., morning hours), and has a low phasor magnitude at 0.17 (Figure 2b).

Activity data from the Sleepwatch-L were also used to estimate circadian disruption through the analysis of the day-to-day consistency in activity-rest pattern (IS) and the fragmentation, or lack of sustained periods of activity, throughout the measurement period (IV). Consistent with the Daysimeter data, Mrs. X had an IS of 0.69 and an IV of 0.71 while Mr. X had an IS of 0.76 and IV of 0.95.

DISCUSSION

The findings from this study support the feasibility of community-based studies using the Daysimeter and actigraph, along with a structured protocol, to obtain reliable and valid data about older adults’ circadian responses to light. Our data indicate that the caregiver had considerably less sleep and more reported and measured fragmentation in her sleep-wake cycle than women in two previous studies (Table 1)^{34, 43}. McKibbin et al.⁴³ used one night of polysomnography in the home setting to measure sleep patterns in spousal caregivers (n=33 caregivers of spouses with moderate-severe Alzheimer’s disease; age 71 years, 67%

women) and Yaffee et al.³⁴ used PIM channel actigraphy (mean=4.1 nights) to estimate sleep disturbances in community-dwelling women (n=2201 cognitively stable, mean age=69 years). Another interesting finding from this study was the dissociation between subjective and objective measures of sleep disturbances. Although Mrs. X did not report poor sleep quality, she did report that she usually knew when her husband was awake at night and her actigraph data suggest that her nighttime sleep was fragmented. These findings must be interpreted cautiously but we suspect that Mrs. X has normalized nighttime sleep interruptions due to her husband's care requirements. These findings also reinforce the need to include multiple objective and subjective measures when conducting sleep research or clinical diagnostics.

Our quantitative analysis of circadian disruption from Daysimeter data indicate that Mrs. X had a small phasor magnitude of 0.17 (expected range=0.0–0.7). For comparison, a sample of 37 day-shift nurses had average phasor magnitude of 0.46, whereas a sample of 78 rotating-shift nurses had average phasor magnitude of 0.12⁴⁰. The caregiver phasor magnitude is about the same as a rotating shift nurse, thus demonstrating a significant level of circadian disruption. We also used a second method for calculating circadian disruption: IS (range = 0.00–1.00) and IV (range = 0.00–2.00); both are useful for comparison. Unlike the phasor analysis, these two statistics are computed solely on an individual's activity and consequently, cannot be used to assess the phase relationship between measured activity and the light-dark cycle. Nevertheless, IS and IV provide additional insight into the circadian entrainment characteristics of both the husband and wife in our study. For example, the IS values for day-shift and rotating shift were, respectively, 0.69 and 0.25. As expected, the rotating-shift nurses were significantly worse in term of day-to-day consistency in their activity-rest patterns. Interestingly, however, both groups had average IV values of about 0.50 indicating that they had sustained, uninterrupted periods of both sleep and wakefulness⁴⁰. By comparison, Van Someren et al.¹⁵ reported IS and IV values for individuals with dementia. Without light treatment, the average IS values were about 0.57, much like the dayshift nurses, but their IV values were close to 1.0, a value very different than either the day-shift or the rotating shift nurses. Thus, it would appear that the husband's data are very similar to the mean scores of Van Someren's sample in terms of rest-activity fragmentation (IV); his caregiver/wife's data, however, are similar to day-shift nurses in terms of IS, while her IV indicates that she was more fragmented than the nurses, but less fragmented than individuals with dementing illness.

As the data indicate, there were very low levels of light in the dyad's home environment and their bright light exposure (>1000 lux) was considerably less than reported in another study of older adults living at home (n=19) or in assisted living (n=19) in which daytime bright light exposure (per wrist actigraph with light sensor) was 48 (±45) minutes and 30 (±61) minutes, respectively⁴⁴. Bright light exposure for the couple was even less than 10 nursing home residents who received an average of 14.9 (±0.66) minutes of bright light over 14 days under standard lighting conditions⁴⁵. More importantly, it is the first time that circadian light exposures experienced by a caregiver of an older adult with dementia were measured for seven consecutive days and these ecological data were used to quantify circadian disruption.

The limitations of this case study include the lack of a physiologic indicator, e.g., melatonin, to concurrently assess sleep-wake circadian rhythm, the lack of Daysimeter data for the older adult with dementia and no assessment of his sleep quality, and the single measurement period in November, which does not allow for seasonal comparison. Although the caregiver reported that she and her husband followed the protocol, the possibility also exists that lower levels of light exposure were recorded due to clothing covering the wrist-worn Sleepwatch-L.

Conclusion

This case study provides beginning support for the use of the Daysimeter in the home setting while also highlighting unrecognized circadian disturbances and very low light levels in an older couple's home. The findings, which showed that the caregiver-wife had less night-time sleep and more recorded disturbances than her husband, are not surprising. Targeted light therapy for both the caregiver and the older adult with dementia is an unexplored avenue for treatment of behavioral and circadian disorders in the home setting. Advances in our understanding of human responses to the light-dark cycle offer intriguing possibilities for pursuing lighting intervention research to improve sleep and quality of life in older adults. Effectiveness research is needed that uses multiple settings, larger samples, and protocols in which both caregivers and persons with dementia receive targeted light therapy while wearing the Daysimeter.

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1a. Caregiver wife

1b. Husband

Figure 1. Caregiver (1a) and husband (1b), one 24-hour period, 12 noon to 12 noon. Single line indicates ambient light exposure at wrist; black is activity level. The horizontal axis is scored, indicating sleep.

Figure 2.
Level of entrainment between caregiver's rest-activity and the 24-hour light-dark cycle per Daysimeter.

Table 1

Sleep and Light Data Comparisons

Sleep and light measurement	Demented husband [80 yrs old]	Caregiver wife [73 years old]	McKibbin et al (43) Caregivers [n=23, 71 yrs, mod-severe dementia caregivers]	Yaffe et al (34) Older women [n=2201 cognitively stable, mean age=69 yrs]
Sleep			Mean (SD)	Mean (SD)
- Mean sleep-rest/24 hours (percent)	38	22	***	***
- Mean nighttime sleep (minutes)	446	257	346.3 (56.4)	408.0 (78.0)
- Mean sleep latency (minutes)	17	81	24.7 (43.6)	38.6 (37.3)
- Mean wake after sleep onset (WASO, in minutes)	105	119	106.6 (38.9)	74.5 (47.1)
- Mean sleep efficiency (percent)	81	70	80.0 (10.0)	78.2 (11.5)
- Mean napping/24 hours (minutes)	96	31	***	74.4 (62.9)
Pittsburgh Sleep Quality Index	***	5	2.2 (5.4)	***
Daily light exposure during time out of bed, per Sleepwatch-L (lux)			***	***
- Mean minutes				
>20 lux	192	636		
>500 lux	0	18		
>1000 lux	0	8		