Determinants of sleep quality in the healthy aged: the role of physical, psychological, circadian and naturalistic light variables

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Abstract

Ageing is associated with a decrease in the quality of night-time sleep with 30% of aged persons experiencing chronic insomnia. Treatment of insomnia typically involves the use of hypnotic medications and these have been associated with a range of negative outcomes in this population cohort. The development of age-related insomnia has been linked, in part, to changes in the strength of the circadian regulation of sleep, these changes typically leading to increased fragmentation of the sleep—wake cycle. Management of insomnia may therefore be linked to strengthening of these regulatory control mechanisms. Previous research has indicated that both daily activity levels and ambient light exposure may act as zeitgebers to consolidate sleep-wakefulness cycles. The current study utilised a naturalistic design to explore the relationship between light, activity and
night-time sleep quality amongst a sample of 33 healthy aged subjects. Findings demonstrated a significant positive relationship between activity and sleep quality. Ambient light was also shown to have a significant impact on night-time sleep though the study identified a critical exposure threshold of 3000 lux. Factor analysis demonstrated the independent contribution of these two variables to subsequent sleep quality. The findings of the current study identify the potential for the development of non-pharmacological treatment strategies for insomnia in aged people.

**Keywords:** ageing, sleep, naturalistic light, circadian rhythms, elderly

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**Introduction**

Insomnia is a sleep disorder of substantive significance to aged populations. The National Institute of Ageing in a study of more than 9,000 community dwelling adults aged over 65 years highlighted the prevalence of insomnia in this cohort with 28% of respondents reporting difficulty falling asleep and 42% reporting difficulty both falling asleep and maintaining sleep [1]. The implications of this decreased sleep quality in ageing are wide ranging and significant, including increased daytime sleepiness and napping [2], a decreased sense of well-being and cognitive functioning [3], increased risk of accidents [4] and potentially increased morbidity and mortality rates [5]. Furthermore, the treatment of insomnia in ageing typically involves the prescription of hypnotic medications and a range of negative outcomes is ascribed to hypnotic use amongst elderly persons [6–9]. The medical burden of disease associated with the experience and treatment of insomnia for aged persons is therefore substantial. In addition the illness carries a significant economic burden with total direct costs for insomnia in the United States in 1995 estimated to be $13.9 billion [10].

A range of aetiological factors has been linked with the onset of insomnia in ageing. Sleep disorders, such as sleep apnoea and restless leg syndrome [11], medical and psychiatric illnesses, including depression and anxiety [12], medication use [13] and the psychosocial experiences of isolation and grief [14] have all been identified as potential causes of insomnia in this population. Separate to these medical and social issues biological factors associated with ageing, specifically age-related changes to the circadian regulation of sleep, have been proposed as causative factors.

The daily cycle of sleep and wakefulness is maintained as a circadian rhythm by the interaction of an endogenous pacemaker with a range of exogenous temporal cues termed zeitgebers. These zeitgebers entrain the free running rhythms of the pacemaker to a 24-hour cycle. The most significant zeitgeber is the daily cycle of light and darkness but other factors such as physical activity, the timing of meals and social interactions have also been shown to be important regulators of endogenous rhythms [15]. The patency of a rhythm such as sleep/wakefulness is therefore dependent on the integrity of the endogenous pacemaker coupled to the strength of entrainment to zeitgebers.

Ageing is associated with key changes to both the endogenous and exogenous circadian control of sleep and wakefulness. The most important of these endogenous changes is a significant decrease in circadian amplitude. In addition ageing is associated with changes to the circadian timing of sleep, specifically the phase relationship between core body temperature (CBT) and sleep–wake rhythms. A phase advance of the temperature rhythm in ageing results in the temperature nadir falling at the midpoint of the sleep period and the second half of sleep for aged persons is therefore occurring against a rising temperature rhythm with its associated drive to wakefulness [16]. Older people therefore wake at an earlier clock time and at an earlier circadian phase and experience more difficulty sleeping after the CBT nadir. These age-related endogenous changes to both the intensity of the sleep–wake drive, and the synchronisation of CBT and sleep/wake rhythms, potentially account for the high prevalence of sleep maintenance insomnia symptoms such as nocturnal arousals and early morning awakenings, amongst older people.

In addition to these changes to the endogenous control mechanisms ageing is associated with decreased efficacy of exogenous zeitgeber cues, particularly light and darkness. Ageing may impact on the efficacy of the light–dark signal as a consequence of both age-related reductions in retinal sensitivity to light and lifestyle based reductions in the duration of exposure to bright light. A study of independent elderly identified that they received on average only 1 hour of natural light each day [17]. This may decrease to less than 10 minutes a day for institutionalised elderly [18].

As light synchronises rhythms and increases body temperature amplitude the combination of decreased light exposure and decreased sensitivity in older people may result in decreased efficiency of circadian rhythms.

Given that age-related changes in sleep quality may be linked to the decreased strength of the circadian regulation of sleep then increases to the patency of this circadian mechanism should result in increased efficacy of night-time sleep. Research has explored this potential for external factors, particularly light, to strengthen circadian regulatory mechanisms and therefore enhance night-time sleep efficiency amongst aged persons. The capacity of ocular bright light exposure to strengthen and/or phase shift the circadian timing system amongst older populations has been well demonstrated [19, 20] with several studies reporting associated increases in the quality of subsequent night-time sleep [18, 21, 22]. Subjective estimates of increased sleep quality, independent of circadian phase shifts, have also been reported consequent to moderate bright light exposure amongst a sample of healthy community dwelling elderly [23]. Estimates of the relationship between naturalistic light exposure across a 24 hour period and subsequent nocturnal sleep indices further demonstrates a correlation between 24 hour illumination and shorter sleep latencies and reduced...
wake within sleep measures [24]. In contrast, however, several studies have reported that despite strengthened indices of circadian regulatory mechanisms following bright light exposure there were no substantive changes in the quality of subjects’ subsequent night-time sleep [20, 25].

In part such differences in study findings may well reflect the diversity of methodological approaches to the field. Studies differ significantly in relation to (i) light parameters, e.g. illumination levels, duration of exposure and the timing of the light manipulation, (ii) subject characteristics, e.g. community dwelling, hospital residents and nursing home care (demented and non demented), and (iii) outcome variables, e.g. actigraphy, polysomnography (PSG), subjective measures and observer ratings. The lack of rigour within and between methodologies or ‘trial evidence’ has led reviewers in the field to conclude that no substantive evidence base currently exists to support the promotion of bright light treatment for insomnia in aged persons [26]. Despite these methodological confounds the need for continued rigorous research in the field remains theoretically sound.

Study aims
This study aimed to explore the relationship between night-time sleep quality and a range of circadian, physical and psychological factors in a sample of healthy aged subjects. Of particular interest was the relative potential of these factors to act as predictors of sleep quality in this cohort.

Method
Thirty-three subjects (11 male and 22 female) participated in this study. Subjects were recruited from the general population and ranged in age from 65–85 years (mean = 74.18). Inclusion criteria included (i) aged over 65 years, (ii) in good general health, living independently and physically mobile, (iii) able to read, write and speak English, (iv) suffered no conditions known to disturb sleep (e.g. sleep apnoea, chronic pain), (v) not depressed – as measured on the Geriatric Depression Scale (GDS), (vi) no symptoms of cognitive dysfunction – as measure on the Mini Mental State (MMS) and, (vii) not taking medications known to disturb sleep.

Following selection subjects were required to complete a range of questionnaires to provide measures of physical and psychological health. These measures were: (i) the Eysenck Personality Questionnaire Inventory (EPI), (ii) the Profile of Mood States (POMS), (iii) the General Health Questionnaire (GHQ), and, (iv) the Medical Outcomes Survey Short Form (SF36). Subjective measures of sleep quality were obtained using the Morningness Evennessness Scale and the Pittsburg Subjective Sleep Quality Index (PSQI). The range of subjects’ global scores on the PSQI was 0–16 with 15 of the subjects scoring above the insomnia criterion.

Following this testing protocol subjects were required to wear a Mini Mitter 2000 Data Logger to collect information on daily activity and light exposure. The data logger was worn on a waistband with a remote activity sensor on the wrist of the non-dominant hand. Movement detected at the waist and wrist levels was recorded in 16 second bins. The measures of motor activity were calculated as defined by the literature, i.e. (i) Activity, (ii) Movement, (iii) Immobility, (iv) Extended Immobility and, (v) Fragmentation index [27]. Each diurnal period was selected using sleep diary data from ‘time finally woke’ to time ‘tried to go to sleep’ for the main night sleep. The activity data were computed using software specifically designed for this study.

Ambient light was measured by a light meter worn on the lapel of the participants’ jacket at chest height. Light exposure data were recorded in minutes as a function of intensity via the Mini-Mitter 2000 Data Logger and analysed to yield minutes of exposure as a function of intensity. Three light thresholds were then used in the subsequent data analysis – i.e. total minutes above 500 lux; 3,000 lux and 10,000 lux. Selection of threshold limits was based on the literature where exposures in the range of 1,000 have been described as moderately bright light [23]; 2500–3000 as bright light [28, 29] and 10,000 as very bright light [26].

Participants were requested to wear the Mini-Loggers for three consecutive 24 hour periods with data collected from the evening of day one to the morning of night four. Across this testing period the research assistant maintained phone contact with participants to ensure compliance and to remind participants to complete sleep diaries and the Social Rhythm Metric questionnaire.

A full overview of all instruments and their role in this study is provided on the journal’s website (please see Appendix 1 available at http://www.ageing.oupjournals.org).

Data analysis
The first issue was to consider possible relationships between the measures of sleep quality with a view to determining whether grouping them would provide a stronger predictive variable than consideration of each alone. Thus correlations were determined between:

- Diary Sleep Efficiency averaged over three nights
- PSQI component variables and Global PSQI
- The five nocturnal actigraphic variables.

A new, grouped ‘Sleep Quality’ variable, or the individual sleep quality variables would then be submitted to linear regression analyses as dependent variables to determine which of the independent variables measured in the study provided the best predictor(s) of sleep quality.

Results
Correlations among sleep variables
The correlation matrix between the two subjective sleep quality groups of variables (PSQI and Diary Sleep Efficiency) and the five nocturnal actigraphy measures are shown in Table 1. Not surprisingly intra-correlations for variables within each of the PSQI grouping and the actigraphy grouping were high.

However, there was only one moderate correlation between the objective and subjective measures; a correlation
of $r = -0.445$ ($P = 0.012$) between the actigraphic mean of Nocturnal Immobility and the PSQI Habitual Sleep Efficiency.

Diary Sleep Efficiency was not correlated to any actigraphic variable and showed only a single moderate correlation with one of the PSQI variables ($r = -0.417$, $P = 0.018$ between diary sleep efficiency and PSQI Subjective Sleep Quality).

Given the lack of relationships between these three sleep quality variable groups, it was decided to explore the relationship of each with the independent variables in the study, via separate linear regressions (rather than grouping them and generating a model).

### Linear regression

A series of multiple linear regressions (stepwise) were undertaken, one with each of the three measures of sleep quality. For each analysis the residuals were checked for normality and found to be satisfactory.

(i) PSQI Global. Using this subjective sleep measure as the dependent variable all the other variables were entered as independent variables. Only one variable, ‘role emotional’ entered the model and this accounted for only 17.6% of the variance in the PSQI variable.

(ii) Diary Sleep Efficiency. Using a similar procedure to the previous analysis, with Diary Sleep Efficiency as the dependent variable, only one variable, ‘general mental health’ entered the model and this accounted for only 10.7% of the variance.

(iii) Nocturnal Immobility. From the range of actigraphy variables the measure nocturnal immobility was selected as the dependent variable. Nocturnal immobility is defined as the summation of the number of 16 second epochs across the night during which a zero mobility score has been recorded. This total score is then converted to minutes of immobility. This outcome measure of nocturnal immobility has been demonstrated previously to have significant relationships with other sleep indices and to provide a reliable indicator of sleep consolidation [27]. Using this objective actigraphy variable as the dependent variable, four variables entered the model with Adjusted R2 values as shown below.

- Daytime extended immobility: 0.211
- Daytime movement average: 0.446
- Minutes light >3000 lux: 0.519
- Bodily pain: 0.575

These four variables together accounted for 57.5% of the total variation (using the adjusted R2) in the Nocturnal Immobility data. The first three of these four variables are measured objectively.

The relevant coefficients are shown in Table 2. Pearson correlations were conducted between Nocturnal Immobility and the variables shown in Table 2 and these indicated the direction of the relationships found. Quieter nocturnal sleep was associated with less daytime immobility, more daytime movement, more minutes of light over 3000 lux and less report of bodily pain.

### Factor analysis

As each of the independent variables in the model is likely to be closely related to a series of other variables, possible relationships within the independent variables were explored using a factor analysis (using a Varimax rotation method with Kaiser normalisation). Four factors were yielded. The results are shown in Table 3.

The high factor loadings within each of the differentiated factors shown in Table 3, examined together with the results of the linear regression indicate that the variables in the first three factors are all important in determining sleep quality (objectively measured). One factor clearly showed a

### Table 1. Pearson correlation coefficients between subjective nocturnal sleep quality measures (PSQI and Sleep Diary Sleep Efficiency) and objective nocturnal actigraphy variables ($n = 33$)

<table>
<thead>
<tr>
<th></th>
<th>PSQI subjective sleep quality</th>
<th>PSQI sleep latency</th>
<th>PSQI sleep duration</th>
<th>PSQI habitual sleep efficiency</th>
<th>PSQI sleep disturbance</th>
<th>PSQI sleeping medication</th>
<th>PSQI daytime dysfunction</th>
<th>PSQI global score</th>
</tr>
</thead>
<tbody>
<tr>
<td>N Activity</td>
<td>0.038</td>
<td>-0.006</td>
<td>0.006</td>
<td>0.035</td>
<td>0.249</td>
<td>-0.060</td>
<td>-0.117</td>
<td>0.036</td>
</tr>
<tr>
<td>N Movement</td>
<td>0.066</td>
<td>0.028</td>
<td>0.117</td>
<td>0.219</td>
<td>-0.061</td>
<td>-0.064</td>
<td>0.103</td>
<td></td>
</tr>
<tr>
<td>N Immobility</td>
<td>-0.264</td>
<td>-0.279</td>
<td>-0.445*</td>
<td>-0.249</td>
<td>0.102</td>
<td>0.050</td>
<td>-0.371*</td>
<td></td>
</tr>
<tr>
<td>N Extended immobility</td>
<td>-0.203</td>
<td>-0.306</td>
<td>-0.331</td>
<td>0.033</td>
<td>0.053</td>
<td>0.256</td>
<td>-0.242</td>
<td></td>
</tr>
<tr>
<td>N Fragmentation index</td>
<td>-0.033</td>
<td>-0.047</td>
<td>-0.094</td>
<td>-0.170</td>
<td>-0.014</td>
<td>-0.061</td>
<td>-0.129</td>
<td></td>
</tr>
<tr>
<td>Diary sleep efficiency</td>
<td>-0.417*</td>
<td>-0.136</td>
<td>-0.239</td>
<td>-0.283</td>
<td>-0.123</td>
<td>-0.017</td>
<td>-0.336</td>
<td></td>
</tr>
</tbody>
</table>

*$P < 0.05$.

N = Nocturnal.
clustering of variables of **diurnal activity**, another of **somatic factors and social functioning** and a third factor described minutes of **ambient light** measured at particular lux thresholds.

**Discussion**

The first finding of the current study related to the lack of correlation between the subjective (PSQI and Diary Sleep Efficiency) and objective (actigraphy) measures of sleep quality. Even across the two subjective measures of nocturnal sleep quality no significant relationship was identified. This lack of convergence between alternate measures of sleep quality generally pervades and confounds sleep research. While PSG recordings may be seen as the benchmark for sleep research the technique requires substantive resources and is not recommended for routine use in the evaluation of insomnia [30]. Utilization of PSG recordings is also methodologically difficult when working with aged cohorts. Actigraphy although reported to be a useful measure of global sleep indices such as sleep–wake consolidation [31], sleep efficiency and total sleep time [32] has been shown to have low predictive validity in relation to PSG measures [31]. Inconsistencies are further evident in correlations between actigraphic indices and subjective sleep log data [33]. These difficulties pervade not only research methodologies but the clinical practice of assessment of insomnia amongst aged persons.

Because of the clear lack of association between the dependent measures of sleep the current study did not amalgamate these variables as anticipated into a global sleep measure but rather explored their separate relationships with the independent variables. The most significant finding of this analysis was the strong predictive relationship between the objective sleep measure nocturnal immobility and the independent variables of daytime activity (measured as both extended immobility and daytime movement average), duration of exposure to light (at a critical intensity of >3000 lux) and reports of somatic pain.

The finding in the current study of the relationship between increased daily activity and improved nocturnal sleep quality amongst aged cohorts is complementary to previous research [34–36]. This previous research has, however, explored this relationship as a function of the effects of the implementation of an exercise program on subsequent sleep quality rather than the naturalistic design of the current work. The association between baseline activity and nocturnal immobility (sleep quality) is theoretically predicted to be mediated by the potential impact of activity on the patency of the circadian regulation of sleep [35]. This effect may be attributable to the capacity for physical activity to directly impact on circadian patency or potentially activity operates as a zeitgeber in moderating the temporal organisation of sleep/wakefulness. Alternatively it has been proposed that low intensity activity amongst aged people may not directly impact on circadian regulatory mechanisms but may improve sleep quality by altering the architecture of sleep with specific increases in slow wave sleep [37].

The second factor to emerge in the current study as a significant predictor of objective sleep quality was exposure to naturalistic light. Specifically the study identified 3000+ lux of exposure as the critical limit associated with improved sleep quality. In a recent population study of sleep quality, light exposure and activity patterns, the average daily light exposure of a sample of 273 American adults (aged 40–64) was 554 lux [38]. Elderly subjects have been estimated to have far lower than ‘average’ naturalistic light exposure with nursing home patients exposed to a daily median of approximately 54 lux [18]. The critical limit of 3000+ lux identified in the current study is therefore substantially greater than this average illumination even for non-elderly subjects. There has been substantial research investigating the impact of bright light therapy on insomnia [26]. Such therapeutic interventions involve subjects sitting in front of light boxes for periods of around 2 hours a day and being exposed to fluorescent emissions in the order of 10,000 lux. The current study suggests that positive effects on sleep quality for aged subjects may be achieved by substantive increases in naturalistic light exposure.

The potential interrelationship between the variables of light and activity and the dependent variable of sleep quality has not been clearly defined. Experimental manipulations of exercise may well involve spurious changes to light levels.

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**Table 3**. Result of factor analyses of all independent variables used in the linear regression where Nocturnal Immobility was the dependent variable. Only variables with a factor loading > ±0.6 were included

<table>
<thead>
<tr>
<th>Diurnal activity factor</th>
<th>Somatic/social factor</th>
<th>Naturalistic light factor</th>
<th>Psychological factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>D Movement</td>
<td>Bodily pain</td>
<td>Min light &gt;3000 lux</td>
<td>General Health Questionnaire</td>
</tr>
<tr>
<td>0.960</td>
<td>0.865</td>
<td>0.899</td>
<td>~0.901</td>
</tr>
<tr>
<td>D Immobility</td>
<td>Social functioning</td>
<td>Min light &gt;10,000 lux</td>
<td>Mental health</td>
</tr>
<tr>
<td>−0.926</td>
<td>−0.732</td>
<td>0.882</td>
<td>0.845</td>
</tr>
<tr>
<td>D Fragmentation</td>
<td>General health</td>
<td>Min light &gt;500 lux</td>
<td>POMS total</td>
</tr>
<tr>
<td>−0.924</td>
<td>0.648</td>
<td>0.740</td>
<td>~0.837</td>
</tr>
<tr>
<td>D Ext Immobility</td>
<td>Physical functioning</td>
<td></td>
<td>Mood scale</td>
</tr>
<tr>
<td>−0.871</td>
<td>0.643</td>
<td></td>
<td>~0.806</td>
</tr>
<tr>
<td>D Activity</td>
<td></td>
<td></td>
<td>Vitality</td>
</tr>
<tr>
<td>0.830</td>
<td></td>
<td></td>
<td>0.763</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>EPI Neuroticism</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>~0.725</td>
</tr>
</tbody>
</table>

Variables in bold type entered the linear regression.

D = Diurnal. Min = Minutes.
and conversely increasing light exposure by encouragement to spend increased time out of doors may well lead to the confound of increased activity levels. Apart from these experimental difficulties of isolating the independent effects of light and activity on nocturnal sleep, animal studies have identified the potential complex interrelationship between the variables. Depending on the temporal relationship between light exposure and activity the variables may act in synergy or as antagonists in the phase shifting of circadian rhythms [28]. Factor analysis of all independent variables in the current study identified, however, that light and activity remain independent determinants of nocturnal sleep quality. A third factor also emerged as significant in the current study; this factor, labelled somatic and social functioning, is well aligned with current research which acknowledges the impact of both physical and psychological health on sleep quality for aged people [12, 14].

The current study has identified that a relationship exists between natural light and nocturnal sleep quality. It is, however, important to note that the correlational nature of the data does not allow for directionality to be assumed, hence this work cannot determine whether light enhances sleep quality or enhanced sleep quality predisposes the elderly to a lifestyle that is associated with increased exposure to naturalistic light. Experimental manipulations of naturalistic light would be necessary to determine this causality. Despite this limitation the current research highlights the potential for the exploration and the development of a lifestyle-based intervention targeted at establishing a naturalistic alternative to the use of hypnotic medications in the management of insomnia amongst aged people.

**Key points**

- A positive relationship exists between daytime activity and nocturnal sleep quality amongst aged persons.
- Exposure to naturalistic light at a level of 3000+ lux is associated with improved nocturnal sleep amongst aged persons.
- Aspects of physical and psychological health impact on the quality of nocturnal sleep for aged persons.

**Acknowledgement**

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Dignity in old age: what do older people in the United Kingdom think?

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Abstract

Background: dignity is a complex concept and there is little empirical research to show how older people view dignity. This study, using qualitative methods, explored the concept of dignity from the older person’s perspective.

Methods: 15 focus groups and two individual interviews were conducted in 12 different settings, with a total of 72 participants. Participants were purposively sampled to ensure a mix of socio-economic status, ethnicity, gender, age (65+) and level of fitness. Focus groups were audio-taped and transcribed. The method of constant comparison was used to analyse the data.

Results: there was strong evidence to suggest that dignity was salient to the concerns of older people. Dignity was seen as a multi-faceted concept: (i) dignity of identity (self-respect/esteem, integrity, trust); (ii) human rights (equality, choice); and (iii) autonomy (independence, control). Examples of dignity being jeopardised rather than being enhanced were given. A loss of self-esteem arose from being patronised, excluded from decision-making, and being treated as an ‘object’. Lack of integrity