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## Association of morning illumination and window covering with mood and sleep among post-menopausal women

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### Abstract

The antidepressant and sleep-promoting effects of light exposure might be useful for treating age-related mood and sleep disorders. In view of recent evidence suggesting beneficial effects of morning light, this study examined the associations of mood and sleep with morning light exposure, 24 h environmental illumination, and the degree to which the volunteers' bedroom windows were covered in the morning. We examined 459 postmenopausal women participating in an ancillary study of the Women's Health Initiative conducted at the University of California, San Diego Clinical Center, San Diego, CA, USA. At baseline, volunteers completed a 4-week sleep-recall questionnaire. Volunteers were then assessed for 5–7 days in their home environments with actigraphic wrist monitors. During home recording, self-reported mood was assessed. Morning illumination during the first 4 h after arising, 24-h illumination mesor (cosine-fitted mean), and illumination acrophase (cosine-fitted peak time) were calculated. Sleep was scored each night using validated wrist actigraphic methods. A sleep diary was completed each morning. During two 24-h periods, urine was collected approximately every 2 h during wakefulness and following any voidings during the sleep period. Cosine-fitting established the acrophase of urinary 6-sulfatoxymelatonin (aMT6s) excretion. Morning illumination and 24-h illumination were modestly associated with better mood and sleep. Associations of light with mood and sleep were consistently greater for subjects whose body clocks were delayed relative to the group median. Less morning window covering in the subjects' bedrooms was associated with more morning light and less depressed mood. The results suggest that both morning and 24-h light exposure may be beneficial for older adults.

### Keywords

Actigraphy; bright light; Circadian phase; older adults

## INTRODUCTION

Higher levels of environmental illumination have been associated with better sleep and mood.<sup>1–3</sup> Moreover, experimental increases in light exposure can elicit profound sleep-promoting<sup>4</sup> and antidepressant effects.<sup>5,6</sup>

Several studies have suggested that antidepressant effects of bright light are greatest in the morning, especially for seasonal affective disorder.<sup>7–11</sup> Also, there is intriguing evidence of antidepressant effects following simulated dawn light exposure.<sup>12–14</sup> Indeed, a recent study found significantly greater antidepressant effects following relatively low-intensity dawn simulation during sleep (maximum intensity 250 lux) compared with morning bright light treatment (10 000 lux).<sup>14</sup> In older individuals, morning bright light can also promote night-time sleep,<sup>15,16</sup> though equally robust effects have been observed following afternoon or evening light.<sup>4</sup>

The mechanistic explanation for a therapeutic advantage of morning light has not been clearly established. Some evidence indicates that antidepressant effects of morning light are correlated with its circadian phase-advancing effects.<sup>17</sup> A phase-shifting mechanism might be especially important for older adults (particularly older women), who might have a higher prevalence of circadian malsynchronization and sleep and mood morbidities than young adults.<sup>18</sup> If morning light promotes sleep and mood via a phase-advancing mechanism, then it can be predicted that these effects would be greater in people who have relatively delayed body clock timing.

A phase-advancing mechanism might also explain the therapeutic effects of dawn light exposure. In animals, the suprachiasmatic nucleus (SCN) is apparently more responsive to light stimuli during sleep,<sup>19</sup> which might make dawn light relatively important compared to light later in the day. One potential practical implication of these data is that having unobscured bedroom windows in the morning might be preferable to having darkly covered windows.<sup>20</sup>

Another potential advantage of morning light might be a greater biological sensitivity to light following night-time darkness. Retinal sensitivity to light is greater in the morning than at other times.<sup>21</sup> Moreover, alerting or ‘energizing’ effects of bright light<sup>22,23</sup> might be greatest in the morning. Since studies in urban environments have consistently shown that adults are generally exposed to lower levels of illumination over 24 h than might be expected,<sup>1,24</sup> exposure to the dawn signal and morning illumination may play an important role in normal regulation of mood, sleep, and circadian timing.

Apart from our preliminary work,<sup>25</sup> we are unaware of any studies that have specifically examined exposure to morning illumination in the home environment. Therefore, the aims of this study were to compare the associations of morning illumination *versus* 24-h illumination with mood and sleep in postmenopausal women. The degree of covering of the subjects’ bedroom windows during the morning was considered a proxy for dawn exposure, and was examined in relation to illumination, sleep, and mood. The assessments were made during a 3.5-year period with an equivalent number of volunteers assessed during the Spring, Summer, Fall, and Winter.

## METHODS

### Subjects

We examined 459 postmenopausal women ages 50–81 years ( $67.7 \pm 0.4$  SE years). The volunteers were recruited by writing to and calling women who had already entered the observational study of Women's Health Initiative (WHI), a large multicenter study that includes clinical trials and observational studies of an ethnically representative sample. The exclusion criteria for the study have been reported elsewhere.<sup>26</sup> All volunteers were women living independently in San Diego, CA, USA. No exclusions based on medication or sleep disorders were made. All volunteers signed informed consent approved by the University of California Institutional Review Board. Other data from these subjects have been reported elsewhere.<sup>27–29</sup>

### Retrospective sleep assessment

Prior to home recording, volunteers completed a 4-week recall questionnaire of sleep habits, which included Likert-scale assessments (Table 1) of the frequency of (i) trouble falling asleep; (ii) waking up often during the night; (iii) awakening earlier than planned; (iv) daytime napping; (v) the sleep quality; and (vi) total sleep time on a 'typical' night.<sup>30</sup>

### Home assessment

Following the volunteers' consent to participate and completion of the 4-week recall sleep questionnaire, laboratory staff went to the volunteers' homes to instruct the volunteers regarding the remainder of the study.

### Window covering

During home visits, research staff categorized the degree to which the subjects' bedroom windows were covered at morning wake times. Virtually all of the subjects slept in bedrooms with windows. The categorization comprised three levels: (i) uncovered ( $n = 64$ ); (ii) light shades or drapes ( $n = 193$ ); and (iii) completely blacked out or heavy shades or drapes ( $n = 173$ ).

**Actillum recording**—Volunteers were then monitored for 5–7 consecutive days in their usual environments. Volunteers were asked to maintain their usual sleep–wake schedules. Throughout recording, volunteers wore Actillum wrist monitors (Ambulatory Monitoring, Ardsley, NY, USA). Each minute, the Actillum recorded illumination exposure via a photometer and wrist activity via a linear accelerometer. The photometer was sensitive to light levels ranging from 0.1 lux (almost complete darkness) to over 100 000 lux (bright outdoor illumination). Actillum photometers were calibrated at regular intervals against external photometers (traceable to the US National Institute of Standards and Technology). Brief intervals in which the Actillum was removed for bathing etc. were deleted from the analyses.

**Actillum illumination metrics:** Three illumination metrics were established: (i) the log of the mesor (mean of the 24-h cosine-fitted lux measures); (ii) the log of the mean illumination during the first 4 h after awakening (AM-LIGHT); and (iii) illumination

acrophase (peak time of 24-h fitted cosine). These values were averaged across all days of recording. Mean illumination during the last 2 h before awakening was also assessed, but it appeared that the low values that were observed ( $1.5 \pm 0.2$  lux) were largely confounded by bed-clothes covering the Actillumes, so these data were not further considered.

**Actillum and diary sleep metrics:** For each night during the recording week, sleep and wakefulness were estimated via an established algorithm associating wrist movement with electroencephalographically assessed sleep.<sup>31</sup> Bedtimes and wake-times were estimated each day using Actillum activity and illumination data combined with sleep diary data. The Actillum-assessed in-bed sleep variables selected for this study were: (i) sleep latency; (ii) total sleep time; (iii) wakefulness after sleep onset; and (iv) sleep efficiency (i.e. hours of sleep/time-in-bed). These were averaged across all available nights of recording. A daily sleep diary also recorded subjective estimates of: (i) sleep latency; (ii) total sleep time; and (iii) total duration of napping, which were averaged for the week.

**Circadian phase assessment**—During two 24-h periods (usually days 3 and 6 of the sleep recordings), urine was collected approximately every 2 h during wakefulness and following any nocturnal voidings. Volunteers recorded the timing and volume of each voiding, and froze samples (2 cc) in duplicate. Following completion of recording, the samples were transferred to a laboratory  $-70^{\circ}\text{C}$  freezer. Urinary concentrations of 6-sulfatoxymelatonin (aMT6s), the primary metabolite of melatonin, was established using an ELISA assay. Cosine-fitting of excretion rate (ng/h) estimated the acrophase (peak time) of excretion.

**Mood assessment**—During the week of recording, subjects completed the CESD-6,<sup>32</sup> a 6-item subset of the 20-item Center for Epidemiologic Studies depression inventory containing the following items:

1. You felt depressed.
2. Your sleep was restless.
3. You enjoyed life (scored with reverse scale).
4. You had crying spells.
5. You felt sad.
6. You felt that people disliked you.

The items were answered on a 4-point Likert scale indicating the frequency of symptoms during the previous week (rarely or none, 1–2 days, 3–4 days, or 5–7 days), and each item was scored from 0 (rarely or none) to 3 (5–7 days). A CESD-6 composite score was calculated by averaging the scores on the individual items.

## Data analysis

Variables that were not normally distributed were log-transformed prior to correlational and regression analyses.

### **Association of illumination with depressed mood, sleep, and aMT6s**

**acrophase**—The associations of AM-LIGHT, illumination mesor, and illumination acrophase with CESD-6, sleep, and aMT6s acrophase were assessed with Pearson product-moment correlations. The associations of illumination with depressed mood and sleep were further compared between volunteers whose aMT6s acrophases were delayed *versus* advanced relative to the median aMT6s acrophase. To make these comparisons, the magnitude of the correlations were compared.<sup>33</sup> The phase-angle between the aMT6s acrophase and wake-time was also compared between advanced *versus* delayed groups because this phase-angle influences sensitivity to morning light.

### **Association of window covering with depressed mood, sleep, and aMT6**

**acrophase**—The association of window covering (3 levels) with AM-LIGHT, illumination mesor, illumination acrophase, CESD-6, sleep, and aMT6s acrophase, was assessed via Kruskal–Wallis non-parametric tests. As with the analyses of illumination, the analyses of window covering further compared volunteers who were phase-delayed *versus* phase-advanced relative to the median aMT6s acrophase.

## **RESULTS**

### **Morning illumination, 24-h illumination, and illumination acrophase**

The mean ( $\pm$  SE) AM-LIGHT was  $999 \pm 66$  lux (median = 653 lux). Twenty-four hour illumination mesor was  $614 \pm 52$  lux (median = 411 lux). The mean illumination acrophase was  $13 : 47 \pm 0 : 03$  (median =  $13 : 45$ ). AM-LIGHT and the illumination mesor were significantly correlated ( $r = 0.48$ ,  $P < 0.001$ ), however, neither was significantly correlated with the illumination acrophase.

### **Self-reported mood**

Depressed mood assessed with the CESD-6 was  $1.88 \pm 0.11$  (median = 1.00).

### **Sleep**

Sleep data are displayed in Tables 2 and 3. In the 4-week recall questionnaire (Table 2), volunteers indicated average duration of sleep, average quality of sleep and only moderate complaints regarding trouble falling asleep, awakening often during the night, awakening earlier than planned, or daytime napping. Actigraphic and sleep diary-assessments of sleep also suggest roughly ‘average’ sleep.

### **aMT6s acrophase, phase-delayed and phase advanced volunteers**

The mean aMT6s acrophase was  $03:47 \text{ h} \pm 6 \text{ min}$ . Data comparing subjects whose aMT6s acrophases were earlier than the median aMT6s acrophase (i.e. earlier than 3:38, the advanced group) or later than the median acrophase (the delayed group) are displayed in Table 4.

### **Association of aMT6s acrophase with aMT6s acrophase-to-wake time phase-angle**

The correlation of aMT6s acrophase with phase-angle between the aMT6 acrophase and wake time was 0.82 ( $P < 0.001$ ) (Fig. 1). This phase-angle was significantly longer in the

phase-advanced group ( $4.04 \pm 0.09$  h) *versus* the phase-delayed group ( $2.23 \pm 0.12$  h) ( $P < 0.001$ ).

### Associations of illumination with mood

AM-LIGHT ( $r = -0.12$ ,  $P = 0.012$ ) and illumination mesor ( $r = -0.17$ ,  $P < 0.001$ ) were significantly inversely associated with the CESD-6 depression rating. The illumination acrophase was not significantly associated with CESD-6.

The correlation of AM-LIGHT and CESD-6 was significantly greater in the phase-delayed volunteers ( $r = -0.209$ ) *versus* the phase-advanced subjects ( $r = -0.063$ ) ( $P = 0.005$ ). The associations of CESD-6 with illumination mesor and illumination acrophase were not significantly different between the phase-delayed *versus* phase-advanced volunteers.

### Associations of illumination with sleep

Correlations of illumination with sleep are displayed in Tables 5 and 6.

**AM-LIGHT and sleep**—AM-LIGHT was positively correlated with 4-week recall, actigraphic, and sleep diary estimates of total sleep time; actigraphically defined final time of awakening, and 4-week recall estimates of sleep quality. AM-LIGHT was inversely correlated with actigraphic and diary estimates of sleep latency, and 4-week recall estimates of trouble falling asleep, waking up often during the night, and waking up earlier than planned.

The correlations of AM-LIGHT with better sleep were more evident among volunteers with delayed *versus* advanced aMT6s acrophases. For four variables, significantly larger correlations of AM-LIGHT with sleep were found for the phase delayed *versus* phase-advanced individuals: diary-assessed total sleep time ( $r = 0.38$  *vs*  $r = 0.11$ , respectively,  $P = 0.004$ ); 4-week recall estimates of trouble falling asleep ( $r = -0.20$  *vs*  $r = 0.04$ ,  $P = 0.010$ ), sleep quality ( $r = 0.23$  *vs*  $r = 0.02$ ,  $P = 0.020$ ), and total sleep time ( $r = 0.34$  *vs*  $r = 0.04$ ,  $P = 0.002$ ).

**Illumination mesor and sleep**—Illumination mesor was significantly positively correlated with 4-week recall estimates of sleep quality. Illumination mesor was: (i) inversely correlated with 4-week recall estimates of trouble falling asleep, and actigraphic and diary estimates of sleep latency; (ii) inversely correlated with 4-week recall complaints of wakefulness during the night and actigraphically recorded wakefulness during the night; and (iii) inversely correlated with 4-week recall estimates of waking up earlier than planned.

The correlations of illumination mesor with better sleep tended to be more evident in phase-delayed *versus* phase advanced volunteers. For four variables, the correlation of illumination mesor with better sleep was significantly larger among phase-delayed *versus* phase-advanced subjects: diary-assessed total sleep time ( $r = 0.18$  *vs*  $r = -0.06$ ,  $P = 0.011$ ); and 4-week recall estimates of trouble falling asleep ( $r = -0.26$  *vs*  $r = -0.01$ ,  $P = 0.007$ ), sleep quality ( $r = 0.26$  *vs*  $r = 0.02$ ,  $P = 0.011$ ), and total sleep time ( $r = 0.20$  *vs*  $r = -0.10$ ,  $P < 0.001$ ). For one variable, the correlation of illumination mesor with better sleep was

significantly less in the phase-delayed vs phase-advanced subjects: actigraphically assessed wake after sleep onset ( $r = -0.06$  vs  $r = -0.25$ ,  $P = 0.034$ ).

**Illumination acrophase and sleep**—Illumination acrophase was significantly correlated with only one sleep variable: actigraphically defined final time of awakening ( $r = 0.64$ ,  $P < 0.001$ ). The association of illumination acrophase with sleep efficiency was significantly different ( $P < 0.001$ ) among the phase-delayed ( $r = 0.17$ ,  $P = 0.047$ ) compared with the phase-advanced volunteers ( $r = -0.04$ ,  $P = 0.647$ ).

### Associations of illumination with aMT6s acrophase

The aMT6s acrophase was significantly associated with the light acrophase ( $r = 0.36$ ,  $P < 0.001$ ), but not with the illumination mesor, nor with AM-LIGHT, even after controlling for wake time.

The correlation of AM-LIGHT with aMT6s acrophase was negative for the phase-delayed subjects (i.e. the greater the AM-LIGHT, the earlier the acrophase) ( $r = -0.12$ ), and positive for the phase-advanced subjects ( $r = 0.24$ ); the difference in correlations was significant ( $P < 0.001$ ).

The correlation of illumination mesor with aMT6s acrophase was also marginally different ( $P = 0.08$ ) and opposite in direction for the phase-delayed subjects ( $r = -0.14$ ; the greater the illumination the earlier the aMT6s acrophase) versus the phase-advanced subjects ( $r = 0.012$ ; the greater the illumination the later the aMT6s acrophase). No difference in correlations of illumination acrophase and aMT6s acrophase was found between the phase-delayed and phase-advanced volunteers.

### Window covering

**Associations with illumination**—Kruskal–Wallis non-parametric tests revealed significant associations of window covering with AM-LIGHT (Chi-Square = 7.89,  $P = 0.019$ ) and illumination mesor (Chi-Square = 10.56,  $P = 0.019$ ). Mean AM-LIGHT was  $856 \pm 60$  lux for volunteers who had black out covering or heavy shades on their bedroom windows ( $n = 168$ );  $954 \pm 95$  lux for volunteers with light shades or drapes ( $n = 184$ ); and  $1629 \pm 321$  lux for volunteers with uncovered windows. Illumination mesor was  $546 \pm 86$ ,  $586 \pm 56$ , and  $627 \pm 55$ , for volunteers with black out covering/heavy shades, light shades/drapes, and uncovered windows, respectively. Window covering was not significantly associated with illumination acrophase. The associations of window covering with illumination did not differ significantly between the phase-delayed versus phase-advanced volunteers.

**Associations with mood**—Kruskal–Wallis analysis indicated a marginal association between window covering and the CESD-6 measure of depressed mood (Chi-Square = 4.6,  $P = 0.102$ ). CESD-6 was  $2.21 \pm 0.21$ ,  $1.63 \pm 0.14$ , and  $1.63 \pm 0.27$  among volunteers with blacked-out or heavy shades, light shades or drapes, and uncovered windows, respectively. The association of window covering with CESD-6 was not significantly different between phase-delayed versus phase-advanced subjects.

**Associations with sleep**—Kruskal–Wallis tests revealed significant associations of the degree of window covering with 4-week recall reports of sleep quality (Chi-Square = 8.92,  $P = 0.01$ ) and more awakening during the night (Chi-Square = 6.01,  $P = 0.05$ ). However, the least complaints were associated with light shades/drapes. Overall sleep quality was rated  $3.38 \pm 0.12$ ,  $3.55 \pm 0.07$ ,  $3.24 \pm 0.08$  for subjects with uncovered windows, light shades or drapes, and blacked out/heavy shades, respectively. Complaints of awakening often during the night were  $3.50 \pm 0.18$ ,  $3.09 \pm 0.11$ ,  $3.45 \pm 0.11$  for subjects with uncovered windows, light shades or drapes, and blacked out/heavy shades, respectively. Post-hoc analyses revealed significant quadratic (U-Shaped) associations of window covering with awakening often ( $F = 3.20$ ;  $P = 0.042$ ) and overall sleep quality ( $F = 4.25$ ;  $P = 0.015$ ). No significant association of window covering was found in any of the other 4-week recall, actigraphic, or diary estimates of sleep. No significant association of window covering with aMT6s acrophase was found. Associations of window covering with sleep did not differ significantly between phase-delayed and phase-advanced subjects.

## DISCUSSION

The analyses confirm that both morning light and 24 h light are modestly associated with better mood and sleep. Less window covering was associated with more morning light and more 24-h illumination. The beneficial effects of light were greater for phase-delayed than for phase-advanced subjects.

Morning light and 24 h illumination were inversely correlated with CESD-6 to an equivalent extent. In contrast, our group did not find that evening light was associated with better mood.<sup>29</sup> Assessment of the associations of light with depression were limited because the shortened 6-item version of this scale (CESD-6) that was available has only modest validity.<sup>32</sup>

No relative advantage of AM-LIGHT or illumination mesor was found for sleep. Both were associated with some measures of better sleep. The negative association of illumination mesor with actigraphically assessed total sleep time, which has been reported previously,<sup>34</sup> is possibly confounded by people spending less time in bed when their sleep durations are short. In post-hoc analyses, controlling for time-in-bed, there were no longer significant associations of illumination mesor with total sleep time.

The marginal association of less morning window covering with better mood is potentially important. If the effects could be confirmed experimentally, they might offer a simple, but valuable strategy for improving health. Whether an association of less window covering with better mood can be explained by exposure to the dawn light signal is unclear. Numerous factors influence dawn light exposure, e.g. whether one's eyes are open, whether one's face is buried in a pillow, weather patterns, etc. The significant correlations of window covering with AM-LIGHT and mesor illumination might reflect simply that individuals with brighter bedroom environments at dawn tend to also have brighter environments at other times-of-day. The 'U-shaped' association of window covering with better sleep was contrary to prediction. Perhaps light shades/ drapes provide an optimal compromise of avoiding light during the night, but allowing sufficient exposure to morning light.



Several lines of evidence indicate that AM-LIGHT and illumination mesor were more closely associated with better mood and sleep in the phase-delayed than the phase-advanced subjects. The mood data provide some support for the hypothesis that antidepressant effects of light are mediated by a circadian phase-advancing effect. Indeed, higher levels of AM-LIGHT and illumination mesor were associated with advanced aMT6s acrophases in the phase-delayed subjects, but delayed acrophases in the phase-advanced subjects. This difference is consistent with phase-group difference in aMT6s acrophase-to wake time phase angles (Fig. 1) and the phase-response curve for light depicting the direction and magnitude of phase shifts depending upon the circadian phase of light exposure. AM-LIGHT occurred during a more sensitive advance region of the light PRC in the phase-delayed subjects (approximately 2–6 h after the aMT6 acrophase) compared with the phase-advanced subjects (approximately 4–8 h after the aMT6s acrophase).

Therapeutic effects of phase-advances might be limited to those with delayed circadian rhythms. Most data suggestive of particular beneficial effects of morning light have been observed in patients with seasonal affective disorder, a disorder that is associated with a delayed circadian system. It is plausible, conversely, that phase-delaying effects of evening light might promote optimal mood in people with advanced body clocks. Of course, it is known that morning and evening light have better sleep-promoting efficacy in people with delayed and advanced sleep–wake syndromes, respectively.

Notwithstanding the phase-group results in the present study, it is noteworthy that the association of illumination acrophase with aMT6s acrophase was quite weak (albeit significant) for both phase-groups. Likewise, numerous studies have indicated that while light has antidepressant, sleep-promoting, and phase-shifting effects, these effects are not necessarily correlated.<sup>35–37</sup> Other hypotheses to explain therapeutic effects of light are that light promotes circadian phase stability or feelings of alertness/energy.<sup>22,23</sup>

A noteworthy finding was that the phase-delayed group was significantly older than the phase-advanced group. Whereas several studies have shown an age-associated advance in circadian timing,<sup>38</sup> others have shown no significant age-group difference.<sup>39</sup> Other work has indicated that in the restricted range over age 55 years, aging is associated with a delay in circadian phase.<sup>40</sup>

The age difference of phase-delayed *versus* phase-advanced subjects led us to hypothesize that other differences between the phase groupings might be confounded by age. However, in post-hoc analyses comparing subjects who were above or below the median age of the sample, none of the significant effects of group-phase were confirmed.

In summary, the results indicate significant, but modest, associations of AM-LIGHT and illumination mesor with better mood and sleep. These effects were consistently greater for subjects who were relatively phase-delayed *versus* phase-advanced. Having a lightly covered or uncovered bedroom window can increase morning light exposure, perhaps resulting in better sleep and mood.

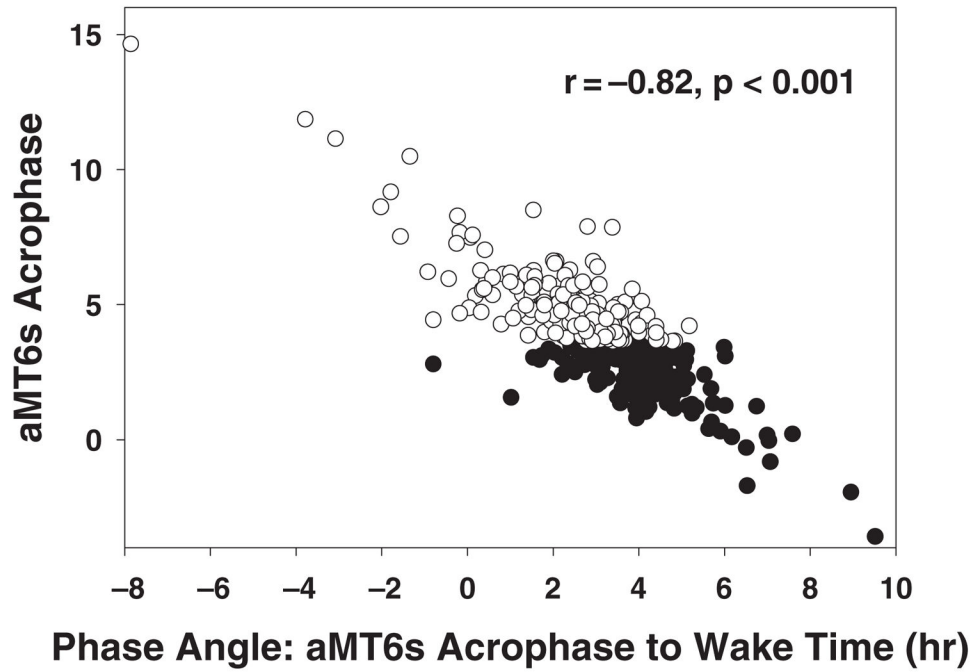
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**Figure 1.**

Association of aMT6s acrophase with phase angle between aMT6s acrophase and wake time for volunteers whose aMT6s acrophases were advanced (closed circles) or delayed (open circles) relative to the sample median.

**Table 1**

## 4-week Recall Questionnaire Likert Scales

Variables	Likert Scale
Frequency of:	
Trouble falling asleep;	1 = Not in past 4 weeks
Waking up often during the night;	2 = Less than once per week
Awakening earlier than planned;	3 = 1–2 times per week
Daytime napping	4 = 3–4 times per week
	5 = 5 or more times per week
Overall sleep quality on typical night	1 = Very restless
	2 = Restless
	3 = Average quality
	4 = Sound or restful
	5 = Very sound or restful
Hours of sleep on typical night	5 h or Less
	6 h
	7 h
	8 h
	9 h
	10+ h

**Table 2**Four week recall questionnaire (mean  $\pm$  SE). See Table 1 for Likert Scale

Variable	Likert Score
Frequency of:	
Trouble falling asleep	2.0 $\pm$ 0.06 (<1 time per week)
Waking up often during night	3.3 $\pm$ 0.07 (~1–2 times per week)
Awakening earlier than planned	2.2 $\pm$ 0.07 (~<1 time per week)
Daytime napping	2.5 $\pm$ 0.06 (~1–2 times per week)
Overall sleep quality	3.4 $\pm$ 0.05 (Average quality)
Hours of sleep	6.7 $\pm$ 0.05 hr

**Table 3**Objective and sleep diary (mean  $\pm$  SE)

Variable	Actigraphic sleep	Sleep diary
Sleep latency (min)	28.90 $\pm$ 1.00	28.30 $\pm$ 1.30
Total sleep time (min)	359.80 $\pm$ 2.60	409.00 $\pm$ 3.00
Wake after sleep onset (min)	87.50 $\pm$ 1.70	–
Sleep efficiency (%)	81.80 $\pm$ 0.30	–
Final wake time	6.92 $\pm$ 0.050	–
Daytime napping (min)	–	17.80 $\pm$ 1.10

–, not measured.

**Table 4**Comparisons between phase-delayed *versus* phase-advanced subjects

Variable	aMT6s Acrophase < Median (Advanced)	aMT6s Acrophase > Median (Delayed)
aMT6s Acrophase (h)	2.45 ± 0.08	5.11 ± 0.12 **
Age (years)	65.93 ± 0.58	69.07 ± 0.56 **
CESD-6	1.67 ± 0.16	1.99 ± 0.18
Final Wake Time (h)	6:30 ± 0.07	7:18 ± 0.08 **
Phase Angle: aMT6s Acrophase-to-Wake Time (h)	4.04 ± 0.093	2.23 ± 0.12 **
AM-LIGHT (lux)	1071.34 ± 120.96	1014.12 ± 92.06
Illumination Mesor (lux)	683.46 ± 76.44	622.59 ± 95.79
Light Acrophase (h)	13.36 ± 0.07	14.04 ± 0.08*
Phase Angle: aMT6s Acrophase-to-Light Acrophase (h)	11.08 ± 0.12	8.98 ± 0.14 **

\*\*  $P < 0.001$  comparing advanced with delayed groups.



**Table 5**

## Correlations of AM-LIGHT with sleep

Significant correlates	Entire sample Pearson r (P)	Advanced Subjects Pearson r (P)	Delayed Subjects Pearson r (P)
Actigraphic Sleep			
Sleep Latency	-0.21 (<0.001)	-0.33 (<0.001)	-0.12 (0.108)
Total Sleep Time	0.14 (0.003)	0.17 (0.027)	0.20 (0.007)
Wake After Sleep Onset	-0.06 (0.222)	-0.15 (0.046)	0.01 (0.893)
Final Awakening Time	0.19 (<0.001)	0.28 (<0.001)	0.18 (0.017)
Diary Sleep			
Sleep Latency	-0.17 (<0.001)	-0.24 (0.001)	-0.12 (0.120)
Total Sleep Time	0.21 (<0.001)	0.11 (0.133)	0.38 (<0.001)*
Naps	-0.05 (0.353)	-0.18 (0.052)	0.01 (0.937)
4-Week Recall			
Trouble Falling Asleep	-0.10 (0.032)	0.04 (0.597)	-0.20 (0.006)*
Wake Up Often in Night	-0.16 (0.001)	-0.09 (0.236)	-0.19 (0.011)
Wake Up Too Early	-0.16 (0.001)	-0.09 (0.260)	-0.24 (0.001)
Total Sleep Time	0.17 (<0.001)	0.04 (0.602)	0.34 (<0.001)*
Sleep Quality	0.15 (0.002)	0.02 (0.800)	0.23 (0.001)*

\* Significantly different correlation for phase-advanced *versus* phase-delayed volunteers.

**Table 6**

Correlations of illumination mesor with sleep

Significant Correlates	Entire Sample Pearson r (P)	Advanced subjects aMT6s < 0338 hr Pearson r (P)	Delayed subjects aMT6s > 0338 hr Pearson r (P)
Actigraphic Sleep			
Sleep Latency	-0.24 (<0.001)	-0.33 (<0.001)	-0.17 (0.023)
Total Sleep Time	-0.12 (0.011)	-0.12 (0.116)	-0.09 (0.223)
Wake After Sleep Onset	-0.14 (0.004)	-0.25 (0.001)	-0.06 (0.409)*
Final Awakening Time	-0.17 (<0.001)	-0.13 (0.088)	-0.12 (0.103)
Diary Sleep			
Sleep Latency	-0.24 (<0.001)	-0.31 (<0.001)	-0.16 (0.025)
Total Sleep Time	0.05 (0.309)	-0.06 (0.407)	0.18 (0.016)*
Naps	0.00 (0.939)	-0.11 (0.227)	0.08 (0.354)
4-Week Recall			
Trouble Falling Asleep	-0.20 (<0.001)	-0.01 (0.920)	-0.26 (<0.001)*
Wake Up Often in Night	-0.18 (<0.001)	-0.09 (0.218)	-0.23 (0.002)
Wake Up Too Early	-0.11 (0.018)	-0.07 (0.376)	-0.21 (0.004)
Total Sleep Time	0.07 (0.145)	-0.10 (0.166)	0.20 (0.005)*
Sleep Quality	0.18 (<0.001)	0.02 (0.749)	0.26 (<0.001)*

\* Significantly different correlation for phase-advanced *versus* phase-delayed volunteers.