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# Bright environmental light ameliorates deficient subjective 'liking' in insomnia: an experience sampling study

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## Abstract

### Study Objectives

Altered comfort sensing and reduced gray matter volume in the orbitofrontal cortex of the brain in people suffering from insomnia disorder (ID) suggest compromised processes of motivation and hedonia. The experience sampling (ES) method was used to evaluate whether, in naturalistic conditions, people with ID differ from those without sleep complaints with respect to subjective Wanting and Liking, two major dimensions of the reward system. Since light affects brain circuits involved in affect and reward, ES was combined with ambulatory monitoring of light intensity fluctuations to evaluate their effect on subjective Wanting and Liking.

### Methods

Participants with ID ($n$ = 17, 12 females, 56.8 ± 6.5 mean ± standard deviation years of age) and matched controls without sleep complaints ($n$ = 18, 12 females, 57.0 ± 8.6 years of age) were probed by a smartphone alarm to log their subjective Wanting, Liking, and mood nine times a day for 7 days. Using an ambulatory light recorder, light intensity exposure was sampled simultaneously and averaged over the intervals between subsequent ES alarms. Mixed-effect models were used to evaluate how ID and varying light intensity affected subjective assessments.

### Results

The results indicated significantly lower subjective Liking and Wanting in people suffering from ID, particularly at low environmental light intensity.

### Conclusions

Wanting and Liking, rather than more commonly used mood adjectives, showed an increased sensitivity to detect deficient hedonic and reward processing in insomnia during everyday life. Deficient Liking may in part be rescued by exposure to bright environmental light.

insomnia, reward, hedonia, mood, experience sampling, bright light, circadian rhythm

## Statement of Significance

A novel, more sensitive method of experience sampling revealed compromised hedonic and reward processes in insomnia during everyday life. Simultaneous ambulatory light monitoring showed that the deficiency was most marked at lower intensities of environmental light. Exposure to bright light may ameliorate a part of the daytime symptoms of insomnia.

# Introduction

With prevalence estimates that vary around 10 per cent, insomnia is among the most frequent complaints in general practice. Insomnia disorder (ID) is the second-most prevalent mental disorder [1], characterized by lasting problems falling asleep or waking up in the night or early morning, with subjective repercussions for daytime functioning. Over the past two decades, it has been recognized increasingly that symptoms of ID are not limited to sleep and involve a round-the-clock state of hyperarousal [2], both subjectively as indexed by e.g. tension, irritability, hypersensitivity and behavioral hyper-responsivity, as well as objectively as indexed by, e.g. fast activity in the sleep and wake electroencephalogram (EEG), elevated cerebral glucose metabolism and enhanced cortical excitability [3–8].

Consensus assigns hyperarousal a key role in the pathophysiology of ID. Hyperarousal is a multidimensional construct, present around the clock in several behavioral, cognitive, and electrophysiological assessments next to fragmented sleep [9]. Several studies have tried to find clues to the underlying mechanisms of hyperarousal [3, 4, 10–12]. The general tenet is that hyperarousal may result from chronic dysfunctional regulation of emotion, stress, and reward. For a deeper understanding of the hyperarousal, it would therefore seem important to further our insight into the dysfunctional regulation of emotion, stress, and reward in insomnia. This has, for example, been pursued using psychometric and physiological paradigms [10, 13], and more recently with magnetic resonance imaging (MRI) studies that linked hyperarousal to suboptimal functioning of a circuit involving the orbitofrontal cortex (OFC) [12]. One of the better recognized OFC functions concerns the subjective experience of pleasantness, which has also been called “hedonic evaluation” or Liking [14, 15], which in controlled lab studies seemed to be compromised in people suffering from insomnia [16, 17].

Liking is one of the two major discriminable dimensions of reward processing, next to another dimension that has been coined Wanting [18, 19]. Although Liking refers to the pleasure dimension of a reward, Wanting represents the incentive motivation that promotes approach toward and consumption of rewarding stimuli. Although both have unconscious aspects as well, Liking can be subjectively experienced as feelings of pleasure or niceness, and Wanting as desires for incentives or declarative goals [20]. Wanting and Liking involve partially overlapping and partially discriminable brain circuits and may both contribute to anhedonia in psychiatric disorders [20]. Although Wanting and Liking may be processed in discriminable circuits of the brain, Baumeister [21] pointed out that the dimensions do not seem entirely orthogonal, i.e. they do not work independently (but see the work of Kruglanski et al. [22] for a comment on their interrelatedness versus independence).

The first aim of the present study was to complement the relatively scarce functional observations of altered “hedonic evaluation” or Liking in laboratory conditions in insomnia [16, 17]. To do so, we employed experience sampling (ES) study to evaluate whether people with ID experience less Liking, in everyday life, under naturalistic conditions. Since their relative contribution to anhedonia may differ across psychiatric disorders, we complemented the ES survey on subjective Liking by similar questions about subjective Wanting. Compared with traditional retrospective self-reports, ES diminishes recall bias and selectivity by capturing current or recent behaviors. Furthermore, ecological validity is high compared with lab studies because subjective experiences can be described as they occur in the naturalistic environment [23]. Based on previous studies suggesting compromised OFC functioning in insomnia (see above and Discussion), and given its involvement in Liking more than in Wanting [14, 15], we expected a particular deficiency in Liking in everyday life in people suffering form ID: more so than in Wanting or in more traditional mood adjectives assessment.

A second aim of the present study was to evaluate how the naturalistically occurring variation in environmental light exposure affects subjective Wanting and Liking ratings in ID. Recent studies indicate that activation of the reward circuitry changes with light intensity [24–26], which is likely to underlie the robust findings of favorable clinical effects of bright light on mood [27–31]. Indeed, intrinsically photosensitive retinal ganglion cells (ipRGCs), which express the blue-light sensitive photopigment melanopsin and integrate information on environmental light intensity, have both direct and indirect projections to limbic areas involved in the regulation of mood and reward, including the lateral habenula, medial amygdala, and periaqueductal grey [32–35]. Although a handful of studies evaluated the effect of clinical application of bright light on sleep complaints in people suffering from ID [36–40], studies on the immediate effect of dynamically changing light intensities on readouts of the reward system in ID are lacking. We therefore complemented the present ES study with wearable sensors for simultaneous ambulatory recording of naturalistic fluctuations in environmental light intensity, to assess how they affect subjective Liking and Wanting. Based on previous experimental work showing activation of the reward circuitry with bright light, we expected a positive association between naturally fluctuations in light intensity and subjective Liking and

Wanting, both in cases and controls.

# Methods

## Participants

Participants were 17 people suffering from ID and 18 age- and sex-matched controls without sleep complaints (Table 1). Volunteers were recruited by advertisement, word of mouth, and the Sleep Registry [41] and were screened using a dedicated online screening form followed by a telephone interview to verify their eligibility to participate in the study. All participants provided written informed consent. Initially, we searched for participants among people suffering from insomnia irrespective of their age. However, it turned out that very few of the responders were younger than 40 years of age. This is in accordance with the age-related increase in prevalence. Because we aimed for a relatively homogeneous sample with respect to age, we set inclusion criteria between 40 and 70 years of age and in addition self-acclaimed good health and working regular office hours. For the ID group, self-reported sleep onset latency or wake after sleep onset is greater than 30 min, and total sleep time is less than 6.5 hr, for at least 6 months and for more than 3 nights per week at the time of intake. Exclusion criteria for all participants were diagnosed ocular pathology, drug abuse, excessive alcohol consumption (>10 glasses per week), crossing one or more time zones in the month prior to the study, current use of alertness-, sleep-, and thermoregulation-altering medication, and any currently diagnosed sleep, neurological or psychiatric disorders other than ID according to the Sleep Registry implementation of the Duke Structured Interview for Diagnosing Sleep Disorders [41, 42]. Prior to inclusion, volunteers were interviewed by telephone to verify the presence (in cases) or absence (in controls) of ID according to the third edition of the International Classification of Sleep Disorders [43]. All participants with ID reported suffering from complaints for more than 8 years. Group differences with respect to insomnia-related complaints were furthermore verified using the 7-item Insomnia Severity Index (ISI) questionnaire [44] and the Pittsburgh Sleep Quality Questionnaire (PSQI) [45] (Table 1). The Munich Chronotype Questionnaire (MCTQ) [46] was administered to evaluate group differences in midsleep on free days adjusted for average sleep need ($MSF_{sc}$) [47] between ID and controls. Participants received monetary compensation after study completion. The protocol was approved by the Ethics Committee of the VU University and Medical Center and performed in accordance with principles of the Helsinki Declaration.

**Table 1.**

Characteristics of participants

| | Control (*n* = 18) | Insomnia disorder (*n* = 17) | *P* |
|---|---|---|---|
| Age (yr) | 57.0 ± 8.6 | 56.8 ± 6.5 | .83 |
| Sex (female/male) | 12/6 | 12/5 | 1 |
| Body mass index ($kg/m^2$) | 24.4 ± 4.0 | 24.6 ± 3.6 | .74 |
| ISI | 4.4 ± 3.4 | 17.0 ± 4.6 | <.0001 |
| DIS | 0.5 ± 0.7 | 2.1 ± 1.5 | <.0001 |
| DMS | 0.4 ± 1.0 | 3.2 ± 1.1 | <.0001 |
| EMA | 0.4 ± 0.6 | 2.8 ± 1.1 | <.0001 |
| PSQI | 3.9 ± 1.7 | 9.9 ± 3.2 | <.0001 |
| MSFsc (HH:MM) | 04:09 ± 00:41 | 03:15 ± 00:57 | .003 |

Mean values ± SD (range) are shown.

ISI = Insomnia Severity Index; DIS = Difficulty Initiating Sleep; DMS = Difficulty Maintaining Sleep; EMA = Early Morning Awakening; PSQI = Pittsburgh Sleep Quality Index; MSFsc = midsleep on free days adjusted for average sleep need as assessed by the Munich Chronotype Questionnaire at recruitment. DIS, DMS, and EMA represent the frequency of the complaint experienced over the last 2 weeks as assessed by the ISI at recruitment.

## Procedure

Volunteers participated in unconstrained ambulatory assessment in their natural environment for 7 consecutive days. On the day prior to the start of the ambulatory assessment, participants were introduced to the project, familiarized with the usage of a smartphone for ES and attachment of the light sensors to their clothes.

## Light assessment

Participants received two dime-sized RGB multiband light sensors (Dimesimeter, also known as Daysimeter-D, Rensselaer Polytechnic Institute, Troy, NY, USA) [48, 49]. Photopic illuminance and the multiband light spectrum were sampled once in every minute for 7 consecutive days. Each sensor was integrated in a brooch. Participants received two brooches. One of the brooches was pinned at chest level on the indoor clothing a participant chose to wear on each particular day from the moment they woke up until bedtime. The other brooch was pinned on the participant's outdoor jacket or coat at the same chest level and left there for all days this jacket or coat was used. The use of two brooches allows for continuous indoor and outdoor assessment: when the brooch on indoor clothing is covered by one's coat or jacket, the signal recorded from the brooch on the coat or jacket can be used to estimate environmental light exposure. Whether a coat was worn could be assessed from the accelerometry signal integrated in each sensor.

## Assessment of Liking and Wanting

ES was used to repeatedly assess subjective Liking and Wanting. The method was implemented using MovisensXS software (Movisens GmbH, Karlsruhe, Germany) installed on a smartphone (Nexus 4, LG, Seoul, Korea). Participants were probed eight times a day at quasirandom intervals timed between 8:00 and 22:00 hr and were asked in addition to provide input after waking up and before bedtime. The interval between subsequent alarms ranged between 16 min and 3 hr. Preceding the first observation of each day, which was made immediately upon awakening, the participants were asleep with eyes closed, usually in a dark bedroom. Hence, the first observation of the day lacks variance in prior light exposure and was therefore not considered in the present study.

The assessment of explicit and implicit Liking and Wanting in humans is an area that is under development [50–53]. At the time of completing the design of the present study, we were not aware of previous work providing examples of their combined momentary assessment within the ES method. An interesting ES study on dieting and self-control of eating that was published later did however evaluate Wanting ("desire") in great detail [54] and an even more recent study on Schizophrenia assessed appraisal of social interaction [55], a specific example of Liking that we included also in our approach. E.V.S. and M.K. (as an expert on hedonia) discussed the domains to be included in a comprehensive assessment of Liking, and developed questions for each domain phrased in such a way that it would fit the limited space on a smartphone screen and could as well be matched by a similarly phrased question about Wanting in each domain. We surveyed both subjective Liking and Wanting at every prompt by six statements each, addressing the dimensions of "taste-smell," "bodily sensation," "watching/listening," "social interaction," "physical activity," and "receiving something." Participants were asked to rate the extent to which each statement applied to them in the period between the current and previous alarm, using visual analogue scales with end points "not" and "very much" scaled to 0 and 100, respectively. The statements are shown as follows: Liking (in Dutch: "genoot ik van…") was queried first and immediately followed by questions on Wanting (in Dutch: "had ik zin in…").

Since the previous alarm, I enjoyed...

| | not | very much |
|---|---|---|
| ... a taste or smell | \|---------- | ----------\| |
| ... a bodily sensation | \|---------- | ----------\| |
| ... watching or listening | \|---------- | ----------\| |
| ... interactions with other | \|---------- | ----------\| |
| ... physical activity, being busy | \|---------- | ----------\| |
| ... receiving something | \|---------- | ----------\| |

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Since the previous alarm, I wanted...

| | not | very much |
|---|---|---|
| ... a taste or smell | \|---------- | ----------\| |
| ... a bodily sensation | \|---------- | ----------\| |
| ... to watch or listen | \|---------- | ----------\| |
| ... to interact with others | \|---------- | ----------\| |
| ... physical activity, to be busy | \|---------- | ----------\| |
| ... to receive something | \|---------- | ----------\| |

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## Complementary assessment of more traditional mood adjectives

Although ES of Liking and Wanting has not previously been reported, several ES studies made use of Positive and Negative Mood adjectives. It would be interesting to evaluate whether direct questions on Wanting and Liking are as sensitive to detect group differences and effects of light intensity as previously used Positive and Negative Mood adjectives. We therefore queried at each alarm, and prior to the Wanting and Liking questions, Positive and Negative Mood adjectives with relevance to insomnia as described in the Daytime Insomnia Symptom Scale (DISS) [56]. The DISS consists of 19 visual analog scales, which load onto four factors labeled Alert Cognition, Sleepiness/Fatigue, Negative Mood, and Positive Mood. The latter two factors were evaluated here.

# Preprocessing

## Light

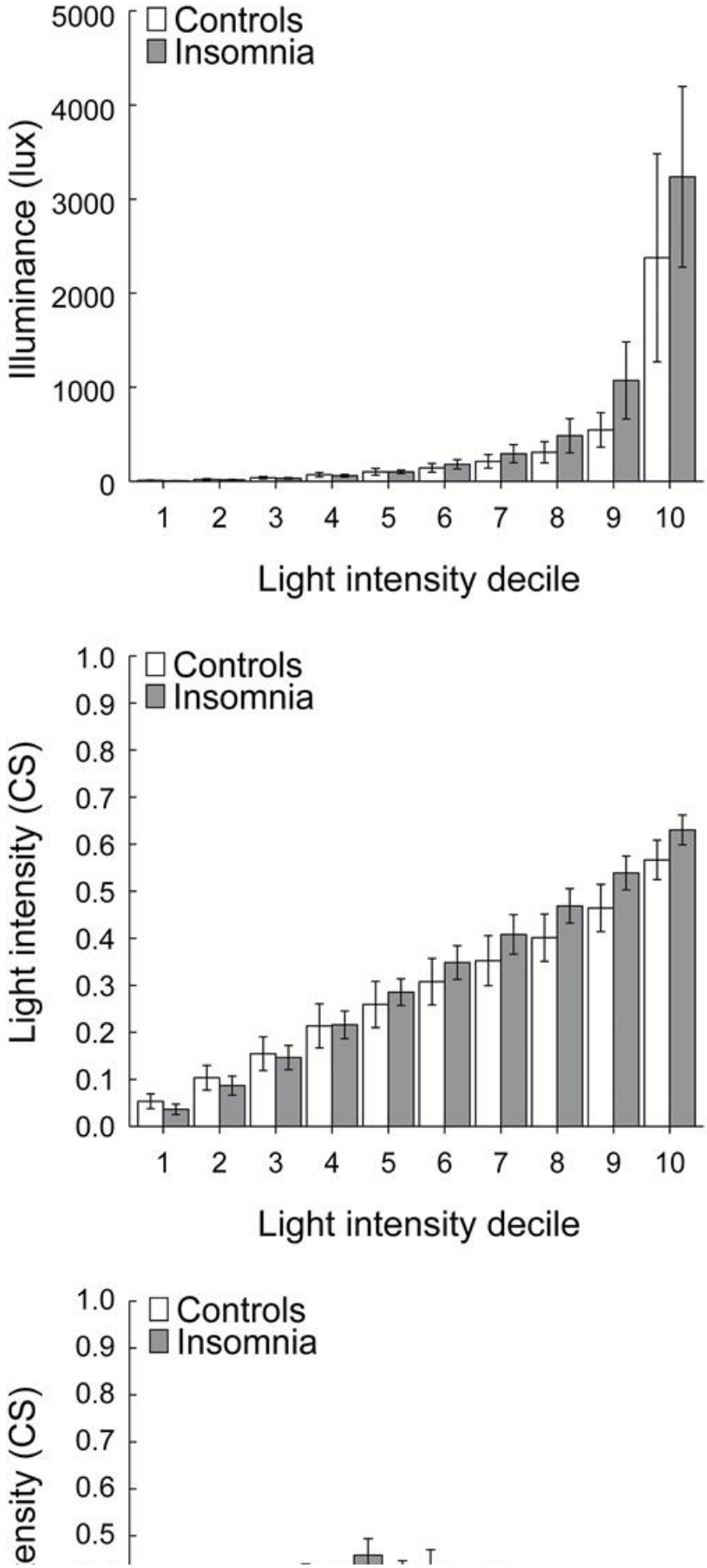
Dimesimeter measurements were preprocessed with MATLAB 2014a (MathWorks, Inc., Natick, MA, USA). The photopic illuminance and accelerometry signals of the sensors on the indoor and outdoor clothing were used to assess the validity of each light sample. Visual inspection indicated baseline noise in the absence of movements in the accelerometry signals. Values below the baseline noise floor were set to zero. Windows of at least 15 min without activity were marked as periods that the sensor was not worn [57] and excluded from analyses. Excluded were moreover all epochs without any light, indicating that the sensor was most likely covered. The remaining 1 min epochs were considered valid measurements. The time series of the two devices were synchronized by means of the recorded time stamps. Sample-by-sample selection of light values of either indoor or outdoor clothing devices was accomplished as follows:

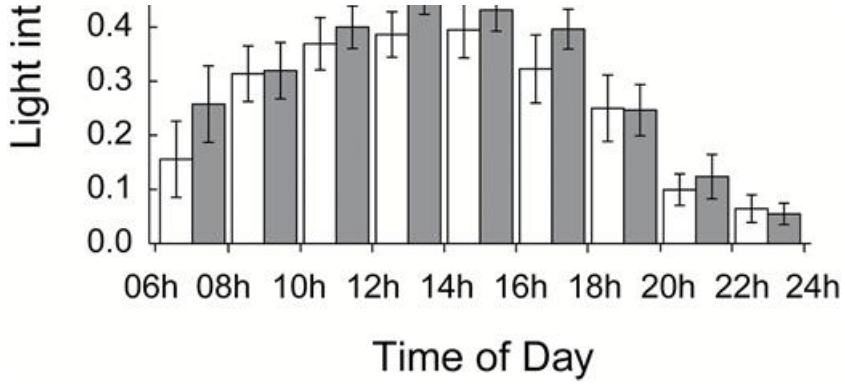
1. If only one of the sensors had a valid measurement, the sensor with the valid measurement was selected.
2. If the sensors on the indoor and outdoor clothing each simultaneously showed valid measurements, the sensor with the maximal photopic illuminance measurement was selected. This accounts, for example, for the situation in which an open jacket folds back to cover the outdoor clothing sensor, exposing the indoor sensor, while still selecting the outdoor sensor if a closed jacket covers the indoor sensor.
3. All other 1 min epochs were discarded.

The photopic illuminance and accelerometry was used only to assess the validity of the measurement and to choose which signal to use, but the corecorded multiband spectrum was used for further analysis. The corecorded multiband spectrum value of each valid photopic illuminance sample was nonlinearly transformed into a value between zero and one that represents the estimated downstream effect of the light intensity on the circadian system, as derived from its effectiveness to suppress melatonin (circadian stimulus, CS [58]), hereinafter referred to as “light intensity.” Valid transformed light intensity values were averaged within each time interval between subsequent alarms. Intervals exceeding 3 hr were discarded and represented the intervals without valid data (e.g. the long interval prior to the first self-initiated ES assessment immediately upon waking). The resulting set of valid CS-transformed light intensity values averaged over the time interval between subsequent alarms was used for mixed-effect regression analyses.

The CS transformation on light samples effectively linearized the otherwise nonlinearly distributed wide range of light illuminance values. For data description and visualization purposes only, the range of interval CS-transformed light intensity averages within each participant was assigned to ten deciles and averaged across participants within each decile. The upper panel of Figure 1 shows the highly nonlinear decile distribution of untransformed interval illuminance averages, whereas the middle panel shows the linearized decile distribution of CS-transformed interval light intensity averages.

**Figure 1.**



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Range of recorded average light intensities in ID (gray bars) and controls (white bars). The upper and middle panels show distributions across ten deciles defined within each participant. The upper panel shows the nonlinear increase of photopic illuminance values averaged in each decile. The middle panel shows how the "circadian stimulus (CS)"-transformation linearizes the distribution across deciles of increasing intensities. The lower panel shows the within-participant averages of CS-transformed light intensity values, with the mid time of alarm-to-alarm intervals aggregated in 2 hr time bins. Error bars indicate 95% confidence intervals. The numbers of observations in each time interval were, respectively, 34, 162, 117, 105, 88, 105, 118, 98, and 31 for the control participants and 63, 141, 110, 109, 103, 99, 119, 115, and 36 for participants suffering from insomnia. Too few observations were available between 0:00 and 6:00 hr for useful visualization. There was no group difference in overall light exposure ($p$ = .57).

## Liking, Wanting, and complementary more traditional Positive and Negative Mood adjectives

For each interval, a Liking and Wanting score was calculated by averaging the six visual analogue ratings in each of the domains assessed by ES at the end of the interval. Likewise, for each interval, a DISS Positive Mood score was calculated by averaging the ratings on the five items: "Relaxed," "Energetic," "Calm," "Happy," and "Efficient," as well as a DISS Negative Mood score from the items "Anxious," "Stressed," "Tense," "Sad," and "Irritable." Intervals with incomplete or ignored ES assessments were discarded.

## Statistical analysis

In order to verify that people suffering from ID and controls did not differ systematically with respect to the time of year of assessment, possible group differences in circular means and standard deviations were evaluated using a Mardia–Watson–Wheeler test [59].

Mixed-effect regression models were used to estimate how subjective Liking, Wanting, Positive Mood, and Negative Mood changed with time of day and were affected by light intensity during the queried interval. The mixed-effect models accounted for the 3-level hierarchical structure of the data with a variable number of intervals ($i$) nested within a variable number of days ($j$), nested within participants ($k$). Participant and days nested within participants were specified as random factors to control for their associated intraclass correlation (ICC; i.e. random intercept).

Time of day, light intensity, ID, and the interaction effect of ID with light intensity and with time of day were included as regressors. Light intensity was added as a random effect to account for individual differences in the response to light intensity.

The diagnosis of ID was included as a dichotomous variable with ID coded as 1 and control coded as 0.

Time of day was included in the models because diurnal rhythms have been demonstrated in reward behavior and neurophysiology [60] and subjective hedonic tone [61]. Time of day effects were estimated using the equivalent linear form of a 24 hr cosine curve [62] that combined the sine and the cosine of the midtime of each interval, expressed in radians where 24 hr equals $2\pi$ and 0 and $2\pi$ indicate midnight.

An additional separate model evaluated the modulation of light intensity by time of day and ID.

ICC coefficients were calculated for each model to understand how much of the variation in the dependent variable could be explained by the 3-level hierarchy of the data.

Multilevel reliability coefficients were calculated to estimate the reliability of between-person differences and the reliability of within-person time variation of the items of the Positive and Negative Mood scales of the DISS [63].

Circular statistics were estimated using the “circular” package [64] and mixed-effects models were estimated using the “lme4” package [65] for R version 3.2.4 [66]. The multilevel reliability coefficients and the ICCs were estimated using the “psych” package [67]. Summary statistics and 95% confidence intervals (CI) were calculated using a bootstrap procedure of 10000 replications [68] using the “boot” package [69]. Significance of the effects of the independent variable on the dependent variable was obtained by calculating the fraction of 10000 bootstrapped log-likelihood ratio (LRT) values that are larger or equal to the observed LRT value obtained from comparing the model with and without the independent variable.

The initially fitted models for the effect of time of day, light intensity, ID, and the interaction effects between ID and light intensity and between ID and time of day on subjective Liking, Wanting, Positive Mood, and Negative Mood were as follows. Note that the last two nonsignificant interaction terms were omitted from the final model for Wanting and Liking,

$$Yijk=ß0ijk+ß1*SineTimeOfDayijk+ß2*CosineTimeOfDayijk+ß3*LightIntensityijk+ß4*IDk+ß5*IDk*LightIntensityijk+ß6*IDk*SineTimeOfDayijk+ß7*IDk*CosineTimeOfDayijk,$$

where Y is the dependent variable, either Liking, Wanting, Positive Mood, or Negative Mood; i, j, k subscripts indicate values measured over interval *i* of day *j* of participant *k*; $ß_0$ is the intercept allowing for random variation over intervals *i*, days *j*, and participants *k*; $ß_1$–$ß_2$ are the sine and cosine components of the linear form of a 24 hr cosine curve to capture diurnal variation; $ß_3$ is the effect of light exposure; $ß_4$ is the effect of a diagnosis of ID; $ß_5$ is the interaction effect describing to what extent ID alters the effects of the within-participant-centered fluctuations in light exposure on the dependent variable; and $ß_6$–$ß_7$ capture the interaction effect describing to what extent ID alters the sine and cosine components that model the diurnal variation.

The fitted model for the modulation of light intensity by time of day and ID was as follows:

$$LightIntensityijk=ß0ijk+ß1*SineTimeOfDayijk+ß2*CosineTimeOfDayijk+ß3*IDk+ß4*IDk*SineTimeOfDayijk+ß5*IDk*CosineTimeOfDayijk,$$

where $LightIntensity_{ijk}$ is the dependent variable, i, j, k subscripts indicate values measured over interval *i* of day *j* of participant *k*; $ß_0$ is the intercept allowing for random variation over intervals *i*, days *j*, and participants *k*; $ß_1$–$ß_2$ are the sine and cosine components of the linear form of a 24 hr cosine curve to capture diurnal variation; $ß_3$ is the effect of a diagnosis of ID; and $ß_4$–$ß_5$ capture the interaction effect describing to what extent ID alters the sine and cosine components that model the diurnal variation.

# Results

We collected a total of 2205 alarms. We discarded any incomplete surveys (dismissed or ignored by the participant; 4.4 per cent), those with an excessively long prior time interval since the last alarm (>3 hr, the maximal time between random intervals; 8.3 per cent) and those with evidence of the light sensor not being worn (7.3 per cent). The remaining 1764 alarms were included in the analysis, indicating that on average 80 per cent of the alarms contained valid data.

Assessments were performed across the year and covered all months except for January, September, and December. The group circular means and standard deviations were 11 June ± 69 days in people suffering from ID and 3 June ± 78 days in controls and did not differ significantly (Mardia–Watson–Wheeler W = 0.04, $p = .98$) [59].

## Light exposure

There was no group difference in overall light exposure between ID and controls ($p = .57$; Figure 1). Light intensity was on average 0.31 ± 0.01 [0.29 0.34] for ID and 0.29 ± 0.02 [0.25 0.32] for controls. Diagnosis by Time of Day interaction terms indicated that people with ID differed slightly from controls with respect to the timing of their diurnal light exposure profile (ID interaction with the Sine component: −0.03 ± 0.01 [−0.05 −0.01] (effect estimate ± standard error of the estimate [95% confidence interval]), $p = .012$; ID interaction with the Cosine component: −0.04 ± 0.01 [−0.06, −0.02], $p = .001$). Light intensity peaked at 13:26 hr in ID and slightly earlier, at 13:14 hr, in controls.

## Wanting and Liking

There were highly significant group differences in overall subjective Liking and Wanting between ID and controls. People with ID rated significantly lower both on subjective Liking ($p = .001$) and on subjective Wanting ($p = .0004$, Table 2). Average Liking was 34.9 ± 2.3 [30.4, 39.4] for ID and 44.6 ± 2.8 [39.0, 50.1] for controls. Average Wanting was 34.1 ± 2.2 [29.8, 38.5] for ID and 45.1 ± 2.9 [39.2, 50.8] for controls. Diagnosis by Time of Day interaction terms indicated that people with ID did not differ from controls with respect to the amplitude or phase of the diurnal 24 hr profiles in Liking or Wanting (all ID·Sine and ID·Cosine component terms were $.26 < p < .90$). Therefore, these terms were excluded from the final mixed-effect regression models. Thus, consistent across all participants, Time of Day significantly modulated Liking, peaking at 16:05 hour (Sine component: $p < .0001$; Cosine component: $p = .0003$, Figure 2). Likewise, Time of Day modulated Wanting resulting in a peak at 15:40 hr (Sine component: $p < .0001$; Cosine component: $p < .0001$).

**Table 2.**

Model estimates of the effects of time of day, light intensity, and insomnia disorder on subjective Wanting and Liking

| Fixed effects | Wanting | | | Liking | | |
|---|---|---|---|---|---|---|
| | β | SE | CI | β | SE | CI |
| Intercept | 41.6 | 2.6 | [36.5, 46.7]*** | 41.5 | 2.6 | [36.3, 46.7]*** |
| sin(TOD) | −4.5 | 0.5 | [−5.6, −3.5]*** | −5.5 | 0.6 | [−6.7, −4.4]*** |
| cos(TOD) | −3.2 | 0.7 | [−4.6, −1.8]*** | −3.0 | 0.8 | [−4.5, −1.5]*** |
| CS | 4.5 | 5.4 | [−6.0, 15.0] | 2.1 | 5.1 | [−7.9, 12.1] |
| ID | −14.8 | 3.7 | [−22.3, −7.5]*** | −14.0 | 3.8 | [−21.5, −6.6]** |
| ID · CS | 12.4 | 7.2 | [−1.5, 26.5] | 14.2 | 6.7 | [1.1, 27.3]* |
| Random effects | σ | SE | CI | σ | SE | CI |
| $\text{Intercept}_{\text{subject}}$ | 10.1 | 1.5 | [7.2, 13.1] | 10.1 | 1.5 | [7.2, 13.1] |
| $\text{Intercept}_{\text{subject/day}}$ | 6.9 | 0.5 | [5.9, 7.8] | 6.4 | 0.5 | [5.4, 7.4] |
| $\text{CS}_{\text{subject}}$ | 18.6 | 3.0 | [12.6, 24.2] | 16.3 | 2.9 | [10.4, 21.9] |
| Residual | 11.8 | 0.2 | [11.4, 12.2] | 12.9 | 0.2 | [12.4, 13.4] |
| ICC | 0.55 | 0.05 | [0.46, 0.63] | 0.49 | 0.05 | [0.40, 0.58] |

Mean values ± SE [95% CI] are shown.

CS = circadian stimulus; TOD = Time Of Day (rad); ID = Insomnia Disorder.

*$p < .05$; **$p < .01$; ***$p < .001$.

For subjective Wanting and Liking, the optimal models are shown. TOD was converted to radians, where 24 hr equals 2π. ID was included in the model as a dichotomous variable coded as 0 for controls and 1 for cases.

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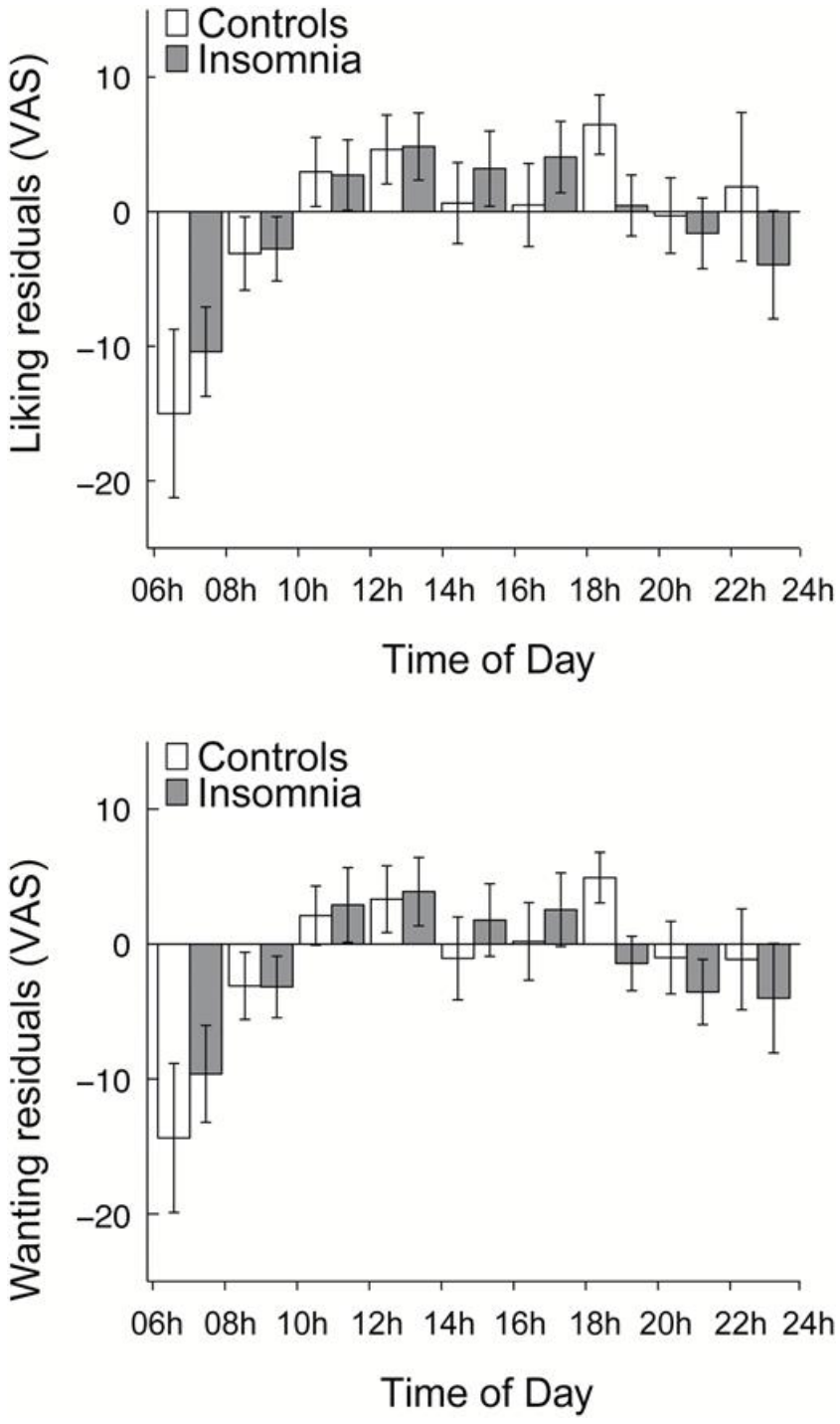
**Figure 2.**

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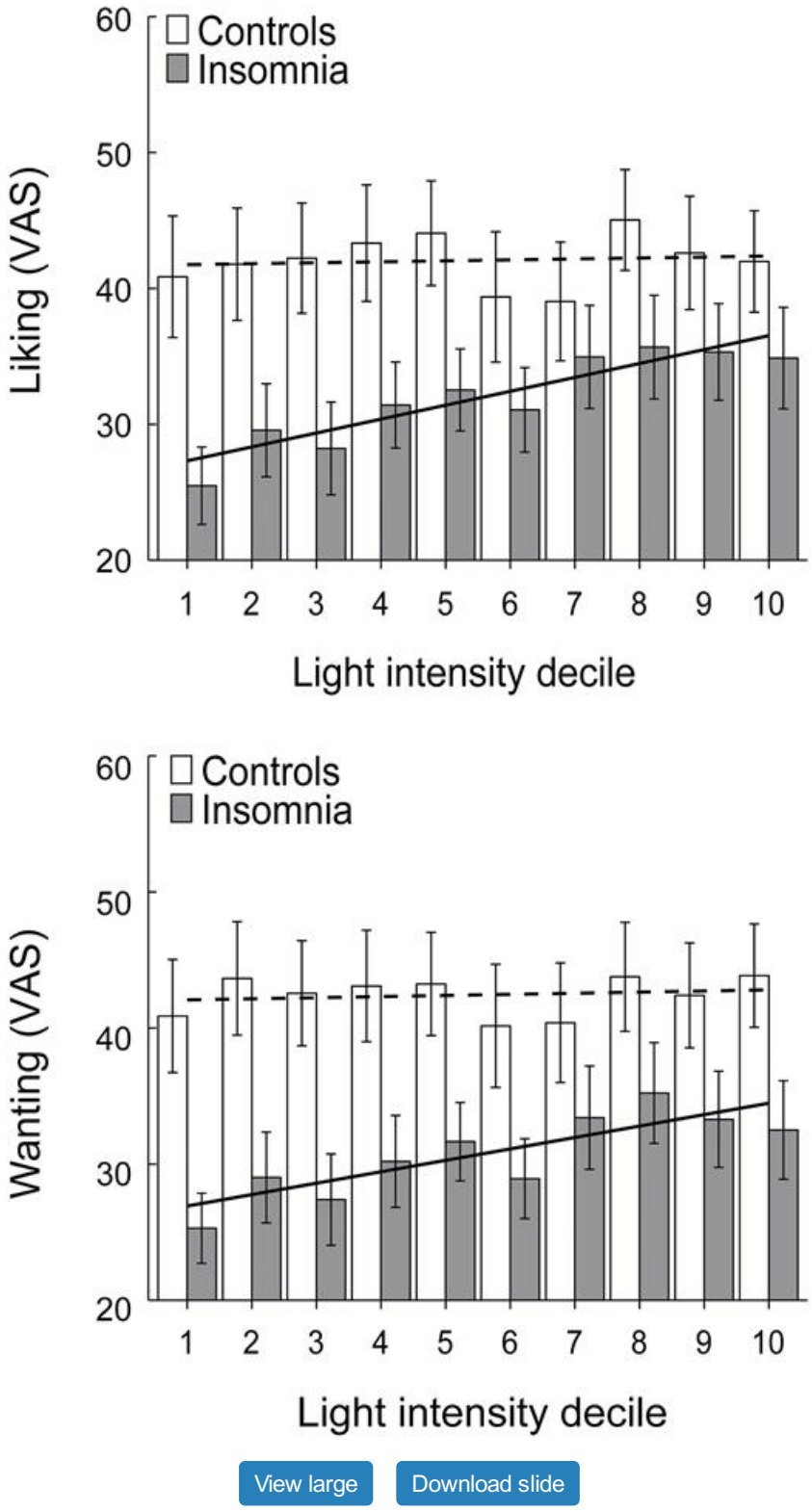
Subjective Liking and Wanting ratings across the day show a peak in the afternoon. Subjective ratings on Liking (upper panel) and Wanting (lower panel) vary across time of day in participants suffering from ID (gray bars) and controls (white bars). Data are aggregated in 2 hr time bins according to the mid time of the intervals between subsequent alarms. In order to be able to visualize time of day effects only, both plots show residual ratings, after adjusting for the effects of intensity of circadian stimulus. Error bars indicate 95% confidence intervals. The numbers of observations in each time interval were, respectively, 34, 162, 117, 105, 88, 105, 118, 98, and 31 for the control participants and 63, 141, 110, 109, 103, 99, 119, 115, and 36 for participants suffering from insomnia. Too few observations were available between 0:00 and 6:00 hr for useful visualization. Mixed-effect regression analysis fitting a linearized 24 hr cosine function indicated significant diurnal variation in both Liking and Wanting that did not differ between ID and controls, respectively, peaking at 15:40 and 16:05 hr. VAS = Visual Analogue Scale.

A significant ID by light intensity interaction effect ($p = .04$) indicated that variability in light exposure significantly affected the experience of Liking only in ID. A similar interaction effect could not be found for Wanting ($p = .09$). As visualized in Figure 3, controls without sleep complaints remained at average levels of subjective Wanting and Liking irrespective of light intensity, whereas higher light intensities partly ameliorated the overall lower subjective Liking but not Wanting in participants suffering from insomnia. We moreover evaluated effects of the severity (ISI) and duration (DSISD) of insomnia among participants diagnosed with ID. Although both Wanting ($p = .03$) and Liking ($p = .02$) increased significantly with light, the effect

of light on Wanting ($p$ = .19) nor Liking ($p$ = .20) was not moderated by severity (ISI*CS interaction). Wanting and Liking were not significantly associated with the duration of insomnia, nor was the effect of severity on Wanting and Liking ($p$ = .10, $p$ = .07, $p$ = .17, and $p$ = .24, respectively).

**Figure 3.**

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Higher environmental light intensities partly ameliorate low subjective Liking but not Wanting ratings in insomnia. Average subjective ratings on Liking (upper panel) increase with light intensity only in participants suffering from insomnia disorder (gray bars, solid line) but not in control participants (white bars, dashed line). Wanting (lower panel) shows a similar but non-significant trend. Bars summarize average ratings, aggregated in ten deciles of increasing CS-transformed light intensity ranges defined within each participant. Error bars indicate 95% confidence intervals. VAS = Visual Analogue Scale.

Wanting and Liking yielded ICCs of 0.54 ± 0.05 [0.45, 0.63] and 0.49 ± 0.05 [0.40, 0.58], respectively, indicating about equal within-participant and between-participant contributions to the variance in Wanting and Liking.

## Positive and Negative Mood

There were no differences in overall Positive or Negative Mood between ID and controls (respectively, $p = .81$; $p = .46$).

Diagnosis by Time of Day interaction terms indicated that people with ID differed from controls with respect to the diurnal profile of Positive and Negative Mood (Table 3, Figure 4). Positive Mood peaked at 15:14 hr for ID and 12:13 hr for controls (ID interaction with Sine component: $p = .003$; ID interaction with Cosine component: $p = .37$). Likewise, Time of Day modulated Negative Mood resulting in a peak at 06:31 hr for ID and 15:33 hr for controls (ID interaction with Sine component: $p = .0001$; ID interaction with Cosine component: $p = .97$).

**Table 3.**

Model estimates of the effects of time of day, light intensity, and insomnia disorder on Positive and Negative Mood

| Fixed effects | Positive Mood | | | Negative Mood | | |
|---|---|---|---|---|---|---|
| | β | SE | CI | β | SE | CI |
| Intercept | 57.7 | 3.1 | [51.5, 63.8]*** | 16.5 | 2.1 | [12.3, 20.6]*** |
| sin(TOD) | −0.2 | 0.6 | [−1.3, 0.9] | −0.5 | 0.5 | [−1.5, 0.5] |
| cos(TOD) | −3.3 | 0.7 | [−4.7, −1.8]*** | −0.4 | 0.7 | [−1.8, 0.9] |
| CS | 2.5 | 3.5 | [−4.4, 9.3] | −0.3 | 2.7 | [−5.5, 5.0] |
| ID | −0.5 | 4.5 | [−9.2, 8.4] | −1.1 | 3.0 | [−7.1, 5.0] |
| ID·CS | 7.2 | 4.9 | [−2.5, 16.8] | −2.8 | 3.7 | [−10.1, 4.6] |
| ID·sin(TOD) | −2.5 | 0.8 | [−4.0, −1.0]** | 3.1 | 0.7 | [1.8, 4.5]*** |
| ID·cos(TOD) | 0.9 | 1.0 | [−1.1, 3.0] | 0.05 | 1.0 | [−1.8, 2.0] |
| Random effects | σ | SE | CI | σ | SE | CI |
| $\text{Intercept}_{\text{subject}}$ | 12.7 | 1.7 | [9.5, 16.1] | 8.3 | 1.2 | [6.2, 10.7] |
| $\text{Intercept}_{\text{subject/day}}$ | 5.5 | 0.4 | [4.8, 6.3] | 5.2 | 0.4 | [4.5, 5.9] |
| $\text{CS}_{\text{subject}}$ | 10.1 | 2.0 | [6.1, 13.8] | 5.7 | 1.8 | [1.4, 8.9] |
| Residual | 8.6 | 0.2 | [8.2, 8.9] | 7.9 | 0.2 | [7.6, 8.2] |

Mean values ± SE [95% CI] are shown.

CS = circadian stimulus; TOD = Time Of Day (rad); ID = Insomnia Disorder.

**$p < .01$; ***$p < .001$.

TOD was converted to radians, where 24 hr equals 2π. ID was included in the model as a dichotomous variable coded as 0 for controls and 1 for cases.

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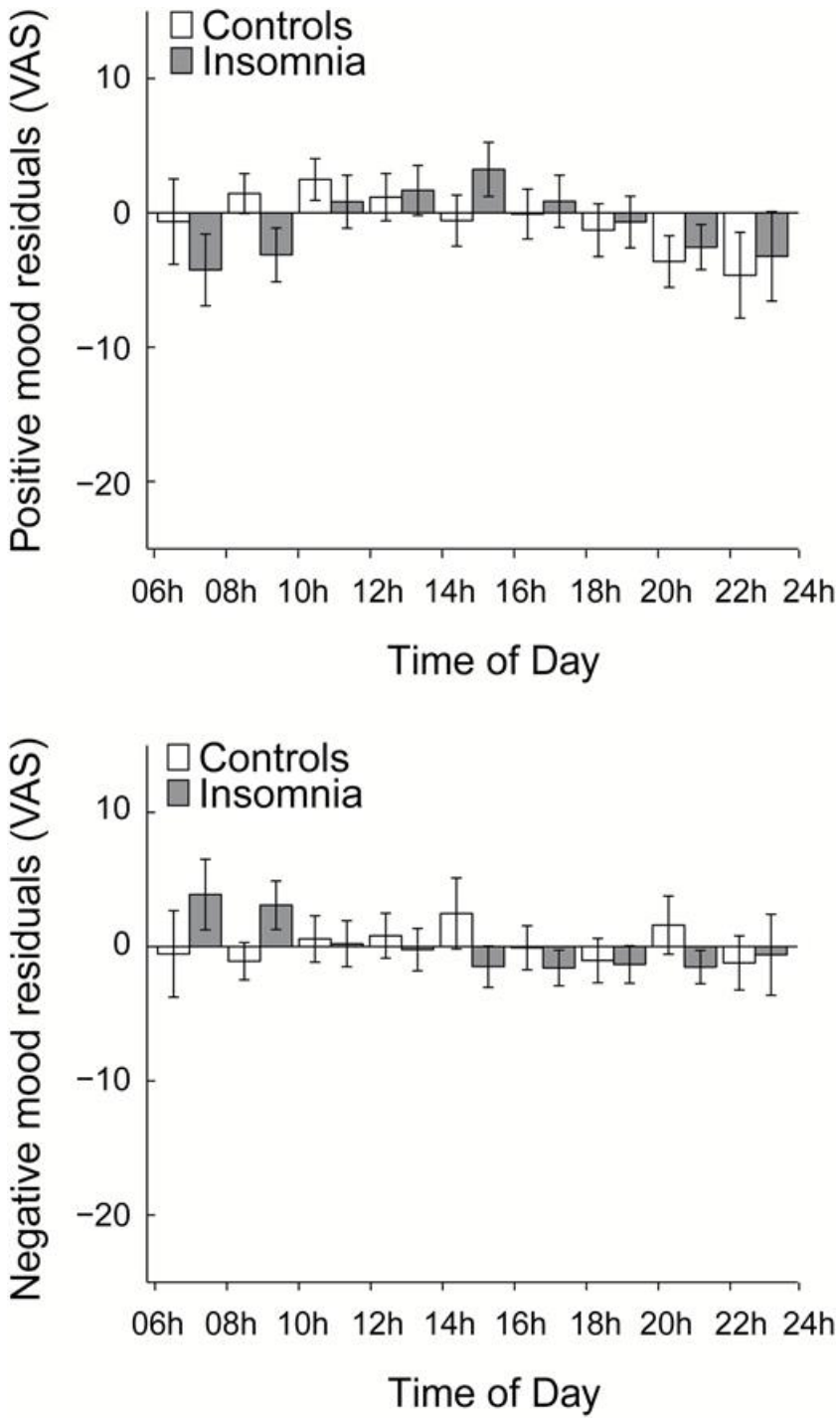
**Figure 4.**

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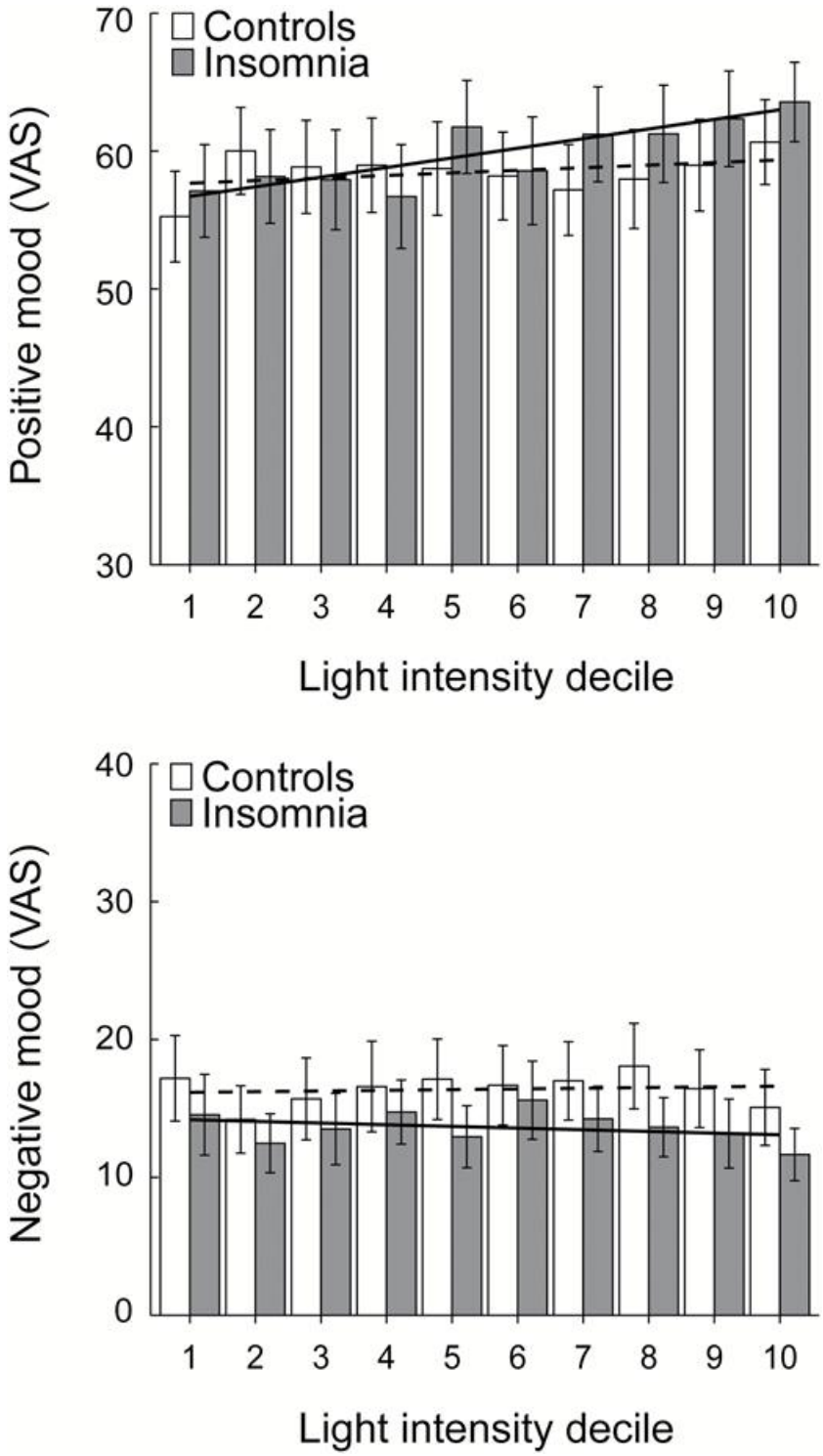
The diurnal peak in Positive and Negative Mood ratings differs between controls and insomnia. Average participant-centered ratings on Positive Mood (upper panel) and Negative Mood (lower panel) vary across time of day in participants suffering from ID (gray bars) and controls (white bars). Data are aggregated in 2 hr time bins according to the mid time of the intervals between subsequent alarms. In order to be able to visualize time of day effects only, both plots show residual ratings, after correcting for the effects of CS-transformed light intensity. Error bars indicate 95% confidence intervals. The numbers of observations in each time interval were, respectively, 34, 162, 117, 105, 88, 105, 118, 98, and 31 for the control participants and 63, 141, 110, 109, 103, 99, 119, 115, and 36 for participants suffering from insomnia. Too few observations were available between 0:00 and 6:00 hr for useful visualization. Mixed-effect regression analysis fitting a linearized 24 hr cosine function indicated significant diurnal variation in both Positive and Negative Mood that differed between ID and controls. Positive Mood peaked at 15:14 hr in ID and 12:13 hr in controls. Negative Mood peaked at 06:31 hr in ID and 15:33 hr in controls. VAS = Visual Analogue Scale.

No ID by light intensity interaction effect was present for Positive and Negative Mood (Figure 5, $p = .14$ and $p = .45$, respectively).

**Figure 5.**

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Positive and Negative Mood ratings of people suffering from insomnia and control participants do not change with more intense environmental light. Average subjective ratings on Positive Mood (upper panel) and Negative Mood (lower panel) do not significantly change with light intensity in participants suffering from insomnia disorder (gray bars, solid line) or control participants (white bars, dashed line). Bars summarize average ratings, aggregated in ten deciles of increasing CS-transformed light intensity ranges defined within each participant. Error bars indicate 95% confidence intervals. VAS = Visual Analogue Scale.

Positive and Negative Mood yielded ICCs of 0.73 ± 0.04 [0.64, 0.81] and 0.62 ± 0.04 [0.53, 0.71], respectively, indicating a larger between-participant than within-participant contribution to the variance in Positive and Negative Mood. The multilevel reliability coefficients for Positive and Negative Mood are shown in Table 4. The between-person reliability is higher than the within-person reliability, indicating that the scales are better at discriminating between-person differences than within-person differences.

**Table 4.**

Variance decomposition and between- and within-person reliability estimates of Positive and Negative Mood

| Variance component | Positive Mood | % | Negative Mood | % |
|---|---|---|---|---|
| $\sigma^2_{PERSON}$ | 169 | 38.1 | 77 | 29.7 |
| $\sigma^2_{TIME(PERSON)}$ | 73 | 16.4 | 67 | 25.9 |
| $\sigma^2_{RESIDUAL}$ | 202 | 45.5 | 116 | 44.8 |
| Total | 444 | 100 | 259 | 100 |
| $R_{KRN}$ | 0.99 | | 0.99 | |
| $R_{CN}$ | 0.64 | | 0.74 | |

Variance components are presented as absolute values and percentages. $\sigma^2_{PERSON}$ represents the between-participant variance. $\sigma^2_{TIME(PERSON)}$ represents the within-participant variance. $\sigma^2_{RESIDUAL}$ represents the error variance. $R_{KRN}$ represents the estimate of between-participant reliability, assuming that items are nested within times, which are nested within participants. $R_{CN}$ represents the estimate of the nested within-participant reliability.

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# Discussion

Previous findings suggested that people suffering from insomnia may have a compromised hedonic capacity that could involve structural deviations in the OFC. Based on these findings, the present study aimed to evaluate whether, during everyday life, people suffering from insomnia differ from those without sleep complaints with respect to subjectively experienced Liking and Wanting, two major dimensions of the reward system. Moreover, based on the previous findings of direct and indirect projections of the retina of the eyes to reward-regulating brain structures, the second aim of the present study was to evaluate immediate effects of light intensity on subjectively experienced Liking and Wanting, and whether possible effects would differ between people suffering from insomnia and those without sleep complaints.

The ES method was used to survey fluctuations in subjective Liking, Wanting, and more commonly used Positive and Negative Mood adjectives across 7 days. The association of these fluctuations with changing ambient light intensities was assessed using ambulatory monitoring. The results indicated that people suffering from insomnia experience significantly less Liking and Wanting than those without sleep complaints. Interestingly, some recent brain imaging studies have also found deviations in the brain circuitry involved in Liking and Wanting, or more general, the regulation of emotion, stress, and reward. Notably, insomnia severity was found to be associated with volume reduction in the OFC [70–72], a key structure in hedonic evaluation (Liking). OFC volume was moreover found to be positively associated with the ability to maintain or resume sleep in the morning in people without sleep complaints [73, 74] and with perceived sleep quality in veterans [75]. In elderly people, OFC volume was negatively associated with sleep fragmentation [76], which is a key characteristic of insomnia as well [10, 77, 78]. One study found that OFC volume correlated with the severity of insomnia but not with its duration [13]. It was therefore suggested that a low volume could indicate suboptimal functioning that could contribute to insomnia and hyperarousal [12]. Given the role of the OFC in Liking, reduced gray matter volume may be involved in the deficient sensing of comfort and other pleasant experiences, which has been reported before in insomnia in a controlled laboratory study [17] as well as during a eyes-closed resting state recorded at home [16].

In turn, insufficient sensing, integration, and updating of hedonic signals by the OFC can result in an insufficient excitatory output to, and activation of, its major projection area, the caudate nucleus, which has an important role in dampening cortical arousal [12]. Using functional MRI, deficient activation of this “brake” on cortical excitability has been demonstrated in insomnia, especially in those with a more pronounced OFC volume reduction, and proposed to thus contribute to hyperarousal [12].

The deficient Wanting and Liking in people suffering from insomnia could not be attributed to a lower overall average exposure to ambient light intensities, which did not differ between cases and controls. Importantly, although fluctuations in ambient light intensity do not affect the subjective experience of Liking and Wanting in those without sleep complaints, high intensities of ambient light ameliorated the compromised experience of Liking of people suffering from insomnia. A third finding of the present study is that the subjective experience of Liking and Wanting changes in the course of the day and peaks in the late afternoon. This suggests the presence of a diurnal rhythm of Liking and Wanting. A recent laboratory study

with a more limited number of time points (10:00, 14:00, and 19:00 hr) in healthy young males supports the afternoon peak for Wanting but may have been too sparsely sampled to detect a diurnal rhythm that was observed for Liking [79]. Whether the diurnal rhythm of Liking and Wanting is endogenously driven cannot be determined from the present observational field study and remains to be determined in well-controlled laboratory studies. A fourth observation of the present study is that ES of fluctuations in subjective Liking and Wanting seems more sensitive to reveal group differences and effects of light intensity than more commonly used Positive and Negative Mood adjectives.

To the best of our knowledge, this is the first study aiming to measure the acute effects of natural light exposure on subjective Liking and Wanting. Only few studies addressed acute effects of natural light exposure on mood outside of the laboratory environment. These studies used less dynamic sampling strategies [80, 81], fixed time intervals [82] or were limited to specific events like social interactions [83]. The present study aimed to circumvent these limitations by using quasirandomly timed ES of Liking and Wanting. No manipulations concerning sleep–wake or leisure time schedules were undertaken and participants followed their normal routines.

A first limitation of the present study is that it addressed subjectively experienced Liking and Wanting only, which may or may not match *implicit* Liking and Wanting [20]. Methods for brief repeated ambulatory assessment of implicit Liking and Wanting are however presently not available. A recent lab study however found converging support for an afternoon peak in implicit Wanting [79]. A second limitation of the present study is that it did not assess individual differences in functionality of the neurobiological substrates that mediate the effect of light on the reward system and may be compromised with advancing age [84, 85], to evaluate their possible involvement in individual differences in the effect of light and time of day on Liking and Wanting. Indirect indicators are available to evaluate the functionality of ipRGCs [86–88] and the SCN [89–92]. A third limitation may be that the age range of our sample, which is based on the biased entry of people suffering from insomnia with a somewhat advanced age, because of the naturally occurring increased prevalence with aging. In order to attain a homogeneous sample, we restricted the age range to 40–70 years, and targeted matched controls in the same age range. We thus did not specifically target a study on aging, rather a case–control study on insomnia.

The diurnal peak for subjective Liking and Wanting occurred in the middle of the afternoon, somewhat later than the early afternoon peak for environmental light exposure. These findings suggest that the effect of light intensity on subjective Liking and Wanting in people suffering from insomnia is additive to the effect of time of day [79, 93]. Although the diurnal peak occurs in the middle of the afternoon, Figure 2 reveals that the actual rating are lower around this time, suggesting a post-lunch decrement in Wanting and Liking which is more pronounced in controls than in ID. As visualized in Figure 3, even under the highest naturally occurring light intensities, the subjective Liking and Wanting of people suffering from insomnia does not match the subjective Liking and Wanting of those without sleep complaints.

Although we have interpreted the findings as supporting a causal contribution of light to Wanting, Liking, and mood, a reverse explanation could be considered as well. Possibly, if people experience stronger Wanting, Liking, or Positive Mood, they might be more likely to subsequently experience bright light, e.g. by going outdoors. We therefore evaluated post hoc whether this possibility would fit the data better than the model we fitted to the data to evaluate the contribution of light to subsequent Wanting, Liking, and mood. However, in the models evaluating whether Wanting, Liking, or mood have a predictive value for subsequent light exposure in addition to the predictive value of light exposure itself for subsequent light exposure, only the interaction effects of ID by positive mood ($p = .05$) and ID by Liking ($p = .06$) were borderline significant, but none of the other main or interaction effects ($.30 < p < .98$). The finding suggests that people with insomnia are also somewhat more likely to expose themselves to bright light after they experience a more Positive Mood.

Still, the findings provide further support the importance of naturalistic exposure to bright light especially in people with vulnerable sleep. The findings moreover suggest that the therapeutic use of bright light on the functionality of the reward system does not have to be limited to the treatment of depression. It is well known that the complaints of people with insomnia are not limited to their sleep, and the present study provides further support for suboptimal functioning of reward processing.

Some studies in the general population pointed out the importance of naturalistic light exposure for those with vulnerable sleep. In a large observational study on workers of a transportation company, one third of the 13000 participants experienced no light exposure during working hours and experienced more insomnia than their colleagues who were exposed to natural light [94]. A similar smaller observational study found similar differences with respect to sleep quality, but, interestingly, also significantly higher self-reported vitality and a trend toward higher daytime activity in those with better light exposure [95]. The latter findings are compatible with that of an activating effect of light to motivational systems. Studies in healthy elderly people [96] and elderly insomniacs [97] support favorable effects of bright light interventions on well-being and daytime functioning also at advanced age.

Although not considered in the present study, the timing of light exposure may be particularly important. A recent study found an association between both higher intensities of nighttime light exposure and lower intensities of morning light exposure and weight gain [98]. These effects were independent of sleep–wake parameters. Combined with a recent finding that hedonic evaluation is an important factor in over-eating, those with poor sleep and suboptimal functioning of reward processing may be at an increased risk of obesity [99], that might in part be mitigated by bright light

exposure.

In conclusion, by using novel and more sensitive assessment tools, the present study indicates relevance during everyday life of previous suggestions of suboptimal reward processing in people suffering from insomnia [12, 16, 17], as well as of previous suggestions that light affects the reward circuitry [24–26] that could be mediated by projections from photosensitive retinal ganglion cells in the eye to limbic areas including the lateral habenula, medial amygdala, and periaqueductal grey [32–35]. Our findings provide further support for considering the addition of bright light to a multicomponent treatment of insomnia [7].

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## Notes

*Conflict of interest statement*. None declared.

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## References

1. Wittchen HUet al. The size and burden of mental disorders and other disorders of the brain in Europe 2010. *Eur Neuropsychopharmacol* . 2011;21(9):655–679.
Google Scholar Crossref PubMed

2. Bonnet MHet al. 24-Hour metabolic rate in insomniacs and matched normal sleepers. *Sleep* . 1995;18(7):581–588.
Google Scholar Crossref PubMed

3. Bonnet MHet al. Hyperarousal and insomnia: state of the science. *Sleep Med Rev* . 2010;14(1):9–15.
Google Scholar Crossref PubMed

4. Riemann Det al. The hyperarousal model of insomnia: a review of the concept and its evidence. *Sleep Med Rev* . 2010;14(1):19–31.
Google Scholar Crossref PubMed

5. Pavlova Met al. Self-reported hyperarousal traits among insomnia patients. *J Psychosom Res* . 2001;51(2):435–441.

Google Scholar Crossref PubMed

6. Perlis MLet al. Beta EEG activity and insomnia. *Sleep Med Rev* . 2001;5(5):365–376.
Google Scholar Crossref

7. van der Werf YDet al. Is disturbed intracortical excitability a stable trait of chronic insomnia? A study using transcranial magnetic stimulation before and after multimodal sleep therapy. *Biol Psychiatry* . 2010;68(10):950–955.
Google Scholar Crossref PubMed

8. Colombo MAet al. Wake high-density electroencephalographic spatiospectral signatures of insomnia. *Sleep* . 2016;39(5):1015–1027.
Google Scholar Crossref PubMed

9. Wei Yet al. I keep a close watch on this heart of mine: increased interoception in insomnia. *Sleep* . 2016;39(12):2113–2124.
Google Scholar Crossref PubMed

10. Wassing Ret al. Slow dissolving of emotional distress contributes to hyperarousal. *Proc Natl Acad Sci U S A* . 2016;113(9):2538–2543.
Google Scholar Crossref PubMed

11. Baglioni Cet al. Sleep and emotions: a focus on insomnia. *Sleep Med Rev* . 2010;14(4):227–238.
Google Scholar Crossref PubMed

12. Stoffers Det al. The caudate: a key node in the neuronal network imbalance of insomnia?*Brain* . 2014;137(Pt 2):610–620.
Google Scholar Crossref PubMed

13. Baglioni Cet al. Psychophysiological reactivity to sleep-related emotional stimuli in primary insomnia. *Behav Res Ther* . 2010;48(6):467–475.
Google Scholar Crossref PubMed

14. Kringelbach ML. The human orbitofrontal cortex: linking reward to hedonic experience. *Nat Rev Neurosci* . 2005;6(9):691–702.
Google Scholar Crossref PubMed

15. Berridge KCet al. Towards a neuroscience of well-being: implications of insights from pleasure research. In: Brockmann H, Delhey J, eds. *Human Happiness and the Pursuit of Maximization* . Dordrecht: Springer Science + Business Media; 2013: 81–100.
Google Scholar Crossref

16. Diaz BAet al. The Amsterdam Resting-State Questionnaire reveals multiple phenotypes of resting-state cognition. *Front Hum Neurosci* . 2013;7:446.
Google Scholar PubMed

17. Raymann RJet al. Diminished capability to recognize the optimal temperature for sleep initiation may contribute to poor sleep in elderly people. *Sleep* . 2008;31(9):1301–1309.
Google Scholar PubMed

18. Kringelbach MLet al. Towards a functional neuroanatomy of pleasure and happiness. *Trends Cogn Sci* . 2009;13(11):479–487.

Google Scholar Crossref PubMed

19. Berridge KCet al. Parsing reward. *Trends Neurosci* . 2003;26(9):507–513.
Google Scholar Crossref PubMed

20. Rømer Thomsen Ket al. Reconceptualizing anhedonia: novel perspectives on balancing the pleasure networks in the human brain. *Front Behav Neurosci* . 2015;9:49.
Google Scholar PubMed

21. Baumeister RF. Toward a general theory of motivation: problems, challenges, opportunities, and the big picture. *Motiv Emotion* 2016;40(1):1–10.
Google Scholar Crossref

22. Kruglanski AWet al. Aspects of motivation: reflections on Roy Baumeister's essay. *Motiv Emotion* 2016;40(1):11–15.
Google Scholar Crossref

23. Reis HT. Why researchers should think "Real-World" - a conceptual rationale. In: Mehl MR, Conner TS, eds. *Handbook of Research Methods for Studying Daily Life* . New York: The Guildford Press; 2012: 3–21.

24. Vandewalle Get al. Spectral quality of light modulates emotional brain responses in humans. *Proc Natl Acad Sci U S A* . 2010;107(45):19549–19554.
Google Scholar Crossref PubMed

25. Vandewalle Get al. Abnormal hypothalamic response to light in seasonal affective disorder. *Biol Psychiatry* . 2011;70(10):954–961.
Google Scholar Crossref PubMed

26. LeGates TAet al. Light as a central modulator of circadian rhythms, sleep and affect. *Nat Rev Neurosci* . 2014;15(7):443–454.
Google Scholar Crossref PubMed

27. Riemersma-van der Lek RFet al. Effect of bright light and melatonin on cognitive and noncognitive function in elderly residents of group care facilities: a randomized controlled trial. *JAMA* . 2008;299(22):2642–2655.
Google Scholar Crossref PubMed

28. Lieverse Ret al. Bright light treatment in elderly patients with nonseasonal major depressive disorder: a randomized placebo-controlled trial. *Arch Gen Psychiatry* . 2011;68(1):61–70.
Google Scholar Crossref PubMed

29. Terman Met al. A controlled trial of timed bright light and negative air ionization for treatment of winter depression. *Arch Gen Psychiatry* . 1998;55(10):875–882.
Google Scholar Crossref PubMed

30. Eastman CIet al. Bright light treatment of winter depression: a placebo-controlled trial. *Arch Gen Psychiatry* . 1998;55(10):883–889.
Google Scholar Crossref PubMed

31. Wirz-Justice Aet al. Brightening depression. *Science* . 2004;303(5657):467–469.
Google Scholar Crossref PubMed

32. Hattar Set al. Melanopsin-containing retinal ganglion cells: architecture, projections, and intrinsic photosensitivity. *Science* . 2002;295(5557):1065–1070.
Google Scholar Crossref PubMed

33. Hattar Set al. Central projections of melanopsin-expressing retinal ganglion cells in the mouse. *J Comp Neurol* . 2006;497(3):326–349.
Google Scholar Crossref PubMed

34. LeGates TAet al. Aberrant light directly impairs mood and learning through melanopsin-expressing neurons. *Nature* . 2012;491(7425):594–598.
Google Scholar Crossref PubMed

35. Ren Cet al. Dendritic morphology of caudal periaqueductal gray projecting retinal ganglion cells in Mongolian gerbil (*Meriones unguiculatus*). *PLoS One* . 2014;9(7):e103306.
Google Scholar Crossref PubMed

36. Friedman Let al. Scheduled bright light for treatment of insomnia in older adults. *J Am Geriatr Soc* . 2009;57(3):441–452.
Google Scholar Crossref PubMed

37. Fetveit Aet al. Bright light treatment improves sleep in institutionalised elderly–an open trial. *Int J Geriatr Psychiatry* . 2003;18(6):520–526.
Google Scholar Crossref PubMed

38. Lack Let al. The treatment of early-morning awakening insomnia with 2 evenings of bright light. *Sleep* . 2005;28(5):616–623.
Google Scholar Crossref PubMed

39. Lack LCet al. Treating chronobiological components of chronic insomnia. *Sleep Med* . 2007;8(6):637–644.
Google Scholar Crossref PubMed

40. Pallesen Set al. Bright light treatment has limited effect in subjects over 55 years with mild early morning awakening. *Percept Mot Skills* . 2005;101(3):759–770.
Google Scholar Crossref PubMed

41. Benjamins Jet al. Erratum to: The sleep registry. An international online survey and cognitive test assessment tool and database for multivariate sleep and insomnia phenotyping [Sleep Medicine 14S (2013) e293-e294]. *Sleep Med* . 2016;21:178.
Google Scholar Crossref PubMed

42. Edinger Jet al. *The Duke Structured Interview Schedule for DSM-IV-TR and International Classification of Sleep Disorders, Second Edition (ICSD-2) Sleep Disorder Diagnoses* . Durham, NC: Duke University Medical Center; 2004.

43. Diagnostic Classification Steering Committee. *ICSD3—International Classification of Sleep Disorders: Diagnostic and Coding Manual* . 3rd ed. Rochester, MN: American Sleep Disorders Association; 2014.

44. Bastien CHet al. Validation of the Insomnia Severity Index as an outcome measure for insomnia research. *Sleep Med* . 2001;2(4):297–307.
Google Scholar Crossref PubMed

45. Buysse DJet al. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res* . 1989;28(2):193–213.
Google Scholar Crossref PubMed

46. Roenneberg Tet al. Life between clocks: daily temporal patterns of human chronotypes. *J Biol Rhythms* . 2003;18(1):80–90.
Google Scholar Crossref PubMed

47. Roenneberg Tet al. A marker for the end of adolescence. *Curr Biol* . 2004;14(24):R1038–R1039.
Google Scholar Crossref PubMed

48. Bierman Aet al. The Daysimeter: a device for measuring optical radiation as a stimulus for the human circadian system. *Meas Sci Technol* . 2005;16(11):2292–2299.
Google Scholar Crossref

49. Figueiro MGet al. Comparisons of three practical field devices used to measure personal light exposures and activity levels. *Light Res Technol* . 2013;45(4):421–434.
Google Scholar Crossref PubMed

50. Tibboel Het al. Implicit measures of “wanting” and “liking” in humans. *Neurosci Biobehav Rev* . 2015;57:350–364.
Google Scholar Crossref PubMed

51. Born JMet al. Differences between liking and wanting signals in the human brain and relations with cognitive dietary restraint and body mass index. *Am J Clin Nutr* . 2011;94(2):392–403.
Google Scholar Crossref PubMed

52. Parsons CEet al. The motivational salience of infant faces is similar for men and women. *PLoS One* . 2011;6(5):e20632.
Google Scholar Crossref PubMed

53. Finlayson Get al. Is it possible to dissociate ‘liking’ and ‘wanting’ for foods in humans? A novel experimental procedure. *Physiol Behav* . 2007;90(1):36–42.
Google Scholar Crossref PubMed

54. Hofmann Wet al. Dieting and the self-control of eating in everyday environments: an experience sampling study. *Br J Health Psychol* . 2014;19(3):523–539.
Google Scholar Crossref PubMed

55. Depp CAet al. Social behavior, interaction appraisals, and suicidal ideation in schizophrenia: the dangers of being alone. *Schizophr Res* . 2016;172(1–3):195–200.
Google Scholar Crossref PubMed

56. Buysse DJet al. Daytime symptoms in primary insomnia: a prospective analysis using ecological momentary assessment. *Sleep Med* . 2007;8(3):198–208.
Google Scholar Crossref PubMed

57. Romeijn Net al. Cold hands, warm feet: sleep deprivation disrupts thermoregulation and its association with vigilance. *Sleep* . 2012;35(12):1673–1683.
Google Scholar Crossref PubMed

58. Rea MSet al. Circadian light. *J Circadian Rhythms* . 2010;8(1):2.
Google Scholar Crossref PubMed

59. Batschelet E.*Circular Statistics in Biology* . London: Academic Press; 1981.

60. Webb ICet al. Diurnal and circadian regulation of reward-related neurophysiology and behavior. *Physiol Behav* . 2015;143:58–69.
Google Scholar Crossref PubMed

61. Jankowski KSet al. Diurnal variation in energetic arousal, tense arousal, and hedonic tone in extreme morning and evening types. *Chronobiol Int* . 2008;25(4):577–595.
Google Scholar Crossref PubMed

62. Fernández JRet al. Inferential statistical method for analysis of nonsinusoidal hybrid time series with unequidistant observations. *Chronobiol Int* . 1998;15(2):191–204.
Google Scholar Crossref PubMed

63. Shrout PEet al. Psychometrics. In: Mehl MR, Conner TS, eds. *Handbook of Research Methods for Studying Daily Life* . New York: The Guildford Press;2012:302–320.

64. Agostinelli C, Lund U. *R package 'circular': Circular Statistics (Version 0.4-7). 2013*. Retrieved from https://CRAN.R-project.org/package=circular

65. Bates Det al. Fitting linear mixed-effects models using lme4. *J Stat Softw* . 2015;67(1): 1–48.
Google Scholar Crossref

66. R Core Team . R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. 2016. Retrieved from https://www.R-project.org/

67. Revelle W. psych: procedures for Personality and Psychological Research (Version 1.7.5). 2017. Retrieved from https://CRAN.R-project.org/package=psych

68. Davison ACet al. *Bootstrap Methods and Their Applications* . Cambridge: Cambridge University Press; 1997.
Google Scholar Crossref

69. Canty A, Ripley B. boot: Bootstrap R (S-Plus) Functions. (Version 1.3-18). 2016. Retrieved from https://CRAN.R-project.org/package=boot

70. Joo EYet al. Brain gray matter deficits in patients with chronic primary insomnia. *Sleep* . 2013;36(7):999–1007.
Google Scholar Crossref PubMed

71. Altena Eet al. Reduced orbitofrontal and parietal gray matter in chronic insomnia: a voxel-based morphometric study. *Biol Psychiatry* . 2010;67(2):182–185.
Google Scholar Crossref PubMed

72. Winkelman JWet al. Increased rostral anterior cingulate cortex volume in chronic primary insomnia. *Sleep* . 2013;36(7):991–998.
Google Scholar Crossref PubMed

73. Stoffers Det al. Orbitofrontal gray matter relates to early morning awakening: a neural correlate of insomnia complaints?*Front Neurol* . 2012;3:105.

Google Scholar Crossref PubMed

74. Weber Met al. Habitual ‘sleep credit’ is associated with greater grey matter volume of the medial prefrontal cortex, higher emotional intelligence and better mental health. *J Sleep Res* . 2013;22(5):527–534.
Google Scholar Crossref PubMed

75. Chao LLet al. Associations between subjective sleep quality and brain volume in Gulf War veterans. *Sleep* . 2014;37(3):445–452.
Google Scholar Crossref PubMed

76. Lim ASet al. Regional neocortical gray matter structure and sleep fragmentation in older adults. *Sleep* . 2016;39(1):227–235.
Google Scholar Crossref PubMed

77. Feige Bet al. Does REM sleep contribute to subjective wake time in primary insomnia? A comparison of polysomnographic and subjective sleep in 100 patients. *J Sleep Res* . 2008;17(2):180–190.
Google Scholar Crossref PubMed

78. Riemann Det al. REM sleep instability–a new pathway for insomnia?*Pharmacopsychiatry* . 2012;45(5):167–176.
Google Scholar PubMed

79. Byrne JEet al. Diurnal rhythms in psychological reward functioning in healthy young men: ‘Wanting’, Liking, and learning. *Chronobiol Int* . 2017;34(2):287–295.
Google Scholar Crossref PubMed

80. Espiritu RCet al. Low illumination experienced by San Diego adults: association with atypical depressive symptoms. *Biol Psychiatry* . 1994;35(6):403–407.
Google Scholar Crossref PubMed

81. Jean-Louis Get al. Daily illumination exposure and melatonin: influence of ophthalmic dysfunction and sleep duration. *J Circadian Rhythms* . 2005;3:13.
Google Scholar Crossref PubMed

82. Einon D. The influence of ambient light and menstrual status on the moods of a nonclinical population of young women. *Psychosom Med* . 1997;59(6):616–619.
Google Scholar Crossref PubMed

83. aan het Rot Met al. Exposure to bright light is associated with positive social interaction and good mood over short time periods: a naturalistic study in mildly seasonal people. *J Psychiatr Res* . 2008;42(4):311–319.
Google Scholar Crossref PubMed

84. Swaab DFet al. Biological rhythms in the human life cycle and their relationship to functional changes in the suprachiasmatic nucleus. *Prog Brain Res* . 1996;111:349–368.
Google Scholar Crossref PubMed

85. Turner PLet al. The role of environmental light in sleep and health: effects of ocular aging and cataract surgery. *Sleep Med Rev* . 2010;14(4):269–280.
Google Scholar Crossref PubMed

86. van der Meijden WPet al. Post-illumination pupil response after blue light: reliability of optimized melanopsin-based phototransduction assessment. *Exp Eye Res* . 2015;139:73–80.

Google Scholar Crossref PubMed

87. van der Meijden WPet al. Individual differences in sleep timing relate to melanopsin-based phototransduction in healthy adolescents and young adults. *Sleep* . 2016;39(6):1305–1310.
Google Scholar Crossref PubMed

88. Bruijel Jet al. Individual differences in the post-illumination pupil response to blue light: assessment without mydriatics. *Biology* . 2016; 5(3):34.

89. Harper DGet al. Dorsomedial SCN neuronal subpopulations subserve different functions in human dementia. *Brain* . 2008;131(Pt 6):1609–1617.
Google Scholar Crossref PubMed

90. Hu Ket al. Reduction of scale invariance of activity fluctuations with aging and Alzheimer's disease: involvement of the circadian pacemaker. *Proc Natl Acad Sci U S A* . 2009;106(8):2490–2494.
Google Scholar Crossref PubMed

91. Hu Ket al. Progression of dementia assessed by temporal correlations of physical activity: results from a 3.5-year, longitudinal randomized controlled trial. *Sci Rep* . 2016;6:27742.
Google Scholar Crossref PubMed

92. Van Someren EJet al. Improving melatonin circadian phase estimates. *Sleep Med* . 2007;8(6):590–601.
Google Scholar Crossref PubMed

93. Murray Get al. Nature's clocks and human mood: the circadian system modulates reward motivation. *Emotion* . 2009;9(5):705–716.
Google Scholar Crossref PubMed

94. Leger Det al. Underexposure to light at work and its association to insomnia and sleepiness: a cross-sectional study of 13296 workers of one transportation company. *J Psychosom Res* . 2011;70(1):29–36.
Google Scholar Crossref PubMed

95. Boubekri Met al. Impact of windows and daylight exposure on overall health and sleep quality of office workers: a case-control pilot study. *J Clin Sleep Med* . 2014;10(6):603–611.
Google Scholar PubMed

96. Sörensen Set al. Quality of light and quality of life: an intervention study among older people. *Lighting Res Technol* . 1995;27(2):113–118.
Google Scholar Crossref

97. Murphy PJet al. Enhanced performance in elderly subjects following bright light treatment of sleep maintenance insomnia. *J Sleep Res* . 1996;5(3):165–172.
Google Scholar Crossref PubMed

98. Obayashi Ket al. Ambient light exposure and changes in obesity parameters: a longitudinal study of the HEIJO-KYO cohort. *J Clin Endocrinol Metab* . 2016;101(9):3539–3547.
Google Scholar Crossref PubMed

99. Nguyen KPet al. Why do mice overeat palatable diets? A comparsion of hedonic and homeostatic mechanisms. In: proceedings from the Neuroscience; 2016; San Diego.

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These authors contributed equally to this work.



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