Light exposure behaviors predict chronotype, mood, sleep quality, memory, and concentration

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# Abstract

The light exposure behavior assessment (LEBA) tool helps us to categorize light exposure behaviors, but whether this categorization is effective in predicting different aspects of our health, memory and concentration is not clear. Hence, we tested whether LEBA categories could predict chronotype, mood, sleep quality, memory and concentration using a partial least squares structural equation model (PLS-SEM). A total of 301 Malaysian adult residents (MeanAge±SD=28±9) – 218 females and 83 males participated in this study. Participants completed LEBA, Morningness-Eveningness questionnaire, Positive and Negative Affect Schedule, Pittsburgh Sleep Quality Index, and single items assessing trouble in memory and concentration. Results indicated that the fitted model exhibited satisfactory predictive power (61.36%). The model predicted that increased use of wearable blue filters indoors and outdoors would decrease the morning affect (Direct effect, DE=-0.16). Increased time spending outdoors predicted positive affect (DE=0.32) and early chronotype (DE: RI=0.14, PT=0.15, RT=0.15). Increased use of smart gadgets on the bed before sleeping predicted late chronotype (DE: RT=-0.26; RI=-0.23; PT=-0.24; MA=-0.13), increased negative affect, reduced sleep quality (DE=0.13) and increased trouble in memory and concentration (Total effect=0.20 & 0.23, respectively). Increased use of electric light in the morning and daytime predicted positive affect (DE=0.16) and sleep quality (DE=-0.16). Collectively these results provide valuable insights into developing a healthy light diet to promote health and wellness.

Keywords: *light exposure; light-related behaviors; non-visual effects of light; light diet; PLS-SEM*

# Introduction

Research conducted over the last four decades has shown that retinal light exposure exhorts a profound influence on our physiology, behavior and emotion, including modulation of sleep, circadian rhythms, alertness, mood, neuroendocrine and neurobehavioral functions [1-5]. These influences of light on human physiology and behaviors are collectively known as non-image-forming responses (NIF) of light. The NIF effects of light are mediated mainly by stimulating the photopigments of the intrinsically photoreceptive retinal ganglion cells (ipRGCs)-melanopsin that is most sensitive to short wavelength-dominant (blue-enriched, ~480nm) lights [6].

## Light’s influence on chronotype, sleep quality and mood

With the advent of artificial light and self-luminous displays, our retinal light exposure is not limited to the natural day-night cycle. An extensive body of scientific evidence suggests that the imbalance of light and dark exposure disrupts the human circadian system [7]. Subsequently, this disruption gives rise to a series of adverse consequences, including decreased sleep quality, mood and the alteration of sleeping habits [7-9]. Since the natural light-dark cycle is the most vital zeitgeber to synchronize our body clock to the astronomical day, altering this cycle forces the population to have different chronotype-disposition for activity early or late in the day [10]. Bright light exposure at night is reported to be associated with having a late chronotype [11]. In contrast, bright light exposure in the morning is associated with having an early chronotype [12, 13]. Increased nighttime light exposure is also associated with decreased sleep quality [14, 15]. However, several studies reported better nighttime sleep quality after exposure to bright light in the morning in an office environment [8, 9, 16]. Further, brain regions such as limbic areas and the hypothalamic-pituitary-adrenal axis responsible for regulating mood are susceptible to the circadian regulation [17]. Thus, it is reasonable to anticipate that the disruption of circadian regulation will disrupt the mood regulation [17]. Bright light exposure is associated with an increased positive mood in the morning, whereas afternoon bright light exposure is reported to increase negative mood [18-21].

## Light exposure, memory, and concentration

Several studies confirmed that retinal light exposure activates the hippocampus, which is closely associated with memory functions. [22-24]. Thus, it is anticipated that retinal light exposure would influence memory. Vandewalle [25] reported an enhanced working memory performance for blue light exposure compared to green light exposure (*N*=18). Alkozei [26] reported enhanced verbal memory for a 30-minute blue light exposure (*N*=12) compared to amber light. Huiberts [27] provided further evidence of the influence of light on memory-based task performance, where they reported better performance in easy tasks and demerited performance in difficult tasks under bright light conditions (*N*=64). Retinal light exposure is also reported to be associated with improved concentration. Kretschmer [28] reported an improved concentration under a dynamic bright light condition (300-3000 lux) in night shift work (*N*=32). Sleegers [29], in their series of studies on the effects of light in classroom environments, concluded a beneficial influence of a dynamic light environment on students’ concentration (*N*=181).

## Interrelation of chronotype, mood, sleep quality, memory and concentration

The influence of chronotype on sleep quality is well documented in the literature. Juda [30], in their study on 371 shift workers, reported shortened sleep duration and higher sleep disturbance during night shifts among early chronotypes and an oppositive pattern was observed for late chronotypes. Further, late chronotypes are reported to have poor sleep quality with non-regular sleeping habits during weekdays due to the misalignment of their preferred activity period vs. real-world demands [31-33]. Chronotype can influence our memory and concentration [34-36]. Schmidt [34] reported an interaction of chronotype and time of day on memory (*N*=32). Several studies reported a synchrony effect where early chronotypes perform better in the morning, and late chronotypes perform better in the later part of the day [37, 38]. Moreover, a sizable amount of literature has indicated that sleep quality is contingent on mood [39]. Positive affect- a state of pleasurable engagement with the environment is associated with improved sleep patterns [40, 41]. In contrast, negative affect- a state of unpleasurable engagement with the environment is reported to increase sleep deprivation, poor sleep quality, and reduced cognitive functioning [42-46]. Poor sleep quality is reported to reduce memory functions and concentration [47-51].

## Proposing a theoretical framework

Acknowledging the influence of retinal light exposure on our health and well-being, a significant number of studies tried to quantify healthy light exposure. Recommendations are made to specify a healthy indoor light environment [52]. However, less focus is given to light exposure-related behaviors. Light exposure-related behaviors could be an active agent modifying our retinal light exposure. People can modify their light exposure through different behaviors by actively seeking or avoiding certain types of light exposure. However, understanding these behaviors is essential to develop a healthy light diet-a pattern of light exposure promoting health, wellness and performance. In that vein, the *light exposure behavior assessment* [LEBA; 53] tool was developed that helped to categorize these behaviors into five major factors. The first factor (LEBA F1) investigates the propensity of wearing blue light filter glasses indoors and outdoors. The second factor (LEBA F2) captures time spent outdoors. The third-factor measures (LEBA F3) our habit of using smart devices in bed. The fourth factor (LEBA F4) investigates light exposure-related behaviors before bedtime. The last factor (LEBA F5) captures our habit of using different electric light sources throughout the day. However, whether these categorizations of behaviors would effectively be used to predict different aspects of our health, memory and concentration is still less known.

Thus, in this study, we aim to predict the influence of different LEBA categories on chronotype, mood, sleep quality, memory and concentration. We pose the following question: What are the influences of LEBA categories on (a) chronotype, (b) mood, (c) sleep quality, and (d) memory and concentration? To answer this question, we proposed a theoretical framework (Figure 1) based on the literature reviewed. We used the partial least squares structural equation modeling (PLS-SEM), which is best suited to formulate such a predictive model [54, 55]. Predicting relationships using PLS-SEM is a two-step process where first, a *measurement model* is used to assess the reliability and validity of the latent variables used in the model. Second, a *structural model* is used to investigate the precited relationships of the latent structures. In the structural model, (i) the *direct effects (DE)*: influences unmediated by any other constructs in the model, (ii) *indirect effects (IE):* influences mediated by at least one intervening construct in the modeland (iii) *total effects (TE)*: sums of direct and indirect effects of a given construct can be estimated [56].

We predicted that LEBA categories would directly influence chronotype (H1), mood (H2), and sleep quality (H3). We also predicted that sleep quality would be influenced by mood (H4) and chronotype (H5). Memory and concentration would be influenced by sleep quality (H6), mood (H7), and chronotype (H8). LEBA categories would directly influence memory and concentration (H9). Lastly, we predicted that LEBA categories would exhibit a significant total effect on sleep quality (H10), memory and concentration (H11).

# Results

## Structural validity

Table 2 presents the fit indices of the scales used in this study. LEBA, MEQ, and PANAS scales exhibited acceptable to a good fit in terms of CFI and TLI (>0.95 or .90), RMSEA (<0.08 or 0.06), and SRMR (<0.08). The χ2 test was significant for PSQI and MEQ. Since the χ2 test is susceptible to sample size, more emphasis was given to the rest of the fit indices to assess the model fit [57].

## Measurement model

We excluded one item from LEBA (item 04) and four items from MEQ (items 06, 10,16,12) due to weak factor loadings (<0.40; Supplementary Table 1). All remaining factor loadings were significant (p<0.05). The results of the refitted measurement model assessment are shown in Supplementary Table 2. The sleep efficiency (SE) factor of PSQI exhibited poor reliability in terms of coefficient Cronbach’s alpha coefficient (=0.48) but had satisfactory construct reliability (CR=0.79). All other factors exhibited acceptable to satisfactory internal consistency in terms of Cronbach’s coefficient (0.51-0.94) and construct reliability (0.72-0.96). In terms of convergent validity, 8 out of 13 constructs had AVEs > 0.50 (except LEBA F2, NA, PSQ, PT and RI). However, all 13 constructs had CR > 0.60 and AVEs < CR. This indicated acceptable reliability and convergent validity of all constructs in the model.

To establish the discriminant validity, we calculated the square root of each construct’s AVEs and compared them to their corresponding inter-construct correlation (Supplementary Table 3). All constructs’ square root of AVEs were greater than their inter-construct correlation indicating satisfactory discriminant validity. Further evidence of the discriminant validity of the constructs was drawn by HTMT analysis. Supplementary Table 4 presents the HTMT values and indicates satisfactory discriminant validity (HTMT<0.80) for all 13 constructs.

## Structural model

VIFs for all constructs were < 3 indicating no possible collinearity. Figure 3 and Table 3 depict significant (t-value >1.906) direct effects and total effects observed in our model. All direct effects of the structural model are provided in *Supplementary Table 5*.

### Predicted relationships

Table 3 indicated that, in line with our predictions, LEBA categories exhibited direct effects on chronotype *(H1)*, mood *(H2)* and sleep quality *(H3).* We observed a negative significant direct effect of LEBA F1 on MA (= -0.16). LEBA F2 exhibited a direct effect on positive affect (= 0.32) and chronotype factors: PT (= 0.15), RT (= 0.15), RI (= 0.14). LEBA F3 significantly negatively directly influenced the four factors of chronotype: PT (= -0.24), MA (= -0.13; p<0.05), RT (= -0.26) and RI (= -0.23). LEBA F3 also exhibited positive influences on negative affect (= 0.17) and PSQ (= 0.13). In contrast, LEBA F5 exhibited a significant positive influence on positive affect (= 0.16) and a negative influence on PSQ (= -0.16). Both positive and negative affect directly influence sleep quality *(H4)*, where positive mood increased sleep efficiency (= 0.22) and sleep quality (= -0.18), and negative affect decreased sleep quality (= -0.28).

Chronotype directly influenced sleep quality *(H5)*, where morning affect (MA) was observed to increase sleep quality(= -0.20). A negative influence of sleep quality was observed on memory and concentration *(H6),* where poor sleep quality was predicted to increase trouble in memory (= 0.17) and concentration (= 0.26). Increased negative affect predicted a deteriorated memory and concentration (*H7*; memory=0.38; concentration 0.33). No significant direct effect of chronotype *(H8)* and light exposure-related behaviors *(H9)* was observed on memory and concentration. We observed significant total effects of light exposure-related behaviors on sleep quality *(H10)*. LEBA F1 and LEBA F3 were predicted to decrease sleep quality (= 0.11 and= 0.21, respectively). In contrast, LEBA F5 was predicted to improve sleep quality (= -0.17). Lastly, significant total effects of light exposure-related behaviors on memory and concentration were observed *(H11)*. LEBA F3 was predicted to increase trouble in memory and concentration (= 0.20 and= 0.23, respectively).

### Explanatory and predictive Power of the fitted model.

Our fitted model exhibited substantial *R2* for PSQ (26.79%) and trouble in concentration (30.35%). Moderate *R2* was observed for PA (13.85%) and trouble in memory (25.51%). Adequate *R2* was observed for PT (10.96%) and RT (12.45%). Our model exhibited weak R2 for MA, RI, SE and NA. function indicated our model had medium predictive power with 61.36% of the indicators having RMSE value lower than the LM benchmark.

# Discussion

This study investigated the relationship between light exposure behavior with chronotype, sleep quality, mood, memory and concentration. To test the relationships, we conceptualized a framework based on the existing literature and used PLS-SEM to assess the direct and total effects of light exposure behaviors on chronotype, mood, and sleep quality, memory and concentration.

Our measurement model indicated acceptable reliability and validity of the scales used to measure chronotype, sleep quality and mood. Two factors: sleep efficiency (SE) and MEQ Rising (RI), had Cronbach’s alpha <0.60 but exhibited satisfactory construct reliability (>0.60). These two factors were composed of only two items each, which might be a contributor to the low Cronbach’s alpha coefficient. Further, we used two single global items to capture the essence of constructs: trouble in memory and concentration. The use of such global single items allowed us to reduce participants’ cognitive demands required to respond to our survey and increased the response rate with fewer missing parts [58]. Typically, single global items are known to be reliable with good predictive validity and allow the participants to consider the key features of the given construct [59-62].

Results indicated that the structural model had satisfactory explanatory power (*R2*>0.10) for all factors except for morning affect (MA), rising behaviors (RI), sleep efficiency (SE) and negative affect (NA). These four factors exhibited weak *R2*. However, overall, our model exhibited satisfactory predictive relevance, and most relationships were in line with our predictions. Results indicated that LEBA categories influenced chronotype (*H1*), mood (*H2*), and sleep quality (*H3*). Mood (*H4*) and chronotype (*H5*). Sleep quality*(H6)* and mood *(H7)* exhibited significant direct influences on memory and concentration. However, chronotype did not exhibit any significant direct influence on memory and concentration (*H8*). We did not observe any significant direct effect of LEBA categories on memory and concentration (*H9*). However, significant total effects of LEBA categories were observed on sleep quality (*H10*), memory and concentration (*H11*).

Increased use of *blue filters indoors and outdoors* (LEBA F1) was predicted to decrease the morning affect (DE= -0.16), indicating the necessity of the blue light component to synchronize our body clock with the natural light-dark cycle. A group of photoreceptors in our eye- intrinsically photoreceptive retinal ganglion cells (ipRGCs) are highly sensitive to blue light [2, 63]. These ipRGCs receive signals from the light and send them to the suprachiasmatic nucleus (SCN) of the brain, the so-called master clock of our body clock to align our inner rhythm with the astronomical cycle. Hence, deprivation of blue light during daytime misguides our circadian rhythm. Figueiro [64] in their study, reported that blue-enriched light exposure throughout the day promotes better alignment of the circadian rhythm with the earth’s 24-h light-dark cycle. Studies also reported a delay in nighttime melatonin onset due to blue-depleted daytime light exposure causing a phase-shift in our circadian rhythm [65].

*Spending time outdoors* (LEBA F2) led to an improved mood by increasing the positive affect (DE= 0.32) and promoted early chronotype (DE: RI=0.14, PT=0.15, RT=0.15). Similar results were reported in previous studies. Burns [66], using a bio-bank of 400,000 UK participants, conferred that time spent in outdoor light improved mood and promoted early chronotypes. An [67] reported a reduced depressive mood among workers when more sunlight is available in the environment. Further, Figueiro [8] reported reduced depressive symptoms for light exposures with high circadian efficiency-ability to entrain our body clock like the sunlight. Collectively, these findings suggest that sleep and mood-related problems are rooted in people’s behaviors that guide their outdoor light exposure.

*Increased use of smart gadgets on the bed* before sleeping (LEBA F3) was predicted to promote late chronotype (DE: RT=-0.26; RI=-0.23; PT=-0.24; MA=-0.13), negative affect (DE= 0.17) and reduced sleep quality (DE=0.13). Significant total effects were observed on trouble in memory, concentration, and sleep quality (TE= 0.20, 0.230.21, respectively). Previous studies reported adverse effects of using smart devices in bed on sleep quality and mood [68-70]. The self-luminous display of smart gadgets often emits blue lights. Exposure to these blue lights at night is directly associated with reduced cognitive functioning, mood, circadian phase shift and reduced sleep quality [71-75].

Results indicated that the increased *use of electric light in the morning and daytime* (LEBA F5) improved positive affect (DE= 0.16) and sleep quality (DE = -0.16, TE = -0.17). A similar conclusion was also drawn in the works of Figueiro [8], where increased circadian effective daytime light exposure was reported to improve sleep quality and mood among office workers (*N*=109). Several studies independently demonstrated that inadequate daytime light exposure led to greater melatonin suppression at night, thus causing a phase shift, more nighttime awakening sleep deprivation and poor sleep quality [76-78]. Studies based on real-world settings such as offices and schools collectively also indicated that increased electric light exposure improved mood and sleep quality [9, 79, 80]. Brown [52], in their attempt to provide a consensus-based recommendation for healthy light exposure for indoor usage, indicated a requirement of at least 250 melanopic equivalent daylight illuminance to mitigate the adverse effects of reduced sunlight exposure.

In line with the literature, we predicted sleep quality would be contingent upon mood (H4) and chronotype *(H5).* Further, we predicted trouble in memory and concentration would be predicted by sleep quality *(H6)* and mood *(H7).* Our results supported these predictions. However, we did not observe any significant direct effect of chronotype *(H8)* on memory and concentration. Several studies reported the influence of chronotype on memory and concentration [34-36]. These influences are highly dependent on the time of day, with a diurnal variation of performance differences observed between early and late chronotypes. Since our aim was to assess typical memory and concentration problems in the past month, we were not able to specify the diurnal variation in performance. This could be the leading cause of our model not finding any significant relationship among chronotype, memory and concentration.

Some limitations of the present study should be taken into consideration. First, our PLS-SEM-based model is fitted on a female-dominated sample which hinders the generalizability of the findings. Future studies with gender-balanced samples with higher representativeness of the Malaysian population are suggested to increase the generalizability. Second, we used subjective self-report measures to assess different constructs used in the model, which may lead to social desirability bias. Third, we used a cross-sectional research design to predict the relationships. Future studies employing experimental design are suggested to test the relationships predicted in our model. Fourth, morning affect (MA), rising behaviors (RI), sleep efficiency (SE) and negative affect (NA) exhibited weak R2 in our fitted model. Studies with larger sample sizes might yield better explanatory power for these four factors. Lastly, we did not observe any influence of LEBA F4: *Using light before bedtime*. This factor had three items that investigate how we control the light emitted from our devices before our bedtime, such as using blue light filter applications or dimming the monitor one hour before sleep. But, recent recommendations indicated investigations related to light in sleep environment should consider a time span of three hours prior to sleep [52]. Future studies could investigate those behaviors with a three-hour time span prior to sleep.

This research aims to examine whether light exposure-related behaviors could predict chronotype, sleep quality, mood, memory, and concentration to provide insight into developing a healthy light diet. To attain this goal, a conceptual framework was developed, and a partial least square structural equation modeling was applied to a sample of 301 Malaysian Residents. All constructs used in the model exhibited acceptable reliability and validity. Results indicated that wearing blue light filters during the daytime and using smart gadgets in bed before sleep is detrimental to chronotype, mood, sleep quality, memory and concentration. However, spending time outdoors promotes mood and early chronotype. Also, the usage of electric light in the morning and during the daytime promotes mood and sleep quality. Collectively, these findings will facilitate the development of a healthy light diet to facilitate mental health and wellness.

# Methods

## Participants

We conducted a large-scale online survey on Malaysian residents. The exclusion-inclusion criteria for respondents to be included in this study were: (1) any Malaysian resident aged >18 and able to read and write English (2) no physiological and psychological disorder (self-reported). Three hundred and sixty-six adults completed the survey. The completion rate of our survey was 87% (45 participants' data was excluded due to incompleteness). We further excluded 19 participants based on our exclusion-inclusion criteria. Thus, we used data from 301 participants for further processing.

A priori power analysis was conducted to determine the sample size adequacy with G\*Power 3.0 [81]. To achieve an effect size of 0.15 [82] and 80% statistical power and =0.05, for a multiple liner regression with 13 predictors, a total sample size of 131 individuals was needed. Further, the maximum number of items per factor in our model was six. In the PLS-SEM-based analysis, to detect a minimum value of 0.10 for a factor with six items with 80% statistical power and *α*=0.05, at least 130 participants are required [83]. Our sample size exceeded these recommendations. Out of 301 participants (AgeMean±SD=28±9), 72.43% (218) were female, ranging in age from 18 to 59 (AgeMean±SD=26.85±8.07), and 27.57% (83) were male with an age range between 18 to 74 years (AgeMean±SD=30.35±12.14). 78.66% of the participants were unmarried. The majority of the participants were students (71.42%) and of intermediate chronotype (68%).

## Measures

### Light exposure behavior assessment

Light exposure-related behaviors were measured using the short form of the Light Exposure Behavior Assessment [53]. The short form contains five factors with 18 items. Light Exposure Behavior Assessment (LEBA) measures the propensity of different light exposure-related behaviors in the last one month retrospectively using a five-point Likert-type response scale (1 = never; 2 = rarely; 3 = sometimes; 4 = often; 5 = always). All 19 items of LEBA and the participants’ responses to them are shown in Figure 3.

### Positive and negative affect schedule

The positive and negative affect schedule [PANAS; 84] was used to measure positive and negative affect. PANAS comprises two 10-item mood scales measuring positive affect (PA) and negative affect (NA). In this study, participants retrospectively rate their positive and negative affect based on the last month using a five-point Likert-type response scale (1 = very slightly/not at all; 2 = a little; 3 = moderately; 4 = quite a bit; 5 = extremely).

### Memory and concentration

We used two global single items with four-point Likert-type response options investigating trouble in memory and concentration. These global single items asked the participants about the propensity of their memory and concentration difficulty in the last month (0=Absent; 1=Slight; 2=Moderate; 3=Severe).

### Pittsburgh sleep quality index

We used the Pittsburgh Sleep Quality Index [PSQI; 85] to measure the participants' sleep quality. PSQI measures seven domains of sleep to differentiate “poor” from “good” sleep. Participants responded to the PSQI using Likert-type response options ranging from 0 to 3, whereby 3 reflects the negative extreme on the Likert Scale. A sum of scores ≥ 5 indicates poor sleep quality. The latent structure of PSQI was reported to vary from one factor to three factors [85, 86]. Dunleavy [87], in their study recommended using a two-factor model: perceived sleep quality (PSQ) and sleep efficiency (SE) while measuring the sleep quality among Singapore citizens. In this study, we followed their recommended structure.

### Morningness-eveningness questionnaire

Chronotype was measured using Morningness-Eveningness questionnaire [MEQ; 88]. MEQ consists of 19 questions, and the scores range from 16 to 86. A higher score indicates a higher morning propensity. Caci [89] reported a four-factor structure of MEQ: peak time (PT), morning affect (MA), retiring (RT) and rising (RI) in s student sample (N=456). Items in PT investigate the body’s peak time for different activities. MA investigates our bodily responses in the morning. RT captures the time when our body starts to prepare for sleep. Lastly, RI investigates the time when our body prepares for waking up.

## Procedure

The project received ethics clearance from Monash University Human Research Ethics Committee (Project ID: 14786). A quantitative cross-sectional, fully anonymous online survey was conducted. Participants were invited via email and social media (i.e., LinkedIn, Twitter, and Facebook) with the attachment of an Explanatory Statement. It was mentioned in the explanatory statement that their participation was voluntary and that they could withdraw from participation at any time without being penalized. If the participants expressed happiness with the Explanatory Statement, a survey link was sent to them. At the beginning of the survey, their consent was recorded digitally. The survey took around 15 to 20 minutes, for which they were not compensated. We collected the survey data between April 2022 and November 2022.

## Analytic strategies

We used R [version 4.1.2; 90] and several statistical packages, including esemComp [91], “SEMinR” [92] and tabledown [93] for our analysis.

### Structural validity of the scales

We gathered structural validity evidence of LEBA, PSQI, MEQ and PANAS scales in our sample using the exploratory structural equation modeling [ESEM; 94]. ESEM intricates the computational advantages of exploratory and confirmatory factor analysis by allowing the items to cross-load to represent the data more realistically and offering fit indices to assess the model fit. To assess the model fit, we followed the guidelines of Hu and Bentler [95]: comparative fit index (CFI) and the Tucker Lewis index (TLI): acceptable fit.90, good fit .95; the root mean square error of approximation (RMSEA): acceptable fit <0.08, good fit < 0.06; and the standardized root mean square (SRMR): acceptable fit <0.10, good fit<0.08.

### Partial least squares structural equation modeling

**Measurement model assessment.** First, we assessed the quality of the measurement model. We excluded items with factor loading < 0.40 to increase the robustness of the measurement model [92]. Second, we estimated the internal consistency reliability estimates of each construct. We reported both the lower bound estimate of reliability- Cronbach’s coefficient and the upper bound estimate of reliability-construct reliability (CR). Both Cronbach’s and CR coefficient values range between 0 to 1, where higher values represent better reliability. As a general guideline, Cronbach’s above 0.70 is considered satisfactory [96, 97] and a value above 0.50 is considered acceptable [98]. CR coefficient value of 0.60 and above indicates a satisfactory reliability [92].

Third, we assessed the convergent and discriminant validity of the measurement model. For *convergent validity*, we used the average variance extracted (AVE) value of each construct. AVE ≥ 0.50 or AVE < 0.50 with a CR >0.60 and AVE < CR indicate an acceptable convergent validity [99]. For *discriminant validity,* we compared the square root of the AVE of a construct with its corresponding correlation with other constructs [99]. The square root of the AVEs of each construct should be higher than its correlation with other constructs. We have also reported the bootstrapped heterotrait-monotrait ratio (HTMT) of correlations of the construct as additional proof of discriminant validity. For conceptually similar constructs, the HTMT value should be <0 .90, and for constructs that are conceptually distinct, the HTMT value should be <0.80 [100].

**Structural model assessment.** First, we assessed the collinearity of the constructs in our structural model by calculating variance inflation factor (VIF) values. VIF>3 indicates probable collinearity issues [100]. Next, we estimated the direct effects (DE) and total effects (TE) of the structural model using a bootstrapping approach with 10000 sub-samples and reported the significant total effects (p<0.05) observed in our model. Lastly, we reported the adjusted as a measure of the explanatory power. For assessing the explanatory power, we followed the guidelines of Falk and Miller [101]: values 0.10 indicates adequate explanatory power. Further, we have categorized the values following the guidelines of Cohen [82]: 0.02 (weak), 0.13 (moderate), and 0.26 (substantial). For predictive relevance, we assessed the fitted model’s predictive power by K-fold cross-validation using the function from the “SEMinR” package [92]. provides the root-mean-square error (RMSE) and respective linear-regression model benchmarks (LM) for all indicators. We assessed the model’s predictive power by following the guideline of Hair [92]: (i) high predictive power: all indicators in the fitted PLS-SEM model have lower RMSE values compared to the LM (ii) medium predictive power: the majority(≥50%) of the indicators have lower RMSE values than LM (iii) low predictive power: less than 50% of the indicator have lower RMSE value than LM (iv) no predictive power: no indicator has lower RMSE value than LM model. Figure 4 depicts the analysis steps we followed.

**References**

1. Lok R, Smolders K, C. H. J., Beersma Domien GM, de Kort Yvonne AW. Light, Alertness, and Alerting Effects of White Light: A Literature Overview. J Biol Rhythms. 2018;33(6):589-601.

2. Lockley SW. Spectral Sensitivity of Circadian, Neuroendocrine and Neurobehavioral Effects of Light. Journal of the Human - Environment System. 2008;11(1):43.

3. Cajochen C. Alerting Effects of Light. Sleep Medicine Reviews. 2007;11(6):453-64.

4. Siraji M, Kalavally V, Schaefer A, Haque S. Effects of Daytime Electric Light Exposure on Human Alertness and Higher Cognitive Functions: A Systematic Review. Frontiers in Psychology. 2022;12(6079).

5. Xiao H, Cai H, Li X. Non-Visual Effects of Indoor Light Environment on Humans: A Review. Physiol Behav. 2021;228:113195.

6. Hankins MW, Lucas RJ. The Primary Visual Pathway in Humans Is Regulated According to Long-Term Light Exposure through the Action of a Nonclassical Photopigment. Curr Biol. 2002;12(3):191-8.

7. Lunn RM, Blask DE, Coogan AN, Figueiro MG, Gorman MR, Hall JE, et al. Health Consequences of Electric Lighting Practices in the Modern World: A Report on the National Toxicology Program's Workshop on Shift Work at Night, Artificial Light at Night, and Circadian Disruption. Science of the Total Environment. 2017;607:1073-84.

8. Figueiro MG, Steverson B, Heerwagen J, Kampschroer K, Hunter CM, Gonzales K, et al. The Impact of Daytime Light Exposures on Sleep and Mood in Office Workers. Sleep Health. 2017;3(3):204-15.

9. Viola AU, James LM, Schlangen LJM, Dijk D-J. Blue-Enriched White Light in the Workplace Improves Self-Reported Alertness, Performance and Sleep Quality. Scand J Work Environ Health. 2008;34(4):297-306.

10. Porcheret K, Wald L, Fritschi L, Gerkema M, Gordijn M, Merrrow M, et al. Chronotype and Environmental Light Exposure in a Student Population. Chronobiol Int. 2018;35(10):1365-74.

11. Koo YS, Song J-Y, Joo E-Y, Lee H-J, Lee E, Lee S-k, et al. Outdoor Artificial Light at Night, Obesity, and Sleep Health: Cross-Sectional Analysis in the Koges Study. Chronobiol Int. 2016;33(3):301-14.

12. Czeisler CA, Kronauer RE, Allan JS, Duffy JF, Jewett ME, Brown EN, et al. Bright Light Induction of Strong (Type 0) Resetting of the Human Circadian Pacemaker. Science. 1989;244(4910):1328-33.

13. Khalsa SBS, Jewett ME, Cajochen C, Czeisler CA. A Phase Response Curve to Single Bright Light Pulses in Human Subjects. J Physiol. 2003;549(3):945-52.

14. Cho JR, Joo EY, Koo DL, Hong SB. Let There Be No Light: The Effect of Bedside Light on Sleep Quality and Background Electroencephalographic Rhythms. Sleep Medicine. 2013;14(12):1422-5.

15. Obayashi K, Saeki K, Kurumatani N. Association between Light Exposure at Night and Insomnia in the General Elderly Population: The Heijo-Kyo Cohort. Chronobiol Int. 2014;31(9):976-82.

16. Boubekri M, Cheung IN, Reid KJ, Wang C-H, Zee PC. Impact of Windows and Daylight Exposure on Overall Health and Sleep Quality of Office Workers: A Case-Control Pilot Study. Journal of Clinical Sleep Medicine. 2014;10(06):603-11.

17. Bedrosian TA, Nelson RJ. Timing of Light Exposure Affects Mood and Brain Circuits. Translational Psychiatry. 2017;7(1):e1017-e.

18. Leichtfried V, Mair-Raggautz M, Schaeffer V, Hammerer-Lercher A, Mair G, Bartenbach C, et al. Intense Illumination in the Morning Hours Improved Mood and Alertness but Not Mental Performance. Appl Ergonomics. 2015;46:54-9.

19. Borisuit A, Linhart F, Scartezzini JL, Münch M. Effects of Realistic Office Daylighting and Electric Lighting Conditions on Visual Comfort, Alertness and Mood. Lighting research & technology (London, England : 2001). 2015;47(2):192-209.

20. Hoffmann G, Gufler V, Griesmacher A, Bartenbach C, Canazei M, Staggl S, et al. Effects of Variable Lighting Intensities and Colour Temperatures on Sulphatoxymelatonin and Subjective Mood in an Experimental Office Workplace. Appl Ergonomics. 2008;39(6):719-28.

21. Ru T, de Kort YAW, Smolders KCHJ, Chen Q, Zhou G. Non-Image Forming Effects of Illuminance and Correlated Color Temperature of Office Light on Alertness, Mood, and Performance across Cognitive Domains. Build Environ. 2019;149:253-63.

22. Vandewalle G, Maquet P, Dijk D-J. Light as a Modulator of Cognitive Brain Function. Trends Cogn Sci. 2009;13(10):429-38.

23. Vandewalle G, Schwartz S, Grandjean D, Wuillaume C, Balteau E, Degueldre C, et al. Spectral Quality of Light Modulates Emotional Brain Responses in Humans. Proc Natl Acad Sci U S A. 2010;107(45):19549-54.

24. Hattar S, Kumar M, Park A, Tong P, Tung J, Yau K-W, et al. Central Projections of Melanopsin-Expressing Retinal Ganglion Cells in the Mouse. J Comp Neurol. 2006;497(3):326-49.

25. Vandewalle G, Gais S, Schabus M, Balteau E, Carrier J, Darsaud A, et al. Wavelength-Dependent Modulation of Brain Responses to a Working Memory Task by Daytime Light Exposure. Cereb Cortex. 2007;17(12):2788-95.

26. Alkozei A, Smith R, Dailey NS, Bajaj S, Killgore WDS. Acute Exposure to Blue Wavelength Light During Memory Consolidation Improves Verbal Memory Performance. PLOS ONE. 2017;12(9):e0184884.

27. Huiberts LM, Smolders KCHJ, de Kort YAW. Shining Light on Memory: Effects of Bright Light on Working Memory Performance. Behav Brain Res. 2015;294:234-45.

28. Kretschmer V, Schmidt KH, Griefahn B. Bright Light Effects on Working Memory, Sustained Attention and Concentration of Elderly Night Shift Workers. Lighting research & technology (London, England : 2001). 2012;44(3):316-33.

29. Sleegers P, Moolenaar N, Galetzka M, Pruyn A, Sarroukh B, van Der Zande B. Lighting Affects Students’ Concentration Positively: Findings from Three Dutch Studies. Lighting Research & Technology. 2013;45(2):159-75.

30. Juda M, Vetter C, Roenneberg T. Chronotype Modulates Sleep Duration, Sleep Quality, and Social Jet Lag in Shift-Workers. J Biol Rhythms. 2013;28(2):141-51.

31. Vitale JA, Roveda E, Montaruli A, Galasso L, Weydahl A, Caumo A, et al. Chronotype Influences Activity Circadian Rhythm and Sleep: Differences in Sleep Quality between Weekdays and Weekend. Chronobiol Int. 2015;32(3):405-15.

32. Taillard J, Philip P, Bioulac B. Morningness/Eveningness and the Need for Sleep. J Sleep Res. 1999;8(4):291-5.

33. Sukegawa M, Noda A, Morishita Y, Ochi H, Miyata S, Honda K, et al. Sleep and Lifestyle Habits in Morning and Evening Types of Human Circadian Rhythm. Biol Rhythm Res. 2009;40(2):121-7.

34. Schmidt C, Collette F, Reichert CF, Maire M, Vandewalle G, Peigneux P, et al. Pushing the Limits: Chronotype and Time of Day Modulate Working Memory-Dependent Cerebral Activity. Frontiers in Neurology. 2015;6.

35. Rosenthal L, Day R, Gerhardstein R, Meixner R, Roth T, Guido P, et al. Sleepiness/Alertness among Healthy Evening and Morning Type Individuals. Sleep Medicine. 2001;2(3):243-8.

36. Matchock RL, Toby Mordkoff J. Chronotype and Time-of-Day Influences on the Alerting, Orienting, and Executive Components of Attention. Exp Brain Res. 2009;192(2):189-98.

37. May CP, Hasher L. Synchrony Effects in Inhibitory Control over Thought and Action. Journal of experimental psychology Human perception and performance. 1998;24(2):363-79.

38. Hidalgo MPL, Zanette CB, Pedrotti M, Souza CM, Nunes PV, Chaves MLF. Performance of Chronotypes on Memory Tests During the Morning and the Evening Shifts. Psychological Reports. 2004;95(1):75-85.

39. Ong AD, Kim S, Young S, Steptoe A. Positive Affect and Sleep: A Systematic Review. Sleep Medicine Reviews. 2017;35:21-32.

40. Steptoe A, O'Donnell K, Marmot M, Wardle J. Positive Affect, Psychological Well-Being, and Good Sleep. Journal of Psychosomatic Research. 2008;64(4):409-15.

41. Fosse R, Stickgold R, Hobson JA. Emotional Experience During Rapid-Eye-Movement Sleep in Narcolepsy. Sleep. 2002;25(7):724-32.

42. Johnson EO, Roth T, Breslau N. The Association of Insomnia with Anxiety Disorders and Depression: Exploration of the Direction of Risk. J Psychiatr Res. 2006;40(8):700-8.

43. Riemann D, Spiegelhalder K, Feige B, Voderholzer U, Berger M, Perlis M, et al. The Hyperarousal Model of Insomnia: A Review of the Concept and Its Evidence. Sleep Med Rev. 2009;14(1):19-31.

44. Perlstein WM, Elbert T, Stenger VA. Dissociation in Human Prefrontal Cortex of Affective Influences on Working Memory-Related Activity. Proc Natl Acad Sci U S A. 2002;99(3):1736-41.

45. Sharifian N, Zahodne LB. Daily Associations between Social Media Use and Memory Failures: The Mediating Role of Negative Affect. The Journal of General Psychology. 2021;148(1):67-83.

46. Threadgill AH, Gable PA. Negative Affect Varying in Motivational Intensity Influences Scope of Memory. Cognition and Emotion. 2019;33(2):332-45.

47. Cruz T, García L, Álvarez MA, Manzanero AL. Sleep Quality and Memory Function in Healthy Ageing. Neurología (English Edition). 2022;37(1):31-7.

48. Xie W, Berry A, Lustig C, Deldin P, Zhang W. Poor Sleep Quality and Compromised Visual Working Memory Capacity. Journal of the International Neuropsychological Society. 2019;25(6):583-94.

49. Hokett E, Arunmozhi A, Campbell J, Verhaeghen P, Duarte A. A Systematic Review and Meta-Analysis of Individual Differences in Naturalistic Sleep Quality and Episodic Memory Performance in Young and Older Adults. Neurosci Biobehav Rev. 2021;127:675-88.

50. Chakravarty K, Shukla G, Poornima S, Agarwal P, Gupta A, Mohammed A, et al. Effect of Sleep Quality on Memory, Executive Function, and Language Performance in Patients with Refractory Focal Epilepsy and Controlled Epilepsy Versus Healthy Controls – a Prospective Study. Epilepsy & Behavior. 2019;92:176-83.

51. van der Heijden KB, Vermeulen M, Donjacour CEHM, Gordijn MCM, Hamburger HL, Meijer AM, et al. Chronic Sleep Reduction Is Associated with Academic Achievement and Study Concentration in Higher Education Students. J Sleep Res. 2018;27(2):165-74.

52. Brown TM, Brainard GC, Cajochen C, Czeisler CA, Hanifin JP, Lockley SW, et al. Recommendations for Daytime, Evening, and Nighttime Indoor Light Exposure to Best Support Physiology, Sleep, and Wakefulness in Healthy Adults. PLoS Biol. 2022;20(3):e3001571.

53. Siraji M, Lazar RR, van Duijnhoven J, Schlangen LJM, Haque S, Kalavally V, et al., editors. Light Exposure Behaviour Assessment (Leba): A Novel Self-Reported Instrument to Capture Light Exposure-Related Behaviour. CIE Australia Lighting Research Conference; 2022; Australia

54. Hair JF, Risher JJ, Sarstedt M, Ringle CM. When to Use and How to Report the Results of Pls-Sem. European business review. 2019;31(1):2-24.

55. Hair J, Hollingsworth CL, Randolph AB, Chong AYL. An Updated and Expanded Assessment of Pls-Sem in Information Systems Research. Industrial management + data systems. 2017;117(3):442-58.

56. Bollen KA. Total, Direct, and Indirect Effects in Structural Equation Models. Soc Method. 1987;17:37-69.

57. Kline RB. Principles and Practice of Structural Equation Modeling , Publisher = the Guilford Press2015.

58. Drolet AL, Morrison DG. Do We Really Need Multiple-Item Measures in Service Research? Journal of service research : JSR. 2001;3(3):196-204.

59. Youngblut JM, Casper GR. Focus on Psychometrics Single-Item Indicators in Nursing Research. Res Nurs Health. 1993;16(6):459-65.

60. Boer AGEMd, Lanschot JJv, Stalmeier PFM, Sandick JWv, Hulscher JBF, Haes JCJMd, et al. Is a Single-Item Visual Analogue Scale as Valid, Reliable and Responsive as Multi-Item Scales in Measuring Quality of Life? Quality of life research. 2004;13:311-20.

61. Shamir B, Kark R. A Single-Item Graphic Scale for the Measurement of Organizational Identification. J Occup Organ Psychol. 2004;77(1):115-23.

62. Fuchs C, Diamantopoulos A. Using Single-Item Measures for Construct Measurement in Management Research: Conceptual Issues and Application Guidelines. Die Betriebswirtschaft. 2009;69(2):195.

63. Hankins MW, Lucas RJ. The Primary Visual Pathway in Humans Is Regulated According to Long-Term Light Exposure through the Action of a Nonclassical Photopigment. Curr Biol. 2002;12(3):191-8.

64. Figueiro MG, Plitnick BA, Lok A, Jones GE, Higgins P, Hornick TR, et al. Tailored Lighting Intervention Improves Measures of Sleep, Depression, and Agitation in Persons with Alzheimer’s Disease and Related Dementia Living in Long-Term Care Facilities. Clinical Interventions in Aging. 2014;9:1527-37.

65. Figueiro MG, Rea MS. Lack of Short-Wavelength Light During the School Day Delays Dim Light Melatonin Onset (Dlmo) in Middle School Students. Neuro Endocrinol Lett. 2010;31(1):92-6.

66. Burns AC, Saxena R, Vetter C, Phillips AJK, Lane JM, Cain SW. Time Spent in Outdoor Light Is Associated with Mood, Sleep, and Circadian Rhythm-Related Outcomes: A Cross-Sectional and Longitudinal Study in over 400,000 Uk Biobank Participants. Journal of Affective Disorders. 2021;295:347-52.

67. An M, Colarelli SM, O'Brien K, Boyajian ME. Why We Need More Nature at Work: Effects of Natural Elements and Sunlight on Employee Mental Health and Work Attitudes. PLOS ONE. 2016;11(5):e0155614.

68. Rafique N, Al-Asoom LI, Alsunni AA, Saudagar FN, Almulhim L, Alkaltham G. Effects of Mobile Use on Subjective Sleep Quality. Nat Sci Sleep. 2020;12:357-64.

69. Exelmans L, Van den Bulck J. Bedtime Mobile Phone Use and Sleep in Adults. Social Science & Medicine. 2016;148:93-101.

70. Vernon L, Modecki KL, Barber BL. Mobile Phones in the Bedroom: Trajectories of Sleep Habits and Subsequent Adolescent Psychosocial Development. Child Dev. 2018;89(1):66-77.

71. Tosini G, Ferguson I, Tsubota K. Effects of Blue Light on the Circadian System and Eye Physiology. Mol Vis. 2016;22:61-72.

72. Schmid SR, Höhn C, Bothe K, Plamberger CP, Angerer M, Pletzer B, et al. How Smart Is It to Go to Bed with the Phone? The Impact of Short-Wavelength Light and Affective States on Sleep and Circadian Rhythms. Clocks &amp; Sleep. 2021;3(4):558-80.

73. Knufinke M, Fittkau-Koch L, Møst EIS, Kompier MAJ, Nieuwenhuys A. Restricting Short-Wavelength Light in the Evening to Improve Sleep in Recreational Athletes – a Pilot Study. European Journal of Sport Science. 2019;19(6):728-35.

74. Shechter A, Quispe KA, Mizhquiri Barbecho JS, Slater C, Falzon L. Interventions to Reduce Short-Wavelength (“Blue”) Light Exposure at Night and Their Effects on Sleep: A Systematic Review and Meta-Analysis. SLEEP Advances. 2020;1(1).

75. Chang A-M, Aeschbach D, Duffy JF, Czeisler CA. Evening Use of Light-Emitting Ereaders Negatively Affects Sleep, Circadian Timing, and Next-Morning Alertness. Proc Natl Acad Sci U S A. 2015;112(4):1232-7.

76. Chang A-M, Scheer FAJL, Czeisler CA. The Human Circadian System Adapts to Prior Photic History: The Human Circadian System Adapts to Prior Light History. The Journal of physiology. 2011;589(5):1095-102.

77. Carrier J, Dumont M. Sleep Propensity and Sleep Architecture after Bright Light Exposure at Three Different Times of Day. J Sleep Res. 1995;4(4):202-11.

78. Ancoli-Israel S, Gehrman P, Martin JL, Shochat T, Marler M, Corey-Bloom J, et al. Increased Light Exposure Consolidates Sleep and Strengthens Circadian Rhythms in Severe Alzheimer's Disease Patients. Behav Sleep Med. 2003;1(1):22-36.

79. Mills PR, Tomkins SC, Schlangen LJ. The Effect of High Correlated Colour Temperature Office Lighting on Employee Wellbeing and Work Performance. J Circadian Rhythms. 2007;5:2.

80. RautkylÄ E, Puolakka M, Tetri E, Halonen L. Effects of Correlated Colour Temperature and Timing of Light Exposure on Daytime Alertness in Lecture Environments. Journal of light & visual environment. 2010;34(2):59-68.

81. Faul F, Erdfelder E, Lang A-G, Buchner A. G\* Power 3: A Flexible Statistical Power Analysis Program for the Social, Behavioral, and Biomedical Sciences. Behavior research methods. 2007;39(2):175-91.

82. Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed. ed: Hillsdale, NJ : L. Erlbaum Associates; 1988.

83. Hair JF, Hult GTM, Ringle CM, Sarstedt M. A Primer on Partial Least Squares Structural Equation Modeling (Pls-Sem). 2nd ed: Thousand Oaks, California : SAGE Publications Inc; 2017.

84. Watson D, Clark LA, Tellegen A. Development and Validation of Brief Measures of Positive and Negative Affect: The Panas Scales. Journal of personality and social psychology. 1988;54(6):1063-70.

85. Buysse DJ, Reynolds CF, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: A New Instrument for Psychiatric Practice and Research. Psychiatry Res. 1989;28(2):193-213.

86. Manzar MD, BaHammam AS, Hameed UA, Spence DW, Pandi-Perumal SR, Moscovitch A, et al. Dimensionality of the Pittsburgh Sleep Quality Index: A Systematic Review. Health Qual Life Outcomes. 2018;16(1):89-.

87. Dunleavy G, Bajpai R, Tonon AC, Chua AP, Cheung KL, Soh C-K, et al. Examining the Factor Structure of the Pittsburgh Sleep Quality Index in a Multi-Ethnic Working Population in Singapore. Int J Environ Res Public Health. 2019;16(23):4590.

88. Horne JA, Östberg O. A Self-Assessment Questionnaire to Determine Morningness-Eveningness in Human Circadian Rhythms. International journal of chronobiology. 1976.

89. Caci H, Deschaux O, Adan A, Natale V. Comparing Three Morningness Scales: Age and Gender Effects, Structure and Cut-Off Criteria. Sleep Med. 2008;10(2):240-5.

90. Team RC. R: A Language and Environment for Statistical Computing. 2022.

91. Mateus S, Leon TdB. Esemcomp: Esem-within-Cfa Syntax Composer. 2022.

92. Hair JF. Partial Least Squares Structural Equation Modeling (Pls-Sem) Using R : A Workbook. Hult GTM, Ringle CM, Sarstedt M, Danks NP, Ray S, editors. Cham: Cham : Springer International Publishing AG; 2021.

93. Siraji M. Tabledown: Create Publication Quality Tables and Plots. 2022.

94. Asparouhov T, Muthén B. Exploratory Structural Equation Modeling. Structural equation modeling. 2009;16(3):397-438.

95. Hu Lt, Bentler PM. Cutoff Criteria for Fit Indexes in Covariance Structure Analysis: Conventional Criteria Versus New Alternatives. Structural Equation Modeling: A Multidisciplinary Journal. 1999;6(1):1-55 , ISSN = 1070-5511 , DOI = 10.1080/10705519909540118.

96. MacCallum RC, Roznowski M, Mar CM, Reith JV. Alternative Strategies for Cross-Validation of Covariance Structure Models. Multivariate behavioral research. 1994;29(1):1--32.

97. MacKenzie SB, Podsakoff PM, Jarvis CB. The Problem of Measurement Model Misspecification in Behavioral and Organizational Research and Some Recommended Solutions. Journal of applied psychology. 2005;90(4):710.

98. Hinton P, McMurray I, Brownlow C. Spss Explained2014.

99. Fornell C, Larcker DF. Evaluating Structural Equation Models with Unobservable Variables and Measurement Error. Journal of marketing research. 1981;18(1):39--50.

100. Henseler J, Ringle CM, Sarstedt M. A New Criterion for Assessing Discriminant Validity in Variance-Based Structural Equation Modeling. Journal of the academy of marketing science. 2015;43(1):115--35.

101. Falk RF, Miller NB. A Primer for Soft Modeling.1992.

# Author contributions

M.S., V.K., and S.H. designed the study and methods and co-authored the final paper. M.S. conducted the formal analysis and prepared all figures. All authors reviewed the manuscript.

# Data availability statement

The datasets generated and/analyzed during the current study are available in the GitHub repository, <https://github.com/ILLMMU/Study2>

**Conflict of Interest**

The authors declare no competing interests.

# Figure Legends

Figure 1: Theoretical framework of the fitted PLS-SEM model to predict chronotype, sleep quality, mood, memory and concentration using LEBA categories as predictors

Figure 2. Significant path coefficients of the model (t-value >1.906).

Figure 3. Response distribution of LEBA

Figure 4. Analyses steps used in the study

# Tables

Table 1: Demographics

| **Characteristic** | **Female**, N = 218  Mean (SD) or N(%) | **Male**, N = 83  Mean (SD) or N(%) |
| --- | --- | --- |
| Age | 27 (8) | 30 (12) |
| Religion |  |  |
| Atheist | 23 (11%) | 7 (8.4%) |
| Buddhist | 99 (45%) | 35 (42%) |
| Christian | 36 (17%) | 13 (16%) |
| Hindu | 21 (9.6%) | 11 (13%) |
| Muslim | 39 (18%) | 17 (20%) |
| Ethnicity |  |  |
| Malaysian Chinese | 138 (63%) | 46 (55%) |
| Malaysian Indian | 19 (8.7%) | 13 (16%) |
| Malaysian Malay | 26 (12%) | 7 (8.4%) |
| Others | 35 (16%) | 17 (20%) |
| Marital Status |  |  |
| Single | 180 (83%) | 56 (67%) |
| Married | 37 (17%) | 27 (33%) |
| Divorced | 1 (0.5%) | 0 (0%) |
| Education |  |  |
| Doctor of Philosophy (PhD) | 43 (20%) | 13 (16%) |
| Master’s degree | 38 (17%) | 22 (27%) |
| post grad diploma | 1 (0.5%) | 0 (0%) |
| Bachelor’s degree | 129 (59%) | 41 (49%) |
| Diploma | 5 (2.3%) | 4 (4.8%) |
| Pre-university | 1 (0.5%) | 2 (2.4%) |
| Secondary School | 1 (0.5%) | 1 (1.2%) |
| Occupation |  |  |
| Student | 165 (76%) | 50 (60%) |
| Work | 42 (19%) | 31 (37%) |
| Neither | 11 (5.0%) | 2 (2.4%) |
| Community Stance | 7.07 (1.87) | 7.00 (1.85) |
| Sleep Quality |  |  |
| Good Sleep | 69 (32%) | 24 (29%) |
| Poor Sleep | 149 (68%) | 59 (71%) |
| Chronotype |  |  |
| Definite Evening | 8 (3.7%) | 1 (1.2%) |
| Intermediate | 144 (66%) | 60 (72%) |
| Moderate Evening | 43 (20%) | 13 (16%) |
| Moderate Morning | 23 (11%) | 9 (11%) |

Table 2: Structural validity of the scales used in the PLS-SEM model assessed using ESEM.

|  |  | Degrees of freedom, p | Comparative Fit Index (CFI) | Tucker-Lewis Index (TLI) | Root mean square error of approximation (RMSEA;90% CI) | Standardized root mean square residual (SRMR) |
| --- | --- | --- | --- | --- | --- | --- |
|
| LEBA | 57.04 | 73, *p*<0.001 | 0.994 | 0.987 | 0.06(0.0-0.074) | 0.04 |
| PSQI | 19.84 | 8, *p*<0.001 | 0.966 | 0.910 | 0.07(0.03-0.11) | 0.07 |
| MEQ | 91.50 | 101, *p*<0.001 | 0.970 | 0.949 | 0.04(0.03-0.06) | 0.04 |
| PANAS | 293.76 | 151, *p*<0.001 | 0.992 | 0.990 | 0.06(0.05-0.07) | 0.06 |

Table 3: Direct and total effects estimated in the PLS-SEM model (Only significant structural relationships are reported, t >1.906).

| Hypothesis | Path Coefficients | Original Est. | | Bootstrap Mean | | Bootstrap SD | | t Stat. | 2.5% CI | 97.5% CI | Results |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Direct effects | | | | | | | | | | | |
| **H1: Light exposure-related behaviors -> Chronotype** | | | | | | | | | | | Supported |
| H1 | LEBA F1  ->  MA | -0.16 | | -0.16 | | 0.06 | | 2.44 | 0.28 | 0.03 |
| LEBA F2  ->  PT | 0.15 | | 0.15 | | 0.07 | | 2.27 | 0.02 | 0.28 |
| LEBA F2  ->  RT | 0.15 | | 0.15 | | 0.06 | | 2.29 | 0.02 | 0.27 |
| LEBA F2  ->  RI | 0.14 | | 0.14 | | 0.06 | | 2.33 | 0.02 | 0.25 |
| LEBA F3  ->  PT | -0.24 | | -0.24 | | 0.05 | | 4.39 | 0.35 | 0.14 |
| LEBA F3  ->  MA | -0.13 | | -0.13 | | 0.06 | | 2.24 | 0.24 | 0.01 |
| LEBA F3  ->  RT | -0.26 | | -0.27 | | 0.05 | | 4.83 | 0.37 | 0.16 |
| LEBA F3  ->  RI | -0.23 | | -0.23 | | 0.06 | | 3.79 | 0.35 | 0.11 |
| **H2: Light exposure-related behaviors -> Mood** | | | | | | | | | | |  |
| H2 | LEBA F2  ->  PA | 0.32 | | 0.32 | | 0.05 | | 6.21 | 0.22 | 0.42 | Supported |
| LEBA F5  ->  PA | 0.16 | | 0.16 | | 0.06 | | 2.45 | 0.03 | 0.28 |
| LEBA F3  ->  NA | 0.17 | | 0.17 | | 0.06 | | 2.84 | 0.05 | 0.29 |
| **H3: Light exposure-related behaviors -> Sleep Quality** | | | | | | | | | | |  |
| H3 | LEBA F3  ->  PSQ | 0.13 | | 0.13 | | 0.06 | | 2.24 | 0.01 | 0.24 | Supported |
| LEBA F5  ->  PSQ | -0.16 | | -0.16 | | 0.06 | | -2.59 | -0.27 | -0.03 |
| **H4: Mood -> Sleep quality** | | | | | | | | | | |  |
| H4 | PA  ->  PSQ | -0.18 | | -0.18 | | 0.06 | | -3.02 | -0.30 | -0.06 | Supported |
| PA  ->  SE | 0.22 | | 0.21 | | 0.07 | | 3.08 | 0.07 | 0.35 |
| NA  ->  PSQ | 0.28 | | 0.29 | | 0.06 | | 4.83 | 0.17 | 0.40 |
| **H5: Chronotype -> Sleep Quality** | | | | | | | | | | |  |
| H5 | MA  ->  PSQ | -0.20 | | -0.20 | | 0.06 | | -3.31 | -0.31 | -0.08 | Supported |
| **H6: Sleep quality -> Memory and Concentration** | | | | | | | | | | |  |
| H6 | PSQ  ->  Memory | 0.17 | | 0.18 | | 0.06 | | 3.11 | 0.07 | 0.29 | Supported |
| PSQ  ->  Concentration | 0.26 | | 0.26 | | 0.06 | | 4.60 | 0.15 | 0.37 |
| **H7: Mood -> Memory and Concentration** | | | | | | | | | | |  |
| H7 | NA  ->  Memory | 0.38 | | 0.38 | | 0.06 | | 6.63 | 0.26 | 0.49 | Supported |
| NA  ->  Concentration | 0.33 | | 0.32 | | 0.06 | | 5.87 | 0.21 | 0.43 |
| **H8: Chronotype -> Memory and Concentration** | | | | | | | | | | |  |
| H8 | Chronotype ->work performance | Details are provided Supplementary Table 5 | | | | | | | | | Not supported |
| **H9: Light exposure related behavior -> Memory and Concentration** | | | | | | | | | | |  |
| H9 | Light exposure related behavior -> Memory and Concentration | Details are provided Supplementary Table 5 | | | | | | | | | Not supported |
| **Total Effects** | | | | | | | | | | | |
| Hypothesis | Path Coefficients | Original Est. | | Bootstrap Mean | | Bootstrap SD | | T Stat. | 2.5% CI | 97.5% CI | Results |
| **H10: LEBA to Sleep quality** | |  |  | |  | |  | |  |  |  |
| H10 | LEBA F3 -> PSQ | 0.21 | 0.21 | | 0.06 | | 3.53 | | 0.09 | 0.32 | Supported |
| LEBA F5 -> PSQ | -0.17 | -0.17 | | 0.07 | | -2.38 | | -0.30 | -0.02 |
| **H11: LEBA to Memory and Concentration** | |  |  | |  | |  | |  |  |  |
| H11 | LEBA F3 -> Memory | 0.20 | 0.19 | | 0.06 | | 3.12 | | 0.06 | 0.31 | Supported |
| LEBA F3 -> Concentration | 0.23 | 0.23 | | 0.06 | | 3.89 | | 0.11 | 0.34 |