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

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Abstract

**Objectives:** Light has significant influence on human physiology and behavior. The light exposure behavior assessment (LEBA) tool helps us to categorize light exposure-related behaviors, but whether this categorization is effective in predicting our behavior is not clear. Hence, we conducted this study to see if exposure to different types of light during the daytime and in bed before sleep could influence our chronotype, mood, sleep quality, memory and concentration.

**Design:** We collected data online from 301 Malaysian adult residents (Mean age = XX; SD=±XX) – 218 females (Mean age = 26.85; SD=±8.07) and 83 males (Mean age = 30.35; SD=±12.14). In addition to LEBA, the participants completed the Morningness-Eveningness questionnaire, the Positive and Negative Affect Schedule, Pittsburgh Sleep Quality Index, and single items to assess trouble in memory and concentration.

**Results:** We used partial least squares structural equation modeling (PLS-SEM) to predict the influence of LEBA categories on chronotype, mood, sleep quality, memory and concentration. The fitted model exhibited satisfactory reliability (construct reliability>.60), validity (AVEs < reliability; HTMT<0.80) and 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 and reduced sleep quality (DE=0.13). Increased *use of electric light in the morning and daytime* predicted positive affect (DE=0.16) and sleep quality (DE=-0.16).

Conclusion: LEBA categories could predict our chronotype, sleep quality, mood, memory and concentration and provide valuable insights to develop a healthy light diet to promote health and wellness

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

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

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 (Cajochen, 2007; Lockley, 2008; Lok et al., 2022; Lok et al., 2018; Siraji, Kalavally, et al., 2022; Vetter et al., 2021; Xiao et al., 2021). 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 (Hankins & Lucas, 2002b).

## 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 (Lunn et al., 2017). Subsequently, this disruption gives rise to a series of adverse consequences, including decreased sleep quality, mood and the alteration of sleeping habits (Chellappa et al., 2014; Figueiro et al., 2017; Lunn et al., 2017; Viola et al., 2008). 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 (Porcheret et al., 2018). Bright light exposure at night is reported to be associated with having a late chronotype (Koo et al., 2016; Vollmer et al., 2012). In contrast, bright light exposure in the morning is associated with having an early chronotype (Czeisler et al., 1989; Khalsa et al., 2003). Increased nighttime light exposure is also associated with decreased sleep quality (Cho et al., 2013; Obayashi et al., 2014). However, several studies reported better nighttime sleep quality after exposure to bright light in the morning in an office environment (Boubekri et al., 2014; Figueiro et al., 2017; Viola et al., 2008).

Brain regions such as limbic areas and the hypothalamic-pituitary-adrenal axis responsible for regulating mood are susceptible to circadian regulation (Bedrosian & Nelson, 2017). Thus, it is reasonable to anticipate that the disruption of circadian regulation will disrupt the mood regulation (Bedrosian & Nelson, 2017). Bright light exposure is associated with an increased positive mood in the morning, whereas afternoon bright light exposure is reported to increase negative mood (Borisuit et al., 2015; Hoffmann et al., 2008; Leichtfried et al., 2015; Ru et al., 2019).

## Light exposure, memory, and concentration

Several studies confirmed that retinal light exposure activates the hippocampus, which is closely associated with memory functions. (Hattar et al., 2006; Vandewalle et al., 2009; Vandewalle et al., 2010). Thus, it is anticipated that retinal light exposure would influence memory. Vandewalle et al. (2007) reported an enhanced working memory performance for blue light exposure compared to green light exposure (*N*=18). Alkozei et al. (2017) reported enhanced verbal memory for a 30-minute blue light exposure (*N*=12) compared to amber light. Huiberts et al. (2015) 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 et al. (2012) reported an improved concentration under a dynamic bright light condition (300-3000 lux) in night shift work (*N*=32). Sleegers et al. (2013), 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 et al. (2013), 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 (Sukegawa et al., 2009; Taillard et al., 1999; Vitale et al., 2015). Further, chronotype can influence our memory and concentration (Matchock & Toby Mordkoff, 2009; Rosenthal et al., 2001; Schmidt et al., 2015). Schmidt et al. (2015) 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 (Hidalgo et al., 2004; May & Hasher, 1998).

A sizable amount of literature has indicated that sleep quality is contingent on mood (Ong et al., 2017). Positive affect- a state of pleasurable engagement with the environment is associated with improved sleep patterns (Fosse et al., 2002; Steptoe et al., 2008). 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 (Johnson et al., 2006; Perlstein et al., 2002; Riemann et al., 2009; Sharifian & Zahodne, 2021; Threadgill & Gable, 2019). Poor sleep quality is reported to reduce memory functions and concentration (Chakravarty et al., 2019; Cruz et al., 2022; Hokett et al., 2021; van der Heijden et al., 2018; Xie et al., 2019).

## The present study

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 (Brown et al., 2022). 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, light exposure-related behavior assessment (LEBA; Siraji, Lazar, et al., 2022) 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 developed 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 (J. Hair et al., 2017; Hair et al., 2019). 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 (Bollen, 1987, p. 43).

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).

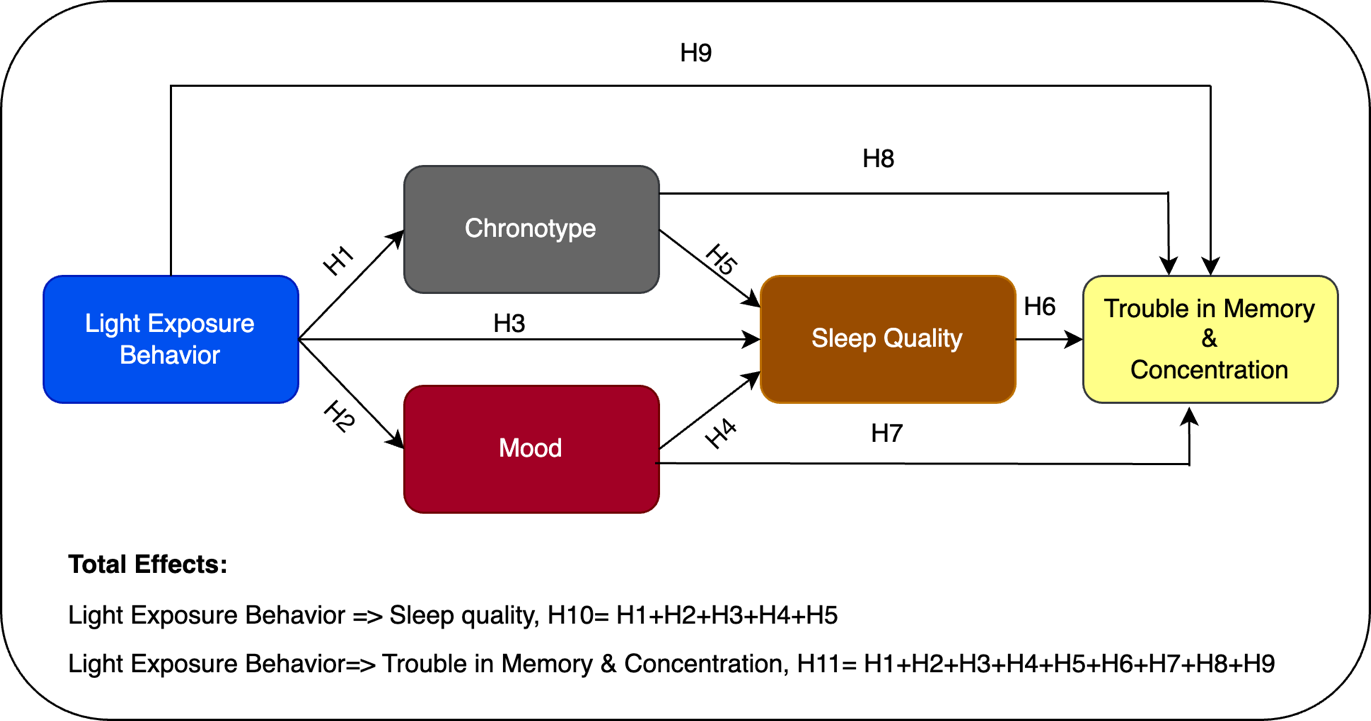


Figure 1: Theoretical framework

# Methods

## Participants

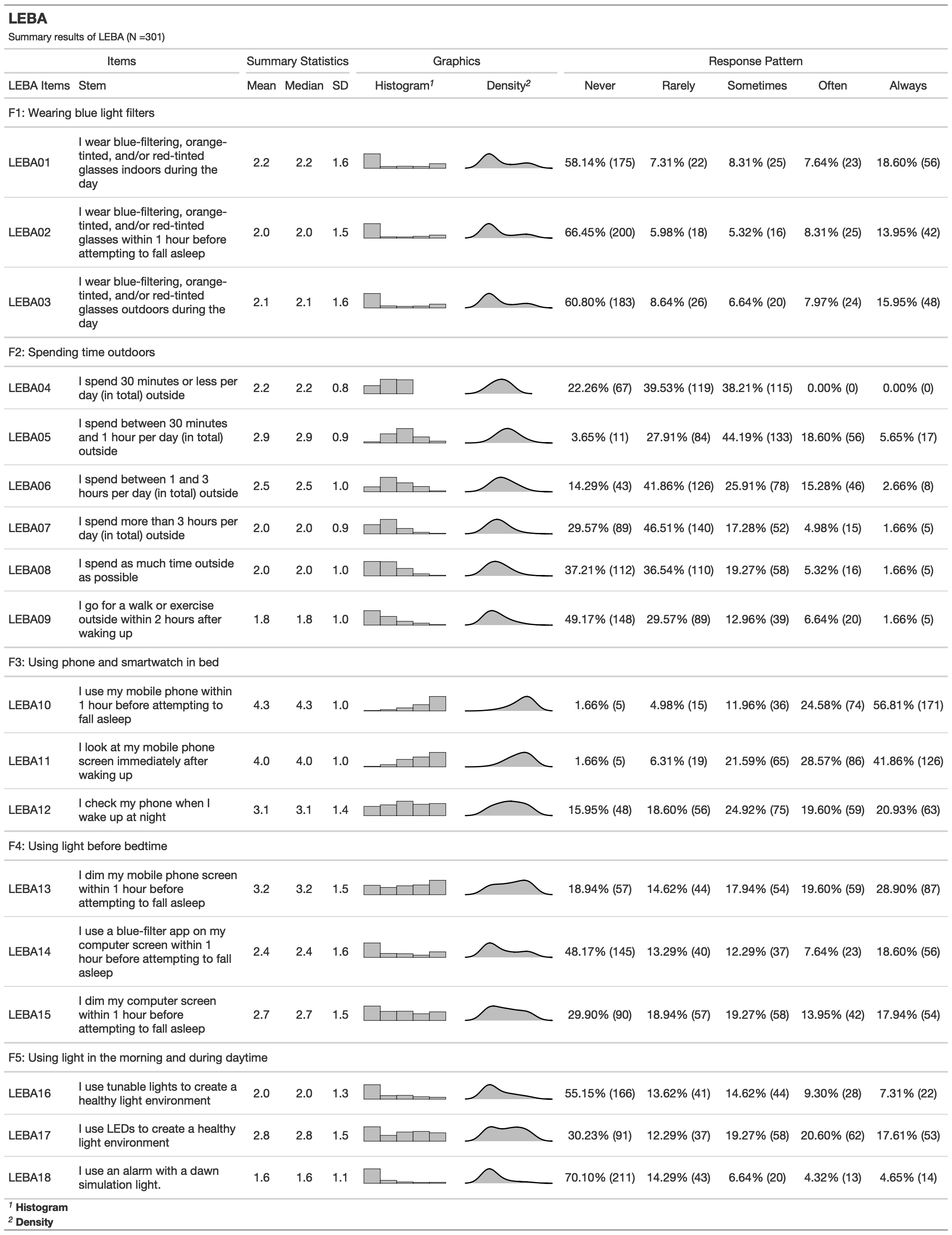
We conducted a large-scale online survey on Malaysian residents. The exclusion-inclusion criteria for respondents to be included in this study were: (1) any Malaysian resident aged >18 and able to read and write English (2) no physiological and psychological disorder (self-reported). Three hundred and 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 (Faul et al., 2007). To achieve an effect size of 0.15 (Cohen, 1988) 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 (J. F. Hair et al., 2017). Our sample size exceeded these recommendations. Out of 301 participants, 72.43% (218) were female, ranging in age from 18 to 59 (26.85±8.07), and 27.57% (83) were male with an age range between 18 to 74 years (30.35±12.14). 78.66% of the participants were unmarried. The majority of the participants (71.42%) were students.

## Material

### Light exposure behavior assessment

Light exposure-related behaviors were measured using the short form of the Light Exposure Behavior Assessment (Siraji, Lazar, et al., 2022). 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 1.



*Figure* *1.*  Response distribution of LEBA

### Positive and negative affect schedule

The positive and negative affect schedule (PANAS; Watson et al., 1988) 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; Buysse et al., 1989) 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 (Buysse et al., 1989; Manzar et al., 2018). Dunleavy et al. (2019), 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; Horne & Östberg, 1976). MEQ consists of 19 questions, and the scores range from 16 to 86. A higher score indicates a higher morning propensity. Caci et al. (2008) 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.

## Data collection

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; Team, 2022) and several statistical packages, including esemComp (Mateus & Leon, 2022), “SEMinR” (Hair, 2021) and tabledown (Siraji, 2022) 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; Asparouhov & Muthén, 2009; Marsh et al., 2009). 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 (Tóth-Király et al., 2017). To assess the model fit, we followed the guidelines of Hu and Bentler (1999): 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 (Hair, 2021). 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 (MacCallum et al., 1994; MacKenzie et al., 2005) and a value above 0.50 is considered acceptable (Hinton et al., 2014). CR coefficient value of 0.60 and above indicates a satisfactory reliability (Hair, 2021).

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 (Fornell & Larcker, 1981). For *discriminant validity,* we compared the square root of the AVE of a construct with its corresponding correlation with other constructs (Fornell & Larcker, 1981). The square root of the AVEs of each construct should be higher than its correlation with other constructs. We have also reported the 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 (Henseler et al., 2015).

**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 (Henseler et al., 2015). 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 (1992): values 0.10 indicates adequate explanatory power. Further, we have categorized the values following the guidelines of Cohen (1988): 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 (Hair, 2021). 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 (2021): (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 (Sarstedt et al., 2021). Figure 2 depicts the analysis steps we followed.

Diagram

Description automatically generated

*Figure* *2.*  Analyses Steps

# 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 (Kline, 2015).

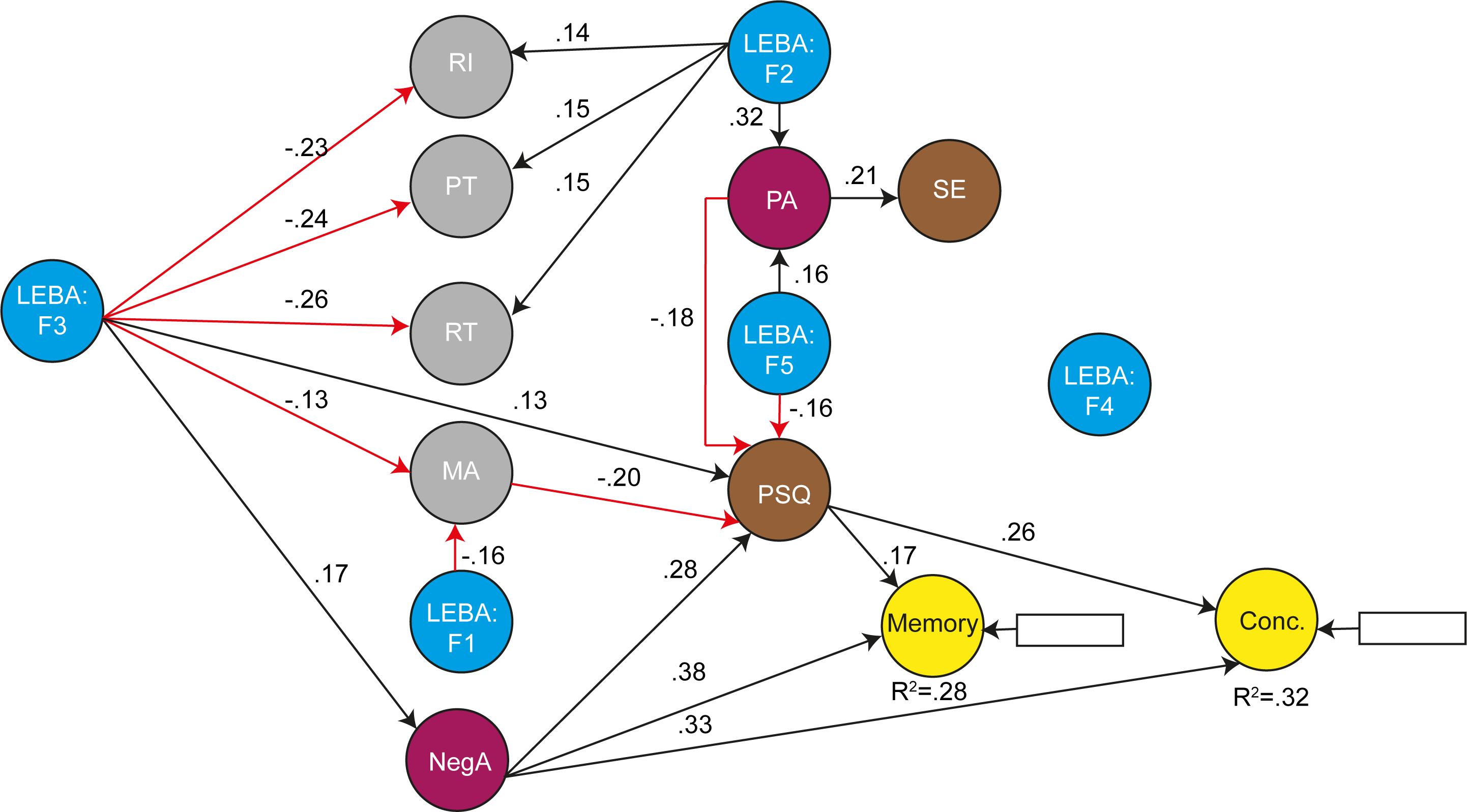
## Measurement model

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 measurement model assessment are shown in Table 3. 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 (Table 4). 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. Table 5 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 6 depict significant (t-value >1.906, p<0.05) direct effects observed in our model. All direct effects of the structural model are provided in *Supplementary Table 2*. Table 6 also presents the total effects of light exposure-related behavior on sleep quality, memory and concentration.



*Figure* *3.*  Significant path coefficients of the model (t-value >1.906, p<0.05).

### Predicted relationships

Table 6 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; p<0.05). LEBA F2 exhibited a direct effect on positive affect (= 0.32; p<0.05) and chronotype factors: PT (= 0.15; p<0.05), RT (= 0.15; p<0.05), RI (= 0.14; p<0.05). LEBA F3 significantly negatively directly influenced the four factors of chronotype: PT (= -0.24; p<0.05), MA (= -0.13; p<0.05), RT (= -0.26; p<0.05) and RI (= -0.23; p<0.05). LEBA F3 also exhibited positive influences on negative affect (= 0.17; p<0.05) and PSQ (= 0.13; p<0.05). In contrast, LEBA F5 exhibited a significant positive influence on positive affect (= 0.16; p<0.05) and negative influence on PSQ (= -0.16; p<0.05). Both positive and negative affect directly influence sleep quality *(H4)*, where positive mood increased sleep efficiency (= 0.22; p<0.05) and sleep quality (= -0.18; p<0.05), and negative affect decreased sleep quality (= -0.28; p<0.05).

Chronotype directly influenced sleep quality *(H5)*, where morning affect (MA) was observed to increase sleep quality(= -0.20; p<0.05). 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; p<0.05) and concentration (= 0.26; p<0.05). Increased negative affect predicted a deteriorated memory and concentration (*H7*; memory=0.38; concentration 0.33, p<0.05). 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, p<0.05). In contrast, LEBA F5 was predicted to improve sleep quality (= -0.17, p<0.05). 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, p<0.05).

### 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.

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# Discussion

This study investigated the relationship of light exposure-related behavior assessment categorizes with chronotype, sleep quality, mood, memory and concentration

## Measurement model

To test the relationships, we conceptualized a framework based on the existing literature and used PLS-SEM to assess the direct and total effects. 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 (Drolet & Morrison, 2001). 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 (Boer et al., 2004; Fuchs & Diamantopoulos, 2009; Shamir & Kark, 2004; Youngblut & Casper, 1993).

## Structural model and predictions

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*).

## Use of blue filters indoors and outdoors

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 (Hankins & Lucas, 2002a; Lockley, 2008). 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 et al. (2014) 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 (Figueiro & Rea, 2010).

## Spending time outdoors

*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 et al. (2021), using a bio-bank of 400,000 UK participants, conferred that time spent in outdoor light improved mood and promoted early chronotypes. An et al. (2016) reported a reduced depressive mood among workers when more sunlight is available in the environment. Further, Figueiro et al. (2017) 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.

## Use of smart gadgets on the bed before sleeping

*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 (Exelmans & Van den Bulck, 2016; Rafique et al., 2020; Vernon et al., 2018). 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 (Chang et al., 2015; Knufinke et al., 2019; Schmid et al., 2021; Shechter et al., 2020; Tosini et al., 2016).

## Use of electric light in the morning and daytime

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 et al. (2017), 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 (Ancoli-Israel et al., 2003; Carrier & Dumont, 1995; Chang et al., 2011). Studies based on real-world settings such as offices and schools collectively also indicated that increased electric light exposure improved mood and sleep quality (Mills et al., 2007; RautkylÄ et al., 2010; Viola et al., 2008). Brown et al. (2022), 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.

## Inter-relation of chronotype, mood, sleep quality, memory and concentration

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 (Matchock & Toby Mordkoff, 2009; Rosenthal et al., 2001; Schmidt et al., 2015). 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.

## Known limitations and future direction

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 (Brown et al., 2022). Future studies could investigate those behaviors with a three-hour time span prior to sleep.

## Conclusion

This research aims to examine the influence of light exposure-related behaviors on 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.

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Tables

Table 1: Demographics

| **Characteristic** | **Female**, N = 218 | **Male**, N = 83 |
| --- | --- | --- |
| 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

|  |  | df | CFI | TLI | RMSEA (90% CI) | SRMR |
| --- | --- | --- | --- | --- | --- | --- |
|
| LEBA | 57.04 | 73 | 0.994 | 0.987 | 0.06(0.0-0.074) | 0.04 |
| PSQI | 19.84 | 8\* | 0.966 | 0.910 | 0.07(0.03-0.11) | 0.07 |
| MEQ | 91.50 | 101 | 0.970 | 0.949 | 0.04(0.03-0.06) | 0.04 |
| PANAS | 293.76 | 151\*\* | 0.992 | 0.990 | 0.06(0.05-0.07) | 0.06 |

\*p<0.05;\*\*p<0.001; df, degrees of freedom; CFI, Comparative Fit Index; TLI, Tucker-Lewis Index; RMSEA, root mean square error of approximation; SRMR, standardized root mean square residual

Table 3:

Results of Measurement assessment

| Constructs | Factor Loading | Cronbach’s alpha | CR | AVE | R2 |
| --- | --- | --- | --- | --- | --- |
| **LEBA F1** |  | 0.94 | 0.96 | 0.66 | - |
| item1 | 0.95 |  |  |  |  |
| item2 | 0.95 |  |  |  |  |
| item3 | 0.94 |  |  |  |  |
| **LEBA F2** |  | 0.71 | 0.80 | 0.45 | - |
| item5 | 0.46 |  |  |  |  |
| item6 | 0.73 |  |  |  |  |
| item7 | 0.62 |  |  |  |  |
| item8 | 0.69 |  |  |  |  |
| item9 | 0.79 |  |  |  |  |
| **LEBA F3** |  | 0.71 | 0.84 | 0.64 | - |
| item10 | 0.85 |  |  |  |  |
| item11 | 0.86 |  |  |  |  |
| item12 | 0.68 |  |  |  |  |
| **LEBA F4** |  | 0.67 | 0.82 | 0.60 | - |
| item13 | 0.73 |  |  |  |  |
| item14 | 0.69 |  |  |  |  |
| item15 | 0.89 |  |  |  |  |
| **LEBA F5** |  | 0.51 | 0.74 | 0.50 | - |
| item16 | 0.76 |  |  |  |  |
| item17 | 0.55 |  |  |  |  |
| item18 | 0.78 |  |  |  |  |
| **Single Item Measures** | |  |  |  |  |
| Trouble in Memory | 1.00 | 1.00 | 1.00 | 1.00 | 0.28 |
| Trouble in Concentration | 1.00 | 1.00 | 1.00 | 1.00 | 0.32 |
| **Perceived Sleep Quality (PSQ)** |  | 0.60 | 0.73 | 0.36 | 0.27 |
| Component 1 | 0.72 |  |  |  |  |
| Component 2 | 0.44 |  |  |  |  |
| Component 5 | 0.51 |  |  |  |  |
| Component 6 | 0.42 |  |  |  |  |
| Component 7 | 0.81 |  |  |  |  |
| **Sleep Efficiency (SE)** |  | 0.48 | 0.79 | 0.66 | 0.05 |
| Component 3 | 0.86 |  |  |  |  |
| Component 4 | 0.75 |  |  |  |  |
| **MEQ Peak Time (PT)** |  | 0.71 | 0.79 | 0.39 | .11 |
| Item 11 | 0.53 |  |  |  |  |
| Item 1 | 0.75 |  |  |  |  |
| Item 18 | 0.58 |  |  |  |  |
| Item 17 | 0.50 |  |  |  |  |
| Item 09 | 0.79 |  |  |  |  |
| Item 15 | 0.55 |  |  |  |  |
| **MEQ Morning Affect (MA)** |  | 0.72 | 0.84 | 0.64 | 0.05 |
| Item 07 | 0.87 |  |  |  |  |
| Item 04 | 0.80 |  |  |  |  |
| Item 05 | 0.73 |  |  |  |  |
| **MEQ Retiring (RT)** |  | 0.60 | 0.77 | 0.46 | 0.12 |
| Item19 | 0.76 |  |  |  |  |
| Item8 | 0.61 |  |  |  |  |
| Item 2 | 0.78 |  |  |  |  |
| Item 14 | 0.53 |  |  |  |  |
| **MEQ Rising (RI**) |  | 0.51 | 0.80 | 0.67 | 0.09 |
| Item 3 | 0.85 |  |  |  |  |
| Item 13 | 0.78 |  |  |  |  |
| **Positive Affect (PA)** |  | 0.92 | 0.93 | 0.57 | 0.14 |
| Interested | 0.74 |  |  |  |  |
| Excited | 0.72 |  |  |  |  |
| Strong | 0.84 |  |  |  |  |
| Enthusiastic | 0.81 |  |  |  |  |
| Proud | 0.71 |  |  |  |  |
| Alert | 0.63 |  |  |  |  |
| Inspired | 0.80 |  |  |  |  |
| Determined | 0.77 |  |  |  |  |
| Attentive | 0.72 |  |  |  |  |
| Active | 0.82 |  |  |  |  |
| **Negative Affect (NA)** |  | 0.86 | 0.89 | 0.45 | 0.03 |
| Distressed | 0.67 |  |  |  |  |
| Upset | 0.72 |  |  |  |  |
| Guilty | 0.64 |  |  |  |  |
| Scared | 0.74 |  |  |  |  |
| Hostile | 0.46 |  |  |  |  |
| Irritable | 0.68 |  |  |  |  |
| Ashamed | 0.65 |  |  |  |  |
| Nervous | 0.73 |  |  |  |  |
| Jittery | 0.58 |  |  |  |  |
| Afraid | 0.78 |  |  |  |  |

*Note.* All factor loadings are significant (p<0.05)

Table 4:

Discriminant validity assessment using the Fornell and Larcker Criterion

| Constructs\* | LEBA F1 | LEBA F2 | LEBA F3 | LEBA F4 | LEBA F5 | PA | NA | PSQ | SE | PT | MA | RT | RI | Memory | Concentration |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| LEBA F1 | **0.95** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| LEBA F2 | 0.05 | **0.67** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| LEBA F3 | -0.10 | -0.21 | **0.80** |  |  |  |  |  |  |  |  |  |  |  |  |
| LEBA F4 | 0.17 | 0.12 | 0.02 | **0.77** |  |  |  |  |  |  |  |  |  |  |  |
| PA | 0.11 | 0.22 | -0.17 | 0.29 | **0.71** |  |  |  |  |  |  |  |  |  |  |
| NA | -0.06 | 0.35 | -0.12 | 0.02 | 0.21 | **0.76** |  |  |  |  |  |  |  |  |  |
| LEBA F1 | 0.09 | 0.02 | 0.14 | 0.05 | 0.13 | -0.19 | **0.67** |  |  |  |  |  |  |  |  |
| PSQ | 0.08 | -0.06 | 0.23 | 0.02 | -0.18 | -0.33 | 0.37 | **0.60** |  |  |  |  |  |  |  |
| SE | 0.02 | 0.01 | -0.06 | -0.03 | 0.02 | 0.22 | -0.08 | -0.04 | **0.81** |  |  |  |  |  |  |
| PT | -0.07 | 0.22 | -0.28 | 0.01 | 0.17 | 0.33 | -0.17 | -0.26 | 0.10 | **0.63** |  |  |  |  |  |
| MA | -0.12 | 0.12 | -0.15 | 0.06 | 0.16 | 0.31 | -0.20 | -0.35 | 0.18 | 0.41 | **0.80** |  |  |  |  |
| RT | -0.01 | 0.21 | -0.31 | -0.09 | 0.16 | 0.27 | -0.08 | -0.18 | 0.10 | 0.63 | 0.37 | **0.68** |  |  |  |
| RI | 0.05 | 0.20 | -0.28 | -0.01 | 0.15 | 0.18 | -0.05 | -0.11 | 0.11 | 0.35 | 0.20 | 0.34 | **0.82** |  |  |
| Memory | 0.01 | -0.09 | 0.20 | 0.11 | 0.08 | -0.16 | 0.47 | 0.32 | -0.10 | -0.22 | -0.28 | -0.22 | -0.10 | **1.00** |  |
| Concentration | 0.01 | -0.05 | 0.23 | 0.06 | -0.04 | -0.26 | 0.46 | 0.43 | -0.15 | -0.26 | -0.31 | -0.16 | -0.17 | 0.52 | **1.00** |

Note. \*The bold numbers listed diagonally are the square root of the AVE of the constructs. The off-diagonals are the inter-correlations of the constructs. For discriminant validity. The diagonal values should be larger than the values of the off-diagonals.

Table 5:

Discriminant validity assessment using the HTMT

| Constructs | LEBA F1 | LEBA F2 | LEBA F3 | LEBA F4 | LEBA F5 | PA | NA | PSQ | SE | PT | MA | RT | RI | Memory |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| LEBA F1 | 0.09 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| LEBA F2 | 0.13 | 0.26 |  |  |  |  |  |  |  |  |  |  |  |  |
| LEBA F3 | 0.21 | 0.23 | 0.09 |  |  |  |  |  |  |  |  |  |  |  |
| LEBA F4 | 0.19 | 0.40 | 0.28 | 0.52 |  |  |  |  |  |  |  |  |  |  |
| PA | 0.07 | 0.41 | 0.15 | 0.09 | 0.31 |  |  |  |  |  |  |  |  |  |
| NA | 0.11 | 0.16 | 0.21 | 0.11 | 0.29 | 0.25 |  |  |  |  |  |  |  |  |
| PSQ | 0.12 | 0.28 | 0.38 | 0.14 | 0.34 | 0.35 | 0.49 |  |  |  |  |  |  |  |
| SE | 0.09 | 0.06 | 0.17 | 0.17 | 0.13 | 0.32 | 0.13 | 0.23 |  |  |  |  |  |  |
| PT | 0.09 | 0.25 | 0.34 | 0.15 | 0.29 | 0.41 | 0.26 | 0.34 | 0.21 |  |  |  |  |  |
| MA | 0.15 | 0.15 | 0.20 | 0.08 | 0.27 | 0.36 | 0.25 | 0.43 | 0.31 | 0.52 |  |  |  |  |
| RT | 0.14 | 0.27 | 0.46 | 0.14 | 0.30 | 0.36 | 0.17 | 0.34 | 0.25 | 0.94 | 0.54 |  |  |  |
| RI | 0.08 | 0.26 | 0.44 | 0.14 | 0.28 | 0.27 | 0.15 | 0.34 | 0.22 | 0.52 | 0.33 | 0.57 |  |  |
| Memory | 0.04 | 0.12 | 0.24 | 0.13 | 0.10 | 0.16 | 0.49 | 0.35 | 0.16 | 0.26 | 0.32 | 0.26 | 0.14 |  |
| Concentration | 0.03 | 0.10 | 0.28 | 0.06 | 0.14 | 0.27 | 0.49 | 0.45 | 0.21 | 0.29 | 0.35 | 0.20 | 0.23 | 0.52 |

Table 6:

Structural model assessment

| 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 |  | |  | |  | |  |  |  | Not supported |
| **H9: Light exposure related behavior -> Memory and Concentration** | | | | | | | | | | |  |
| H9 | Light exposure related behavior -> Memory and Concentration |  | |  | |  | |  |  |  | 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 |

*\** Only significant paths are reported

Supplementary Table

SA T1:

Results of Measurement assessment (Supplemental table)

| Constructs | Factor Loading | Cronbach’s alpha | CR | AVE |
| --- | --- | --- | --- | --- |
| **LEBA F1** |  | 0.94 | 0.96 | 0.66 |
| item1 | 0.95 |  |  |  |
| item2 | 0.95 |  |  |  |
| item3 | 0.94 |  |  |  |
| **LEBA F2** |  |  |  |  |
| Item4 | 0.31 | 0.69 | 0.78 | 0.39 |
| item5 | 0.47 |  |  |  |
| item6 | 0.72 |  |  |  |
| item7 | 0.63 |  |  |  |
| item8 | 0.68 |  |  |  |
| item9 | 0.78 |  |  |  |
| **LEBA F3** |  | 0.71 | 0.84 | 0.64 |
| item10 | 0.85 |  |  |  |
| item11 | 0.86 |  |  |  |
| item12 | 0.68 |  |  |  |
| **LEBA F4** |  | 0.67 | 0.82 | 0.60 |
| item13 | 0.75 |  |  |  |
| item14 | 0.69 |  |  |  |
| item15 | 0.88 |  |  |  |
| **LEBA F5** |  | 0.51 | 0.74 | 0.50 |
| item16 | 0.76 |  |  |  |
| item17 | 0.54 |  |  |  |
| item18 | 0.79 |  |  |  |
| **Single Item Measures** |  |  |  |  |
| Trouble in Concentration | 1.00 | 1.00 | 1.00 | 1.00 |
| Trouble in Memory | 1.00 | 1.00 | 1.00 | 1.00 |
| **Perceived Sleep Quality (PSQ)** |  | 0.60 | 0.73 | 0.36 |
| Component 1 | 0.72 |  |  |  |
| Component 2 | 0.44 |  |  |  |
| Component 5 | 0.51 |  |  |  |
| Component 6 | 0.43 |  |  |  |
| Component 7 | 0.81 |  |  |  |
| **Sleep Efficiency (SE)** |  | 0.48 | 0.79 | 0.66 |
| Component 3 | 0.86 |  |  |  |
| Component 4 | 0.75 |  |  |  |
| **MEQ Peak Time (PT)** |  | 0.71 | 0.79 | 0.39 |
| Item 11 | 0.53 |  |  |  |
| Item 1 | 0.75 |  |  |  |
| Item 18 | 0.58 |  |  |  |
| Item 17 | 0.50 |  |  |  |
| Item 09 | 0.79 |  |  |  |
| Item 15 | 0.55 |  |  |  |
| **MEQ Morning Affect (MA)** |  | 0.53 | 0.70 | 0.48 |
| Item 07 | 0.85 |  |  |  |
| Item 04 | 0.79 |  |  |  |
| Item 05 | 0.73 |  |  |  |
| Item 06 | -0.15 |  |  |  |
| **MEQ Retiring (RT)** |  | 0.42 | 0.61 | 0.29 |
| Item19 | 0.75 |  |  |  |
| Item8 | 0.58 |  |  |  |
| Item 2 | 0.78 |  |  |  |
| Item 10 | 0.38 |  |  |  |
| Item 14 | 0.54 |  |  |  |
| Item 16 | -0.26 |  |  |  |
| Item 12 | 0.06 |  |  |  |
| **MEQ Rising (RI**) |  | 0.51 | 0.80 | 0.67 |
| Item 3 | 0.85 |  |  |  |
| Item 13 | 0.78 |  |  |  |
| **Positive Affect (PA)** |  | 0.92 | 0.93 | 0.57 |
| Interested | 0.74 |  |  |  |
| Excited | 0.72 |  |  |  |
| Strong | 0.84 |  |  |  |
| Enthusiastic | 0.81 |  |  |  |
| Proud | 0.71 |  |  |  |
| Alert | 0.63 |  |  |  |
| Inspired | 0.80 |  |  |  |
| Determined | 0.77 |  |  |  |
| Attentive | 0.72 |  |  |  |
| Active | 0.82 |  |  |  |
| **Negative Affect (NA)** |  | 0.86 | 0.89 | 0.45 |
| Distressed | 0.67 |  |  |  |
| Upset | 0.72 |  |  |  |
| Guilty | 0.64 |  |  |  |
| Scared | 0.74 |  |  |  |
| Hostile | 0.46 |  |  |  |
| Irritable | 0.68 |  |  |  |
| Ashamed | 0.65 |  |  |  |
| Nervous | 0.73 |  |  |  |
| Jittery | 0.58 |  |  |  |
| Afraid | 0.78 |  |  |  |

SA Table 2

Structural Model all path coefficients

|  | Original Est. | Bootstrap Mean | Bootstrap SD | T Stat. | 2.5% CI | 97.5% CI |
| --- | --- | --- | --- | --- | --- | --- |
| L1  ->  PA | -0.09 | -0.09 | 0.06 | -1.54 | -0.20 | 0.02 |
| L1  ->  NA | 0.09 | 0.09 | 0.07 | 1.30 | -0.05 | 0.22 |
| L1  ->  PSQ | 0.04 | 0.04 | 0.05 | 0.68 | -0.07 | 0.14 |
| L1  ->  SE | 0.06 | 0.06 | 0.06 | 0.99 | -0.05 | 0.18 |
| L1  ->  PT | -0.11 | -0.11 | 0.06 | -1.94 | -0.22 | 0.00 |
| L1  ->  MA | -0.16 | -0.16 | 0.06 | -2.44 | -0.28 | -0.03 |
| L1  ->  RT | -0.04 | -0.04 | 0.06 | -0.57 | -0.17 | 0.08 |
| L1  ->  RI | 0.02 | 0.02 | 0.05 | 0.44 | -0.09 | 0.13 |
| L1  ->  Memory | -0.04 | -0.04 | 0.06 | -0.72 | -0.15 | 0.07 |
| L1  ->  Concentration | -0.04 | -0.04 | 0.05 | -0.74 | -0.13 | 0.06 |
| L2  ->  PA | 0.32 | 0.32 | 0.05 | 6.21 | 0.22 | 0.42 |
| L2  ->  NA | 0.03 | 0.02 | 0.07 | 0.35 | -0.12 | 0.16 |
| L2  ->  PSQ | 0.07 | 0.07 | 0.07 | 1.11 | -0.05 | 0.20 |
| L2  ->  SE | -0.09 | -0.09 | 0.07 | -1.27 | -0.23 | 0.05 |
| L2  ->  PT | 0.15 | 0.15 | 0.07 | 2.27 | 0.02 | 0.28 |
| L2  ->  MA | 0.07 | 0.07 | 0.06 | 1.14 | -0.05 | 0.18 |
| L2  ->  RT | 0.15 | 0.15 | 0.06 | 2.29 | 0.02 | 0.27 |
| L2  ->  RI | 0.14 | 0.14 | 0.06 | 2.33 | 0.02 | 0.25 |
| L2  ->  Memory | -0.10 | -0.10 | 0.05 | -1.79 | -0.20 | 0.01 |
| L2  ->  Concentration | 0.01 | 0.01 | 0.06 | 0.18 | -0.11 | 0.14 |
| L3  ->  PA | -0.03 | -0.03 | 0.06 | -0.50 | -0.15 | 0.09 |
| L3  ->  NA | 0.17 | 0.17 | 0.06 | 2.84 | 0.05 | 0.29 |
| L3  ->  PSQ | 0.13 | 0.13 | 0.06 | 2.24 | 0.01 | 0.24 |
| L3  ->  SE | -0.02 | -0.02 | 0.07 | -0.32 | -0.15 | 0.11 |
| L3  ->  PT | -0.24 | -0.24 | 0.05 | -4.39 | -0.35 | -0.14 |
| L3  ->  MA | -0.13 | -0.13 | 0.06 | -2.24 | -0.24 | -0.01 |
| L3  ->  RT | -0.26 | -0.27 | 0.05 | -4.83 | -0.37 | -0.16 |
| L3  ->  RI | -0.23 | -0.23 | 0.06 | -3.79 | -0.35 | -0.11 |
| L3  ->  Memory | 0.09 | 0.09 | 0.06 | 1.59 | -0.02 | 0.20 |
| L3  ->  Concentration | 0.11 | 0.11 | 0.06 | 1.95 | 0.00 | 0.22 |
| L4  ->  PA | -0.05 | -0.05 | 0.07 | -0.68 | -0.19 | 0.09 |
| L4  ->  NA | -0.01 | 0.00 | 0.06 | -0.19 | -0.13 | 0.12 |
| L4  ->  PSQ | 0.05 | 0.05 | 0.07 | 0.74 | -0.08 | 0.17 |
| L4  ->  SE | -0.03 | -0.04 | 0.09 | -0.31 | -0.20 | 0.13 |
| L4  ->  PT | -0.01 | -0.01 | 0.08 | -0.18 | -0.16 | 0.14 |
| L4  ->  MA | 0.04 | 0.03 | 0.08 | 0.51 | -0.12 | 0.18 |
| L4  ->  RT | -0.13 | -0.12 | 0.08 | -1.60 | -0.25 | 0.06 |
| L4  ->  RI | -0.06 | -0.06 | 0.08 | -0.69 | -0.21 | 0.10 |
| L4  ->  Memory | 0.07 | 0.07 | 0.07 | 1.05 | -0.08 | 0.20 |
| L4  ->  Concentration | 0.04 | 0.03 | 0.06 | 0.72 | -0.09 | 0.14 |
| L5  ->  PA | 0.16 | 0.16 | 0.06 | 2.45 | 0.03 | 0.28 |
| L5  ->  NA | 0.15 | 0.13 | 0.10 | 1.43 | -0.09 | 0.32 |
| L5  ->  PSQ | -0.16 | -0.16 | 0.06 | -2.59 | -0.27 | -0.03 |
| L5  ->  SE | -0.03 | -0.03 | 0.07 | -0.49 | -0.16 | 0.11 |
| L5  ->  PT | 0.11 | 0.12 | 0.07 | 1.67 | -0.01 | 0.25 |
| L5  ->  MA | 0.13 | 0.14 | 0.07 | 1.92 | 0.00 | 0.27 |
| L5  ->  RT | 0.12 | 0.12 | 0.07 | 1.73 | -0.02 | 0.26 |
| L5  ->  RI | 0.09 | 0.10 | 0.07 | 1.34 | -0.04 | 0.24 |
| L5  ->  Memory | 0.08 | 0.08 | 0.06 | 1.31 | -0.05 | 0.20 |
| L5  ->  Concentration | -0.01 | -0.01 | 0.06 | -0.16 | -0.13 | 0.11 |
| PA  ->  PSQ | -0.18 | -0.18 | 0.06 | -3.02 | -0.30 | -0.06 |
| PA  ->  SE | 0.22 | 0.21 | 0.07 | 3.08 | 0.07 | 0.35 |
| PA  ->  Memory | 0.01 | 0.01 | 0.06 | 0.12 | -0.12 | 0.13 |
| PA  ->  Concentration | -0.09 | -0.09 | 0.06 | -1.33 | -0.21 | 0.04 |
| NA  ->  PSQ | 0.28 | 0.29 | 0.06 | 4.83 | 0.17 | 0.40 |
| NA  ->  SE | -0.01 | -0.01 | 0.06 | -0.11 | -0.13 | 0.11 |
| NA  ->  Memory | 0.38 | 0.38 | 0.06 | 6.63 | 0.26 | 0.49 |
| NA  ->  Concentration | 0.33 | 0.32 | 0.06 | 5.87 | 0.21 | 0.43 |
| PSQ  ->  Memory | 0.17 | 0.18 | 0.06 | 3.11 | 0.07 | 0.29 |
| PSQ  ->  Concentration | 0.26 | 0.26 | 0.06 | 4.60 | 0.15 | 0.37 |
| SE  ->  Memory | -0.06 | -0.06 | 0.05 | -1.23 | -0.16 | 0.03 |
| SE  ->  Concentration | -0.09 | -0.09 | 0.05 | -1.71 | -0.19 | 0.01 |
| PT  ->  PSQ | -0.06 | -0.06 | 0.08 | -0.69 | -0.22 | 0.11 |
| PT  ->  SE | -0.02 | -0.02 | 0.08 | -0.28 | -0.18 | 0.15 |
| MA  ->  PSQ | -0.20 | -0.20 | 0.06 | -3.31 | -0.31 | -0.08 |
| MA  ->  SE | 0.14 | 0.14 | 0.07 | 1.92 | -0.01 | 0.27 |
| RT  ->  PSQ | 0.04 | 0.04 | 0.07 | 0.59 | -0.10 | 0.19 |
| RT  ->  SE | 0.00 | 0.00 | 0.08 | -0.03 | -0.17 | 0.16 |
| RI  ->  PSQ | 0.02 | 0.03 | 0.05 | 0.45 | -0.08 | 0.14 |
| RI  ->  SE | 0.06 | 0.06 | 0.07 | 0.84 | -0.08 | 0.21 |