Light exposure-related behaviors can predict sleep quality, mood, chronotype and work performance: a PLS-SEM based study

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Abstract

One or two sentences providing a **basic introduction** to the field, comprehensible to a scientist in any discipline.

Two to three sentences of **more detailed background**, comprehensible to scientists in related disciplines.

One sentence clearly stating the **general problem** being addressed by this particular study.

One sentence summarizing the main result (with the words “**here we show**” or their equivalent).

Two or three sentences explaining what the **main result** reveals in direct comparison to what was thought to be the case previously, or how the main result adds to previous knowledge.

One or two sentences to put the results into a more **general context**.

Two or three sentences to provide a **broader perspective**, readily comprehensible to a scientist in any discipline.

*Keywords:* keywords

*Word count:* X

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In the past forty years, numerous scientific studies have confirmed that retinal light exposure exhorts a profound influence on our physiology, mood and behavior, 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 et al., 2002).

## 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). In contrast, 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 et al., 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 and work performance

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 and work performance

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 et al., 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 et al., 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 et al., 2021; Threadgill et al., 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. Thus, in this study, we aim to understand the influence of light exposure-related behavior on chronotype, mood, sleep quality and work performance. We pose the following questions: What are the influences of light exposure-related behavior on (a) chronotype, (b) mood, (c) sleep quality, and (d) work performance?

To answer this question, we developed a theoretical framework (Figure 1) based on the literature reviewed to predict the influence of light exposure-related behavior on other variables, 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*: influences unmediated by any other constructs in the model, (ii) *indirect effects:* influences mediated by at least one intervening construct in the modeland (iii) *total effects*: sums of direct and indirect effects of a given construct can be estimated (Bollen, 1987).

We predicted that light exposure-related behaviors 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). Work performance would be influenced by sleep quality (H6), mood (H7), and chronotype (H8). Light exposure-related behavior would directly influence work performance (H9). Additionally, we predicted that light exposure-related behavior would exhibit a significant total effect on work performance (H10) and sleep quality (H11).

Diagram

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Figure 1: Theoretical Framework

To answer this question, we based on the theoritical

# Methods

## Sample and Sampling adequacy

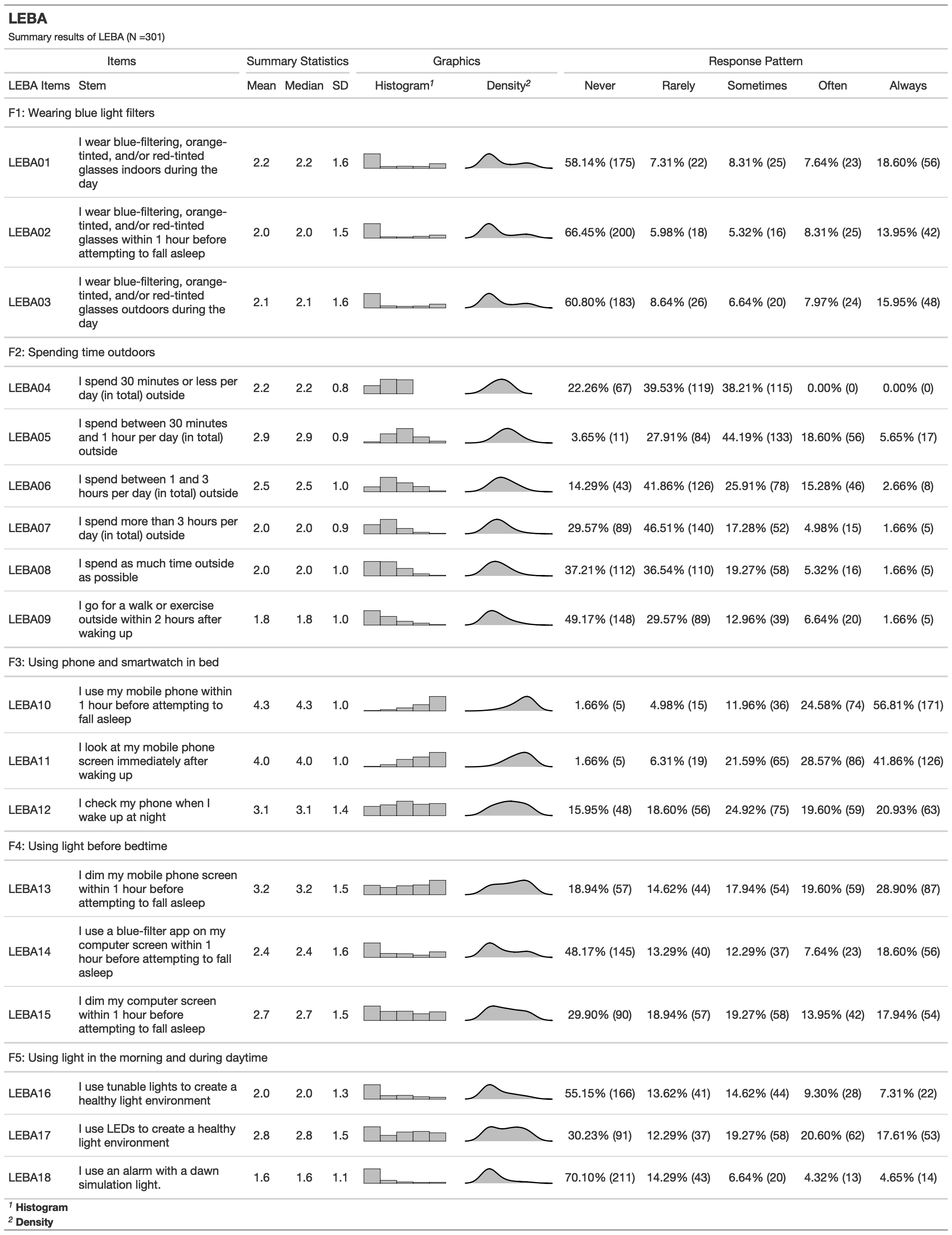
We conducted a large-scale online survey on Malaysian residents. The exclusion-inclusion criteria for respondents to be included in this study were: (1) any Malaysian resident aged >18 and able to read and write English (2) no physiological and psychological disorder (self-reported). Three hundred and 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). The first factor of LEBA (F1) investigates the propensity of wearing blue light filter glasses indoors and outdoors. The second factor (F2) captures time spent under the sunlight. The third-factor measures (F3) our habit of using smart devices in bed. The fourth factor (F4) investigates light exposure-related behaviors before bedtime. The last factor (F5) captures our habit of using different electric light sources throughout the day. 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).

### Work performance

To assess work performance, 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 et al., 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 Strategy

We used R (version 4.1.2; Team, 2022) and several statistical packages, including esemComp (Mateus et al., 2022), “SEMinR” (Hair, 2021) and tabledown (Siraji, 2022) for our analysis.

### Structural Validity of the Scales

We will gather structural validity evidence of LEBA, PSQI, MEQ and PANAS scales in our sample using the exploratory structural equation modeling (ESEM; Asparouhov et al., 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 would follow the guideline of we followed the guidelines of Hu et al. (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 <.08, good fit < .06; and the standardized root mean square (SRMR): acceptable fit <.10, good fit<.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 .70 is considered satisfactory (MacCallum et al., 1994; MacKenzie et al., 2005) and a value above .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. To indicate satisfactory convergent validity, the AVEs should be ≥ 0.50 (Fornell et al., 1981). However, AVEs < 0.50 with a composite reliability >0.60 also 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 path coefficients 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 of our model and values for the constructs as a predictive relevance index of our model. For assessing the explanatory power, we followed the guidelines of Falk et al. (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 (LM) benchmarks 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 linear regression (LM) benchmarks (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 analyses steps we followed.

Diagram

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*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 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).

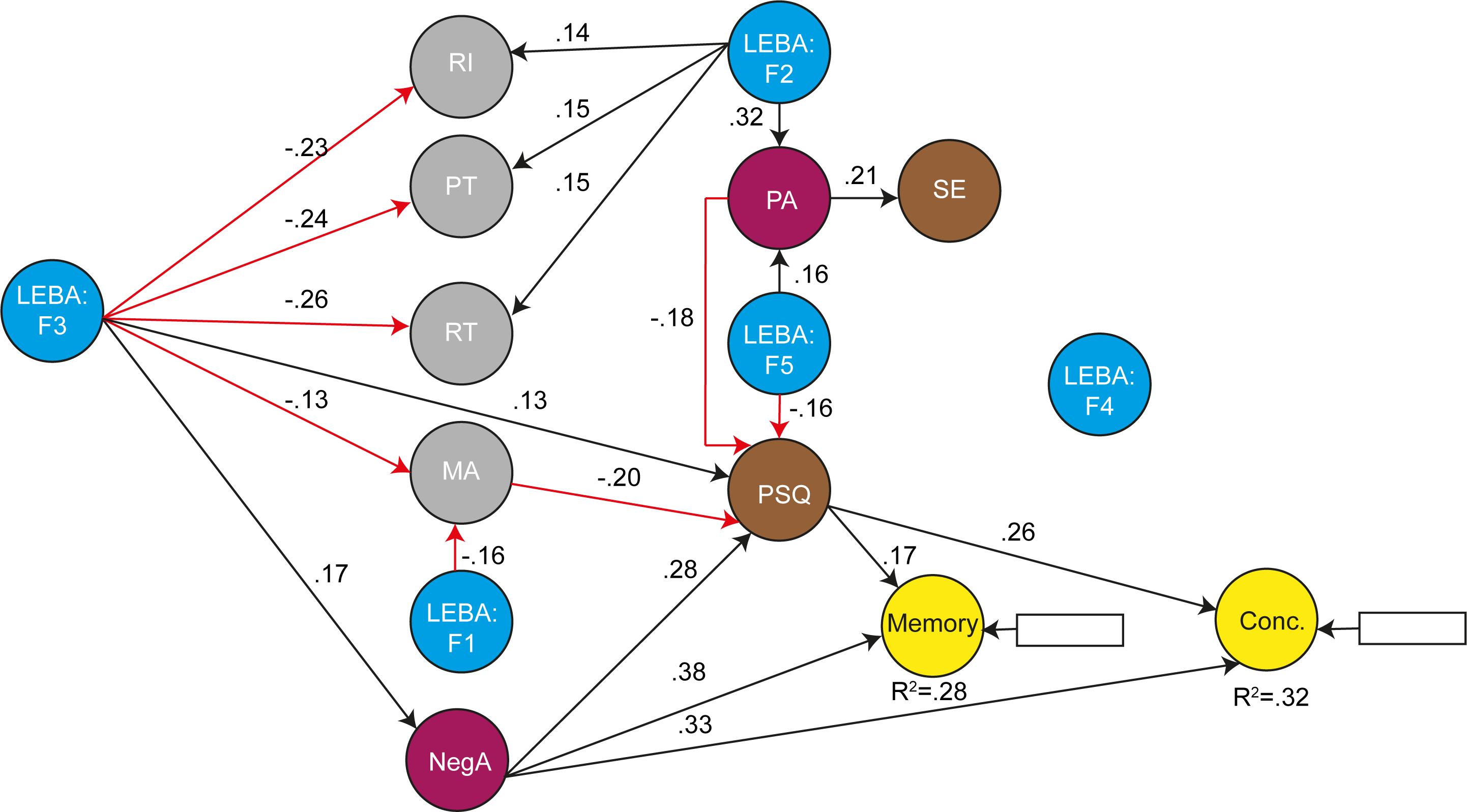
## Measurement Model

We excluded one item from LEBA (item04) 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 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 were less than their respective CRs. 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 direct effects (t-value >1.906, p<0.05) observed in our model.



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

### Total effects of light exposure-related behavior

Table 7 presents the total effects observed in our model. We observed a positive significant total effect of LEBA F1 on PSQ ( = 0.11) and a negative effect on MA (= -0.16). There are significant positive total effects of LEBA F2 on PA (= 0.32), PT (= 0.15), RT (= 0.15), RI (= 0.14). LEBA F3 had significant positive total effects on NA (= 0.17) and PSQ (= 0.21). LEBA F3 also exhibited significant positive effects on trouble in memory (= 0.20) and concentration (= 0.23). LEBA F3 also exhibited negative total effects on all four chronotype factors (PT:=; MA:=; RI:=; RI:=). LEBA F5 showed significant total effects on PA (= 0.16) and PSQ (= -0.17). LEBA F4 did not yield any significant total effect of on sleep quality, chronotype, mood and work performance.

### Total effects of mood, chronotype and sleep quality

In our model, we observed a significant negative total effect of PA on PSQ (= -0.18). In contrast, NA had a significant positive total effect on PSQ (= 0.28), trouble in memory (= 0.43) and concentration (= 0.40). Both PSQ and MA also showed significant positive total effects on trouble in memory (PSQ:= 0.17; MA: = -0.04)) and concentration (PSQ:= 0.26; MA:= -0.06).

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

Our fitted model exhibited substantial explanatory power for PSQ (26.79%) and trouble in concentration (30.35%). Moderate explanatory power was observed for PA (13.85%) and trouble in memory (25.51%). Adequate explanatory power was observed for PT (10.96%) and RT (12.45%). Our model did not exhibit adequate explanatory power 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

While measuring work performance, we focused on trouble in concentration and memory. We used two global single items that captured the essence of constructs. The use of such global single items allowed us to reduce participants’ cognitive demands required to respond to our survey, thus increasing the response rate with fewer missing parts (Drolet et al., 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 et al., 2009; Shamir et al., 2004; Youngblut et al., 1993).

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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 of Work Performance** | |  |  |  |  |
| 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 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 | Direct effects | Original Est. | Bootstrap Mean | Bootstrap SD | T Stat. | 2.5% CI | 97.5% CI | Results |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| H1 | LEBA F1  ->  MA | -0.16 | -0.16 | 0.06 | -2.44 | -0.28 | -0.03 | Supported |
| LEBA F2  ->  PA | 0.32 | 0.32 | 0.05 | 6.21 | 0.22 | 0.42 | Supported |
| LEBA F2  ->  PT | 0.15 | 0.15 | 0.07 | 2.27 | 0.02 | 0.28 | Supported |
| LEBA F2  ->  RT | 0.15 | 0.15 | 0.06 | 2.29 | 0.02 | 0.27 | Supported |
| LEBA F2  ->  RI | 0.14 | 0.14 | 0.06 | 2.33 | 0.02 | 0.25 | Supported |
| LEBA F3  ->  PT | -0.24 | -0.24 | 0.05 | -4.39 | -0.35 | -0.14 | Supported |
| LEBA F3  ->  MA | -0.13 | -0.13 | 0.06 | -2.24 | -0.24 | -0.01 | Supported |
| LEBA F3  ->  RT | -0.26 | -0.27 | 0.05 | -4.83 | -0.37 | -0.16 | Supported |
| LEBA F3  ->  RI | -0.23 | -0.23 | 0.06 | -3.79 | -0.35 | -0.11 | Supported |
| 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 | Supported |
| LEBA F3  ->  NA | 0.17 | 0.17 | 0.06 | 2.84 | 0.05 | 0.29 | Supported |
| H3 | LEBA F 3  ->  PSQ | 0.13 | 0.13 | 0.06 | 2.24 | 0.01 | 0.24 | Supported |
| LEBA F 5  ->  PSQ | -0.16 | -0.16 | 0.06 | -2.59 | -0.27 | -0.03 | Supported |
| 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 | Supported |
| NegA  ->  PSQ | 0.28 | 0.29 | 0.06 | 4.83 | 0.17 | 0.40 | Supported |
| H5 | MA  ->  PSQ | -0.20 | -0.20 | 0.06 | -3.31 | -0.31 | -0.08 | Supported |
| 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 | Supported |
| H7 | NegA  ->  Memory | 0.38 | 0.38 | 0.06 | 6.63 | 0.26 | 0.49 | Supported |
| NegA  ->  Concentration | 0.33 | 0.32 | 0.06 | 5.87 | 0.21 | 0.43 | Supported |
| H8 | Chronotype ->work performance |  |  |  |  |  |  | Not supported |
| H9 | Light exposure related behavior -> work performance |  |  |  |  |  |  | Not supported |

*\** Only significant paths are reported

Table 7

Significant Total effects

| Total Effects\* | Original Est. | Bootstrap Mean | Bootstrap SD | T Stat. | 2.5% CI | 97.5% CI |
| --- | --- | --- | --- | --- | --- | --- |
| **LEBA to chronotype** |  |  |  |  |  |  |
| LEBA F1 -> MA | -0.16 | -0.16 | 0.06 | -2.44 | -0.28 | -0.03 |
| LEBA F2 -> PA | 0.32 | 0.32 | 0.05 | 6.21 | 0.22 | 0.42 |
| 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 |
| **LEBA to Mood** |  |  |  |  |  |  |
| LEBA F3 -> NA | 0.17 | 0.17 | 0.06 | 2.84 | 0.05 | 0.29 |
| LEBA F5 -> PA | 0.16 | 0.16 | 0.06 | 2.45 | 0.03 | 0.28 |
| **LEBA to Sleep quality** |  |  |  |  |  |  |
| LEBA F1 -> PSQ | 0.11 | 0.12 | 0.05 | 2.06 | 0.01 | 0.22 |
| LEBA F3 -> PSQ | 0.21 | 0.21 | 0.06 | 3.53 | 0.09 | 0.32 |
| LEBA F5 -> PSQ | -0.17 | -0.17 | 0.07 | -2.38 | -0.30 | -0.02 |
| LEBA F5 -> PSQ | -0.18 | -0.18 | 0.06 | -3.02 | -0.30 | -0.06 |
| **LEBA to Work performance** |  |  |  |  |  |  |
| LEBA F3 -> Memory | 0.20 | 0.19 | 0.06 | 3.12 | 0.06 | 0.31 |
| LEBA F3 -> Concentration | 0.23 | 0.23 | 0.06 | 3.89 | 0.11 | 0.34 |
| **Mood to sleep quality** |  |  |  |  |  |  |
| 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 |
| **Chronotype to sleep quality** |  |  |  |  |  |  |
| MA -> PSQ | -0.20 | -0.20 | 0.06 | -3.31 | -0.31 | -0.08 |
| **Mood to work performance** |  |  |  |  |  |  |
| PA -> Concentration | -0.15 | -0.15 | 0.06 | -2.56 | -0.27 | -0.04 |
| NA -> Memory | 0.43 | 0.43 | 0.05 | 8.26 | 0.33 | 0.53 |
| NA -> Concentration | 0.40 | 0.40 | 0.05 | 7.86 | 0.30 | 0.50 |
| **Sleep quality to work performance** |  |  |  |  |  |  |
| 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 |
| **Chronotype to work performance** |  |  |  |  |  |  |
| MA -> Memory | -0.04 | -0.04 | 0.02 | -2.37 | -0.08 | -0.01 |
| MA -> Concentration | -0.06 | -0.06 | 0.02 | -2.98 | -0.11 | -0.03 |

*\** Only significant effects are reported

Supplementary Table

SA T1:

Results of Measurement assessment (Supplemental table)

| Constructs | Factor Loading | Cronbach’s alpha | CR | AVE |
| --- | --- | --- | --- | --- |
| Trouble in Concentration | 1.00 | 1.00 | 1.00 | 1.00 |
| Trouble in Memory | 1.00 | 1.00 | 1.00 | 1.00 |
| PSQ |  | 0.60 | 0.73 | 0.36 |
| PSQ1 | 0.72 |  |  |  |
| PSQ2 | 0.44 |  |  |  |
| PSQ3 | 0.51 |  |  |  |
| PSQ4 | 0.43 |  |  |  |
| PSQ5 | 0.81 |  |  |  |
| Sleep Efficiency |  | 0.48 | 0.79 | 0.66 |
| Sleep\_efficieny1 | 0.86 |  |  |  |
| Sleep\_efficieny2 | 0.75 |  |  |  |
| LEBA Factor 1 |  | 0.94 | 0.96 | 0.66 |
| LEBA\_F1\_item1 | 0.95 |  |  |  |
| LEBA\_F1\_item2 | 0.95 |  |  |  |
| LEBA\_F1\_item3 | 0.94 |  |  |  |
| LEBA Factor 2 |  |  |  |  |
| LEBA\_F2\_item1 | 0.31 | 0.69 | 0.78 | 0.39 |
| LEBA\_F2\_item2 | 0.47 |  |  |  |
| LEBA\_F2\_item3 | 0.72 |  |  |  |
| LEBA\_F2\_item4 | 0.63 |  |  |  |
| LEBA\_F2\_item5 | 0.68 |  |  |  |
| LEBA\_F2\_item6 | 0.78 |  |  |  |
| LEBA Factor 3 |  | 0.71 | 0.84 | 0.64 |
| LEBA\_F3\_item1 | 0.85 |  |  |  |
| LEBA\_F3\_item2 | 0.86 |  |  |  |
| LEBA\_F3\_item3 | 0.68 |  |  |  |
| LEBA Factor 4 |  | 0.67 | 0.82 | 0.60 |
| LEBA\_F4\_item1 | 0.75 |  |  |  |
| LEBA\_F4\_item2 | 0.69 |  |  |  |
| LEBA\_F4\_item3 | 0.88 |  |  |  |
| LEBA Factor 5 |  | 0.51 | 0.74 | 0.50 |
| LEBA\_F5\_item1 | 0.76 |  |  |  |
| LEBA\_F5\_item2 | 0.54 |  |  |  |
| LEBA\_F5\_item3 | 0.79 |  |  |  |
| MEQ F1 |  | 0.71 | 0.79 | 0.39 |
| MEQ\_F1\_item1 | 0.53 |  |  |  |
| MEQ\_F1\_item2 | 0.75 |  |  |  |
| MEQ\_F1\_item3 | 0.58 |  |  |  |
| MEQ\_F1\_item4 | 0.50 |  |  |  |
| MEQ\_F1\_item5 | 0.79 |  |  |  |
| MEQ\_F1\_item6 | 0.55 |  |  |  |
| MEQ F2 |  | 0.53 | 0.70 | 0.48 |
| MEQ\_F2\_item1 | 0.85 |  |  |  |
| MEQ\_F2\_item2 | 0.79 |  |  |  |
| MEQ\_F2\_item3 | 0.73 |  |  |  |
| MEQ\_F2\_item4 | -0.15 |  |  |  |
| MEQ F3 |  | 0.42 | 0.61 | 0.29 |
| MEQ\_F3\_item1 | 0.75 |  |  |  |
| MEQ\_F3\_item2 | 0.58 |  |  |  |
| MEQ\_F3\_item3 | 0.78 |  |  |  |
| MEQ\_F3\_item4 | 0.38 |  |  |  |
| MEQ\_F3\_item5 | 0.54 |  |  |  |
| MEQ\_F3\_item6 | -0.26 |  |  |  |
| MEQ\_F3\_item7 | 0.06 |  |  |  |
| MEQ F3 |  | 0.51 | 0.80 | 0.67 |
| MEQ\_F4\_item1 | 0.85 |  |  |  |
| MEQ\_F4\_item2 | 0.78 |  |  |  |
| Positive Affect |  | 0.92 | 0.93 | 0.57 |
| PA1 | 0.74 |  |  |  |
| PA2 | 0.72 |  |  |  |
| PA3 | 0.84 |  |  |  |
| PA4 | 0.81 |  |  |  |
| PA5 | 0.71 |  |  |  |
| PA6 | 0.63 |  |  |  |
| PA7 | 0.80 |  |  |  |
| PA8 | 0.77 |  |  |  |
| PA9 | 0.72 |  |  |  |
| PA10 | 0.82 |  |  |  |
| Negative Affect |  | 0.86 | 0.89 | 0.45 |
| NegA1 | 0.67 |  |  |  |
| NegA2 | 0.72 |  |  |  |
| NegA3 | 0.64 |  |  |  |
| NegA4 | 0.74 |  |  |  |
| NegA5 | 0.46 |  |  |  |
| NegA6 | 0.68 |  |  |  |
| NegA7 | 0.65 |  |  |  |
| NegA8 | 0.73 |  |  |  |
| NegA9 | 0.58 |  |  |  |
| NegA10 | 0.78 |  |  |  |