Light exposure related behaviors influences chronotype, sleep quality and trouble in memory and concentration: a partial least squares-path modeling Analysis

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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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##Objectives: We pose the following questions: 1. What are the influences of light exposure related behaviour on our chronotype? 2. What are the influences of light exposure related behaviour on sleep quality? 3. What are the influences of light exposure related behaviour on trouble in memory and concentration? 4. What are the influences of light exposure related behaviour on mood?

Hypothesis

Light exposure related behaviour will successfully predict: Trouble in Concentration and memory Chronotype and Sleep quality Mood

Methods

Participants

We conducted a large-scale online survey to gather data for this study. The inclusion criteria for respondents to be included in this study were as follows: (1) Malaysian resident >18 years of age and able to read and write English (2) no physiological and psychological disorder (self reported) . 366 adults completed the survey. However, we excluded 45 participants, due to incomplete data (87$\%$ completion rate). We further excluded 19 participants based on our inclusion criteria. Thus, we used we data form 301 participants for further processing. A priori power analysis was done to determine adequate sample sizes with G$*$Power 3.0 (Faul, Erdfelder, Lang, & Buchner, 2007). To achieve a effect size of .15 (Cohen, 1988) and 80% statistical power and $alpha$=0.05, for a multiple liner multiple regression with 13 predictors will need a total sample of 131 individuals. Also, the maximum number of items per factor in our model

was six.To detect minimum R^2 vale of 0.10 for a factor with six items with 80% statistical power and $alpha$=0.05 at least 130 participants are required (Joseph F. Hair Jr, Hult, Ringle, & Sarstedt, 2021). 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. Majority of the participants were students (71.42%). 56.29% participants had at least a Bachelor Degree.

Material

Light exposure behaviour assessment. Light exposure related behaviours was measured using the short form of Light Exposure Behaviour Assessment (LEBA)(Siraji et al., 2022). The short form contains five factors with 19 items. LEBA measures the propensity of different light exposure related behaviours 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) investigate the propensity of wearing blue light filter glasses indoors and outdoors. The second factor (F2) measures how much time spend under sunlight. The third factor measures (F3) our habit of using smart devices in bed. The fourth factor(F4) looks into our habit of controlling light exposure before bedtime. The last factor (F5) captures our habit of using different electric light sources throughout the day. All 19 items of LEBA and and the participants' responses to them are shown in 1.

Positive and Negative Affect Schdule. The positive and negative affect schedule (PANAS) (Watson, Clark, & Tellegen, 1988) was used to measure positive and negative affect. PANAS is comprised two 10-item mood scales measuring positive affect (PA) and negative affect (NA). The internal consistency reliability of the original scale was satisfactory (PA:0.88; NA:0.87) (Watson et al., 1988). In this study participants rate their positive and negative affect based on the last one month retrospectively 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).

Trouble in Memory and Concentration. To assess trouble in memory and concentration we used two items with four-point Likert type response options. These two items asked the participants about the propensity of their memory and concentration difficulty in the last one month (0=Absent; 1=Slight; 2=Moderate; 3=Severe)

Pittsburgh Sleep Quality Index. We used the Pittsburgh Sleep Quality Index (PSQI) (Buysse, Reynolds C. F., Monk, Berman, & Kupfer, 1989) to measure the sleep quality of the participants. PSQI measures seven domains of sleep to differentiate “poor” from “good” sleep. Participants responded to the PSQI using a Likert type responses option ranging from zero the three, whereby 3 reflects the negative extreme on the Likert Scale. A sum of scores equal to or greater than five indicates poor sleep quality. Though Buysse et al. (1989) reported an one factor structure of the scale, there are evidence that the factor structure of PSQI varies from one factor to three factors (Manzar et al., 2018). Dunleavy et al. (2019) in their study recommended to use a two-factor model: perceived sleep quality (PSQ) and sleep efficiency (SE) while measuring the sleep quality among Singapore citizen. In this study we followed their recommended structure.

Morningness-Eveningness Questionnaire. Chronotype was measured using Morningness-Eveningness questionnaire (MEQ) (Horne & Ostberg, 1976). MEQ is consist of 19 questions and the scores range from 16 to 86. A higher score indicates more morning propensity. Caci, Deschaux, Adan, and Natale (2009) reported a four factor structure of MEQ: peak time (PT), morning affect (MA), retiring (RT) and rising (RI) in s student sample.

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, 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 anytime 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 September 2022.

Analytic Strategy

Our aim was to predict chronotype, sleep quality and trouble in memory and concentration from the light exposure related behaviour. The partial least squares structural equation modelling (PLS-SEM) is best suited to formuate such predictive model (Joe F. Hair Jr, Matthews, Matthews, & Sarstedt, 2017). We used partial least squares structural equation modelling in R ((R Core Team, 2021); version 4.1.2) using "SeminR"(Ray, Danks, & Calero Valdez, 2022) package. Additionally, PLS-SEM is able to facilitate solution of models regardless of model complexity.

Measurement Model Assessment. First, we assessed the quality of measurement model. We excluded items with factor loading bellow .40 to increase the robustness of the measurement model (Joseph F. Hair Jr et al., 2021). Second, we estimated the internal consistency reliability estimates of each costruct. We reported both the lower bound estimate of reliability- Cronbach's α coefficient and upper bound estimate of reliability-construct reliability (CR). Both Cronbach's α and CR coefficient

values range between 0 to 1, where higher values represent better reliability. As a general guideline Cronbach's α above .70 is considered satisfactory(MacCallum, Roznowski, Mar, & Reith, 1994; MacKenzie, Podsakoff, & Jarvis, 2005). and value above .50 is considered acceptable (Hinton, McMurray, & Brownlow, 2014). CR coefficient value .60 and above indicates satisfactory reliability(Joseph F. Hair Jr et al., 2021).

Third, We assessed the convergent and discriminant validity of the measurement model. We used the average variance extracted (AVE) value of each construct to assess convergent validity. To indicate satisfactory convergent validity the AVE value should be 0.50 and above (Fornell & Larcker, 1981). However, AVE value lower than 0.5 with a composite reliability coefficient higher than 0.6 also indicate acceptable convergent validity (Fornell & Larcker, 1981). We assessed the discriminant validity of the measurement model by comparing the square root of each construct's AVE with its correlation with other constructs (Fornell & Larcker, 1981). The square root of the AVE values 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 to assess discriminant validity. For conceptually similar construct the HTMT value should be lower than .90 and for constructs which are conceptually distinct the HTMT value should be lower than .80 (Henseler, Ringle, & Sarstedt, 2015).

Structural Model Assessment. First, we assessed collinearity of the constructs in our structural model by calculating variance inflation factor (VIF) values. VIF>5 indicates probable collinearity issues (Henseler et al., 2015). Next, we estimated the 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 R^2 as a measure of explanatory power of our model and Q^2 values for the constructs as a predictive relevance index of our model. For assessing the explanatory power we followed the guidelines of Falk and Miller (1992) : R^2 values $\geq$ 0.10 indicates adequate explanatory power and categorize the values following and

Cohen (2013) guidelines : 0.02 (weak), 0.13 (moderate), and 0.26 (substantial). Q^2>0 indicates good predictive relevance. We further assessed the fitted model's predictive power by K-fold cross-validation using the $PLS_{predict}$ function from "SeminR" package(Ray et al., 2022). $PLS_{predict}$ 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 Sarstedt, Ringle, and 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 vale than LM the model has low predictive power, (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.

Results

Measurement Model

We excluded one items from LEBA (item04) and four items from MEQ(items 06, 10,16,12) due to weak factor loadings (<0.40) (SA1). All renaming factor loadings were significant. The results of the measurement model assessment are shown in Table 3.

Sleep Efficiency construct exhibited poor reliability in terms of coefficient Cronbach's alpha coefficient (α=.0.48) but had a satisfactory construct reliability (CR=0.79). All other constructs exhibited acceptable to satisfactory internal consistency in terms of Cronbach's α coefficient [0.51-0.94] and construct reliability[0.72-0.96]. In terms of convergent validity, AVE for all constructs were higher than .50 except LEBA factor 2, negative affect, PSQ, PT and RI. However all constructs construct validity were higher than .60 and AVEs were less than their respective construct reliability indicating sufficient reliability and convergent validity. To establish the discriminant validity we summarized the square root of each constructs' AVE and compared them with the its correlation with other construct in table 4. All constructs' square root of AVE values were greater than their inter construct correlation indicating satisfactory discriminant validity. Table 5 summarises the HTMT values and also indicated satisfactory discriminant validity (HTMT<.80).

Structural Model

VIF for all constructs were bellow 3 indicating no possible collinearity problem. **??** reports the significant (T-value >1.906, p<0.05) path coefficients and total effects observed in our model.

Total effects of light exposure related behavior. We observed a positive significant total effect of LEBA F1 on perceived sleep quality (PSQ) (β= 0.11) and negative effect on MA (β= -0.16). There are significant positive total effect of LEBA F2 on PA (β= 0.32), PT (β= 0.15), RT (β= 0.15), RI (β= 0.14). LEBA F3 had significant positive total effect on negative affect (β= 0.17), PSQ (β= 0.21). LEBA F3 also exhibited significant positive effect on trouble in memory (β= 0.20) and concentration (β= 0.23). LEBA F3 also exhibited negative total effect all four chronotype factors (PT, MA, RI, RI). LEBA F5 showed significant total effect on PA (β= 0.16) and PSQ (β= -0.17). Our model did not yield any significant total effect of LEBA factor 4 on sleep quality, chronotype,

mood and trouble in memory and concentration.

Total effects of mood, chronotype and sleep quality. Our model indicated a significant negative total effect of positive affect on trouble in concentration (β= -0.18). Negative affect had a significant positive total effect on PSQ (β= 0.28), trouble in memory (β= 0.43) and concentration (β= 0.40). Both PSQ and MA also showed significant positive total effects on trouble in memory (PSQ:β= 0.17; MA: β= -0.04)) and concentration (PSQ:β= 0.26; MA:β= -0.06). Figure 3 depicts significant path coefficents.

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 Memory (25.51%). For the two factors of chronotype we observed weak but adequate explanatory power for PT (10.96%) and RT (12.45%). MA, RI, SE and negative affect did not had adequate explanatory power. The Q^2 values of the respective constructs indicated good predictive relevance (Q^2>0) for all constructs except positive and negative affect (Q^2<0) and RI (Q^2close to 0). $PLS_{predict}$ function indicated our model had medium predictive power with 61.36% of the indicators having RMSE value lower than the LM benchmark.

Discussion

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Table 1

Dempgraphics

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%)
Your marital status		
Divorced	1 (0.5%)	0 (0%)
Married	37 (17%)	27 (33%)
Single	180 (83%)	56 (67%)
Please state your current level of education - Selected Choice		
Bachelor’s degree	129 (59%)	41 (49%)
Diploma	5 (2.3%)	4 (4.8%)
Doctor of Philosophy (PhD)	43 (20%)	13 (16%)
Master’s degree	38 (17%)	22 (27%)
post grad diploma	1 (0.5%)	0 (0%)

Characteristic	**Female**, N = 218	**Male**, N = 83
Pre-university	1 (0.5%)	2 (2.4%)
Secondary School	1 (0.5%)	1 (1.2%)
Do you primarily go to …		
Neither	11 (5.0%)	2 (2.4%)
School/University	165 (76%)	50 (60%)
Work	42 (19%)	31 (37%)
Community_Stance	7.07 (1.87)	7.00 (1.85)
Time_of_ Day		
afternoon	101 (46%)	42 (51%)
evening	75 (34%)	22 (27%)
morning	24 (11%)	9 (11%)
night	18 (8.3%)	10 (12%)
Positive_Affect	28 (9)	29 (8)
Negative_Affect	23.3 (5.8)	22.8 (5.3)
PSQI	5.70 (2.44)	6.34 (3.09)
Sleep_Quality		
Good Sleep	69 (32%)	24 (29%)
Poor Sleep	149 (68%)	59 (71%)
Sleep_Environment	6.1 (4.4)	7.1 (5.1)
Avg_Corneal_Illuminance	209 (231)	224 (227)
MEQ	48 (9)	49 (8)
Chronotype		
Definite Evening	8 (3.7%)	1 (1.2%)
Intermediate	144 (66%)	60 (72%)
Moderate Evening	43 (20%)	13 (16%)

Characteristic	**Female**, N = 218	**Male**, N = 83
Moderate Morning	23 (11%)	9 (11%)
LEBA1	6.5 (4.5)	5.6 (4.2)
LEBA2	13.8 (3.8)	14.3 (4.1)
LEBA3	14.7 (3.7)	15.3 (3.6)
LEBA4	12.0 (4.0)	12.1 (4.1)
LEBA5	11.0 (4.0)	10.9 (3.6)
Cups_of_Coffee(Weekday)	0.79 (1.15)	0.94 (1.22)
Cups_of Coffee(Weekend)	0.68 (1.05)	0.76 (1.15)
Your working /school/university shift		
Day Shift	173 (79%)	68 (82%)
Mixed shift work (Both Night and day in alternating way)	34 (16%)	7 (8.4%)
Night Shift	3 (1.4%)	2 (2.4%)
Off Work	8 (3.7%)	6 (7.2%)
Subjective_Alertness	7.5 (4.4)	8.4 (4.3)
For the last 4 weeks, how much are you bothered by: - 2.		
Trouble concentrating or thinking clearly		
Absent	27 (12%)	11 (13%)
Moderate	84 (39%)	32 (39%)
Severe	30 (14%)	7 (8.4%)
Slight	77 (35%)	33 (40%)
For the last 4 weeks, how much are you bothered by: - 5.		
Trouble with memory		
Absent	59 (27%)	20 (24%)
Moderate	57 (26%)	20 (24%)
Severe	20 (9.2%)	5 (6.0%)

Characteristic	**Female**, N = 218	**Male**, N = 83
Slight	82 (38%)	38 (46%)

Table 2

Results of Measurement assessment(Supplimental table)

Constructs	Factor Loading	Cronbach's alpha	CR	AVE
OLS_Concentration_rec	1.00	1.00	1.00	1.00
PSQ1	0.72	0.60	0.73	0.36
PSQ2	0.44	NA	NA	NA
PSQ3	0.51	NA	NA	NA
PSQ4	0.43	NA	NA	NA
PSQ5	0.81	NA	NA	NA
Sleep_efficieny1	0.86	0.48	0.79	0.66
Sleep_efficieny2	0.75	NA	NA	NA
LEBA_F1_item1	0.95	0.94	0.96	0.66
LEBA_F1_item2	0.95	NA	NA	NA
LEBA_F1_item3	0.94	NA	NA	NA
LEBA_F2_item1	0.31	0.69	0.78	0.39
LEBA_F2_item2	0.47	NA	NA	NA
LEBA_F2_item3	0.72	NA	NA	NA
LEBA_F2_item4	0.63	NA	NA	NA
LEBA_F2_item5	0.68	NA	NA	NA
LEBA_F2_item6	0.78	NA	NA	NA
LEBA_F3_item1	0.85	0.71	0.84	0.64
LEBA_F3_item2	0.86	NA	NA	NA
LEBA_F3_item3	0.68	NA	NA	NA
LEBA_F4_item1	0.75	0.67	0.82	0.60
LEBA_F4_item2	0.69	NA	NA	NA
LEBA_F4_item3	0.88	NA	NA	NA
LEBA_F5_item1	0.76	0.51	0.74	0.50
LEBA_F5_item2	0.54	NA	NA	NA
LEBA_F5_item3	0.79	NA	NA	NA
MEQ_F1_item1	0.53	0.71	0.79	0.39
MEQ_F1_item2	0.75	NA	NA	NA
MEQ_F1_item3	0.58	NA	NA	NA
MEQ_F1_item4	0.50	NA	NA	NA
MEQ_F1_item5	0.79	NA	NA	NA
MEQ_F1_item6	0.55	NA	NA	NA
MEQ_F2_item1	0.85	0.53	0.70	0.48
MEQ_F2_item2	0.79	NA	NA	NA
MEQ_F2_item3	0.73	NA	NA	NA

Table 2 continued

Constructs	Factor Loading	Cronbach's alpha	CR	AVE
MEQ_F2_item4	-0.15	NA	NA	NA
MEQ_F3_item1	0.75	0.42	0.61	0.29
MEQ_F3_item2	0.58	NA	NA	NA
MEQ_F3_item3	0.78	NA	NA	NA
MEQ_F3_item4	0.38	NA	NA	NA
MEQ_F3_item5	0.54	NA	NA	NA
MEQ_F3_item6	-0.26	NA	NA	NA
MEQ_F3_item7	0.06	NA	NA	NA
MEQ_F4_item1	0.85	0.51	0.80	0.67
MEQ_F4_item2	0.78	NA	NA	NA
PA1	0.74	0.92	0.93	0.57
PA2	0.72	NA	NA	NA
PA3	0.84	NA	NA	NA
PA4	0.81	NA	NA	NA
PA5	0.71	NA	NA	NA
PA6	0.63	NA	NA	NA
PA7	0.80	NA	NA	NA
PA8	0.77	NA	NA	NA
PA9	0.72	NA	NA	NA
PA10	0.82	NA	NA	NA
OLS_Memory_rec	1.00	1.00	1.00	1.00
NegA1	0.67	0.86	0.89	0.45
NegA2	0.72	NA	NA	NA
NegA3	0.64	NA	NA	NA
NegA4	0.74	NA	NA	NA
NegA5	0.46	NA	NA	NA
NegA6	0.68	NA	NA	NA
NegA7	0.65	NA	NA	NA
NegA8	0.73	NA	NA	NA
NegA9	0.58	NA	NA	NA
NegA10	0.78	NA	NA	NA

Table 3

Results of Measurement assessment

Constructs	Factor Loading	Cronbach's alpha	CR	AVE
OLS_Concentration_rec	1.00	1.00	1.00	1.00
PSQ1	0.72	0.60	0.73	0.36
PSQ2	0.44	NA	NA	NA
PSQ3	0.51	NA	NA	NA
PSQ4	0.42	NA	NA	NA
PSQ5	0.81	NA	NA	NA
Sleep_efficieny1	0.86	0.48	0.79	0.66
Sleep_efficieny2	0.75	NA	NA	NA
LEBA_F1_item1	0.95	0.94	0.96	0.66
LEBA_F1_item2	0.95	NA	NA	NA
LEBA_F1_item3	0.94	NA	NA	NA
LEBA_F2_item1	0.46	0.71	0.80	0.45
LEBA_F2_item2	0.73	NA	NA	NA
LEBA_F2_item3	0.62	NA	NA	NA
LEBA_F2_item4	0.69	NA	NA	NA
LEBA_F2_item5	0.79	NA	NA	NA
LEBA_F3_item1	0.85	0.71	0.84	0.64
LEBA_F3_item2	0.86	NA	NA	NA
LEBA_F3_item3	0.68	NA	NA	NA
LEBA_F4_item1	0.73	0.67	0.82	0.60
LEBA_F4_item2	0.69	NA	NA	NA
LEBA_F4_item3	0.89	NA	NA	NA
LEBA_F5_item1	0.76	0.51	0.74	0.50
LEBA_F5_item2	0.55	NA	NA	NA
LEBA_F5_item3	0.78	NA	NA	NA
MEQ_F1_item1	0.53	0.71	0.79	0.39
MEQ_F1_item2	0.75	NA	NA	NA
MEQ_F1_item3	0.58	NA	NA	NA
MEQ_F1_item4	0.50	NA	NA	NA
MEQ_F1_item5	0.79	NA	NA	NA
MEQ_F1_item6	0.55	NA	NA	NA
MEQ_F2_item1	0.87	0.72	0.84	0.64
MEQ_F2_item2	0.80	NA	NA	NA
MEQ_F2_item3	0.73	NA	NA	NA
MEQ_F3_item1	0.76	0.60	0.77	0.46
MEQ_F3_item2	0.61	NA	NA	NA
MEQ_F3_item3	0.78	NA	NA	NA

Table 3 continued

Constructs	Factor Loading	Cronbach's alpha	CR	AVE
MEQ_F3_item4	0.53	NA	NA	NA
MEQ_F4_item1	0.85	0.51	0.80	0.67
MEQ_F4_item2	0.78	NA	NA	NA
PA1	0.74	0.92	0.93	0.57
PA2	0.72	NA	NA	NA
PA3	0.84	NA	NA	NA
PA4	0.81	NA	NA	NA
PA5	0.71	NA	NA	NA
PA6	0.63	NA	NA	NA
PA7	0.80	NA	NA	NA
PA8	0.77	NA	NA	NA
PA9	0.72	NA	NA	NA
PA10	0.82	NA	NA	NA
OLS_Memory_rec	1.00	1.00	1.00	1.00
NegA1	0.67	0.86	0.89	0.45
NegA2	0.72	NA	NA	NA
NegA3	0.64	NA	NA	NA
NegA4	0.74	NA	NA	NA
NegA5	0.46	NA	NA	NA
NegA6	0.68	NA	NA	NA
NegA7	0.65	NA	NA	NA
NegA8	0.73	NA	NA	NA
NegA9	0.58	NA	NA	NA
NegA10	0.78	NA	NA	NA

Note. All factors loadings are significant($p<0.05$)

Table 4

Discriminant validity assessment using the Fornell-Larker Criterion

rowname	L1	L2	L3	L4	L5	PA	NegA	PSQ	SE	PT	MA	RT	RI	Memory	Concentration
L1	0.95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
L2	0.05	0.67	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
L3	-0.10	-0.21	0.80	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
L4	0.17	0.12	0.02	0.77	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
L5	0.11	0.22	-0.17	0.29	0.71	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA	-0.06	0.35	-0.12	0.02	0.21	0.76	NA	NA	NA	NA	NA	NA	NA	NA	NA
NegA	0.09	0.02	0.14	0.05	0.13	-0.19	0.67	NA	NA	NA	NA	NA	NA	NA	NA
PSQ	0.08	-0.06	0.23	0.02	-0.18	-0.33	0.37	0.60	NA	NA	NA	NA	NA	NA	NA
SE	0.02	0.01	-0.06	-0.03	0.02	0.22	-0.08	-0.04	0.81	NA	NA	NA	NA	NA	NA
PT	-0.07	0.22	-0.28	0.01	0.17	0.33	-0.17	-0.26	0.10	0.63	NA	NA	NA	NA	NA
MA	-0.12	0.12	-0.15	0.06	0.16	0.31	-0.20	-0.35	0.18	0.41	0.80	NA	NA	NA	NA
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	NA	NA	NA
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	NA	NA
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	NA
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

Table 5

Discriminant validity assessment using the HTMT

rowname	L1	L2	L3	L4	L5	PA	NegA	PSQ	SE	PT	MA	RT	RI	Memory	Concentration
L1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
L2	0.09	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
L3	0.13	0.26	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
L4	0.21	0.23	0.09	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
L5	0.19	0.40	0.28	0.52	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA	0.07	0.41	0.15	0.09	0.31	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NegA	0.11	0.16	0.21	0.11	0.29	0.25	NA	NA	NA	NA	NA	NA	NA	NA	NA
PSQ	0.12	0.28	0.38	0.14	0.34	0.35	0.49	NA	NA	NA	NA	NA	NA	NA	NA
SE	0.09	0.06	0.17	0.17	0.13	0.32	0.13	0.23	NA	NA	NA	NA	NA	NA	NA
PT	0.09	0.25	0.34	0.15	0.29	0.41	0.26	0.34	0.21	NA	NA	NA	NA	NA	NA
MA	0.15	0.15	0.20	0.08	0.27	0.36	0.25	0.43	0.31	0.52	NA	NA	NA	NA	NA
RT	0.14	0.27	0.46	0.14	0.30	0.36	0.17	0.34	0.25	0.94	0.54	NA	NA	NA	NA
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	NA	NA	NA
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	NA	NA
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	NA

Table 6

Structural model assessment

rowname	Original Est.	Bootstrap Mean	Bootstrap SD	T Stat.	2.5% CI	97.5% CI
L1 -> MA	-0.16	-0.16	0.06	-2.44	-0.28	-0.03
L2 -> PA	0.32	0.32	0.05	6.21	0.22	0.42
L2 -> PT	0.15	0.15	0.07	2.27	0.02	0.28
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
L3 -> NegA	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 -> 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
L5 -> PA	0.16	0.16	0.06	2.45	0.03	0.28
L5 -> PSQ	-0.16	-0.16	0.06	-2.59	-0.27	-0.03
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
NegA -> PSQ	0.28	0.29	0.06	4.83	0.17	0.40
NegA -> Memory	0.38	0.38	0.06	6.63	0.26	0.49
NegA -> 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
MA -> PSQ	-0.20	-0.20	0.06	-3.31	-0.31	-0.08

Note. Only significant paths are reported

Table 7

Significant Total effects

rowname	Original Est.	Bootstrap Mean	Bootstrap SD	T Stat.	2.5% CI	97.5% CI
L1 -> PSQ	0.11	0.12	0.05	2.06	0.01	0.22
L1 -> MA	-0.16	-0.16	0.06	-2.44	-0.28	-0.03
L2 -> PA	0.32	0.32	0.05	6.21	0.22	0.42
L2 -> PT	0.15	0.15	0.07	2.27	0.02	0.28
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
L3 -> NegA	0.17	0.17	0.06	2.84	0.05	0.29
L3 -> PSQ	0.21	0.21	0.06	3.53	0.09	0.32
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	0.20	0.19	0.06	3.12	0.06	0.31
L3 -> Concentration	0.23	0.23	0.06	3.89	0.11	0.34
L5 -> PA	0.16	0.16	0.06	2.45	0.03	0.28
L5 -> PSQ	-0.17	-0.17	0.07	-2.38	-0.30	-0.02
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 -> Concentration	-0.15	-0.15	0.06	-2.56	-0.27	-0.04
NegA -> PSQ	0.28	0.29	0.06	4.83	0.17	0.40
NegA -> Memory	0.43	0.43	0.05	8.26	0.33	0.53
NegA -> Concentration	0.40	0.40	0.05	7.86	0.30	0.50
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
MA -> PSQ	-0.20	-0.20	0.06	-3.31	-0.31	-0.08
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

Note. Only significant effects are reported

LEBA

Summary results of LEBA (N =301)

Items		Summary Statistics			Graphics		Response Pattern				
LEBA Items	Stem	Mean	Median	SD	Histogram[1]	Density[2]	Never	Rarely	Sometimes	Often	Always
F1: Wearing blue light filters											
LEBA01	I wear blue-filtering, orange-tinted, and/or red-tinted glasses indoors during the day	2.2	2.2	1.6			58.14% (175)	7.31% (22)	8.31% (25)	7.64% (23)	18.60% (56)
LEBA02	I wear blue-filtering, orange-tinted, and/or red-tinted glasses within 1 hour before attempting to fall asleep	2.0	2.0	1.5			66.45% (200)	5.98% (18)	5.32% (16)	8.31% (25)	13.95% (42)
LEBA03	I wear blue-filtering, orange-tinted, and/or red-tinted glasses outdoors during the day	2.1	2.1	1.6			60.80% (183)	8.64% (26)	6.64% (20)	7.97% (24)	15.95% (48)
F2: Spending time outdoors											
LEBA04	I spend 30 minutes or less per day (in total) outside	2.2	2.2	0.8			22.26% (67)	39.53% (119)	38.21% (115)	0.00% (0)	0.00% (0)
LEBA05	I spend between 30 minutes and 1 hour per day (in total) outside	2.9	2.9	0.9			3.65% (11)	27.91% (84)	44.19% (133)	18.60% (56)	5.65% (17)
LEBA06	I spend between 1 and 3 hours per day (in total) outside	2.5	2.5	1.0			14.29% (43)	41.86% (126)	25.91% (78)	15.28% (46)	2.66% (8)
LEBA07	I spend more than 3 hours per day (in total) outside	2.0	2.0	0.9			29.57% (89)	46.51% (140)	17.28% (52)	4.98% (15)	1.66% (5)
LEBA08	I spend as much time outside as possible	2.0	2.0	1.0			37.21% (112)	36.54% (110)	19.27% (58)	5.32% (16)	1.66% (5)
LEBA09	I go for a walk or exercise outside within 2 hours after waking up	1.8	1.8	1.0			49.17% (148)	29.57% (89)	12.96% (39)	6.64% (20)	1.66% (5)
F3: Using phone and smartwatch in bed											
LEBA10	I use my mobile phone within 1 hour before attempting to fall asleep	4.3	4.3	1.0			1.66% (5)	4.98% (15)	11.96% (36)	24.58% (74)	56.81% (171)
LEBA11	I look at my mobile phone screen immediately after waking up	4.0	4.0	1.0			1.66% (5)	6.31% (19)	21.59% (65)	28.57% (86)	41.86% (126)
LEBA12	I check my phone when I wake up at night	3.1	3.1	1.4			15.95% (48)	18.60% (56)	24.92% (75)	19.60% (59)	20.93% (63)
F4: Using light before bedtime											
LEBA13	I dim my mobile phone screen within 1 hour before attempting to fall asleep	3.2	3.2	1.5			18.94% (57)	14.62% (44)	17.94% (54)	19.60% (59)	28.90% (87)
LEBA14	I use a blue-filter app on my computer screen within 1 hour before attempting to fall asleep	2.4	2.4	1.6			48.17% (145)	13.29% (40)	12.29% (37)	7.64% (23)	18.60% (56)
LEBA15	I dim my computer screen within 1 hour before attempting to fall asleep	2.7	2.7	1.5			29.90% (90)	18.94% (57)	19.27% (58)	13.95% (42)	17.94% (54)
F5: Using light in the morning and during daytime											
LEBA16	I use tunable lights to create a healthy light environment	2.0	2.0	1.3			55.15% (166)	13.62% (41)	14.62% (44)	9.30% (28)	7.31% (22)
LEBA17	I use LEDs to create a healthy light environment	2.8	2.8	1.5			30.23% (91)	12.29% (37)	19.27% (58)	20.60% (62)	17.61% (53)
LEBA18	I use an alarm with a dawn simulation light.	1.6	1.6	1.1			70.10% (211)	14.29% (43)	6.64% (20)	4.32% (13)	4.65% (14)

[1] **Histogram**
[2] **Density**

Figure 1. Response distriction of LEBA

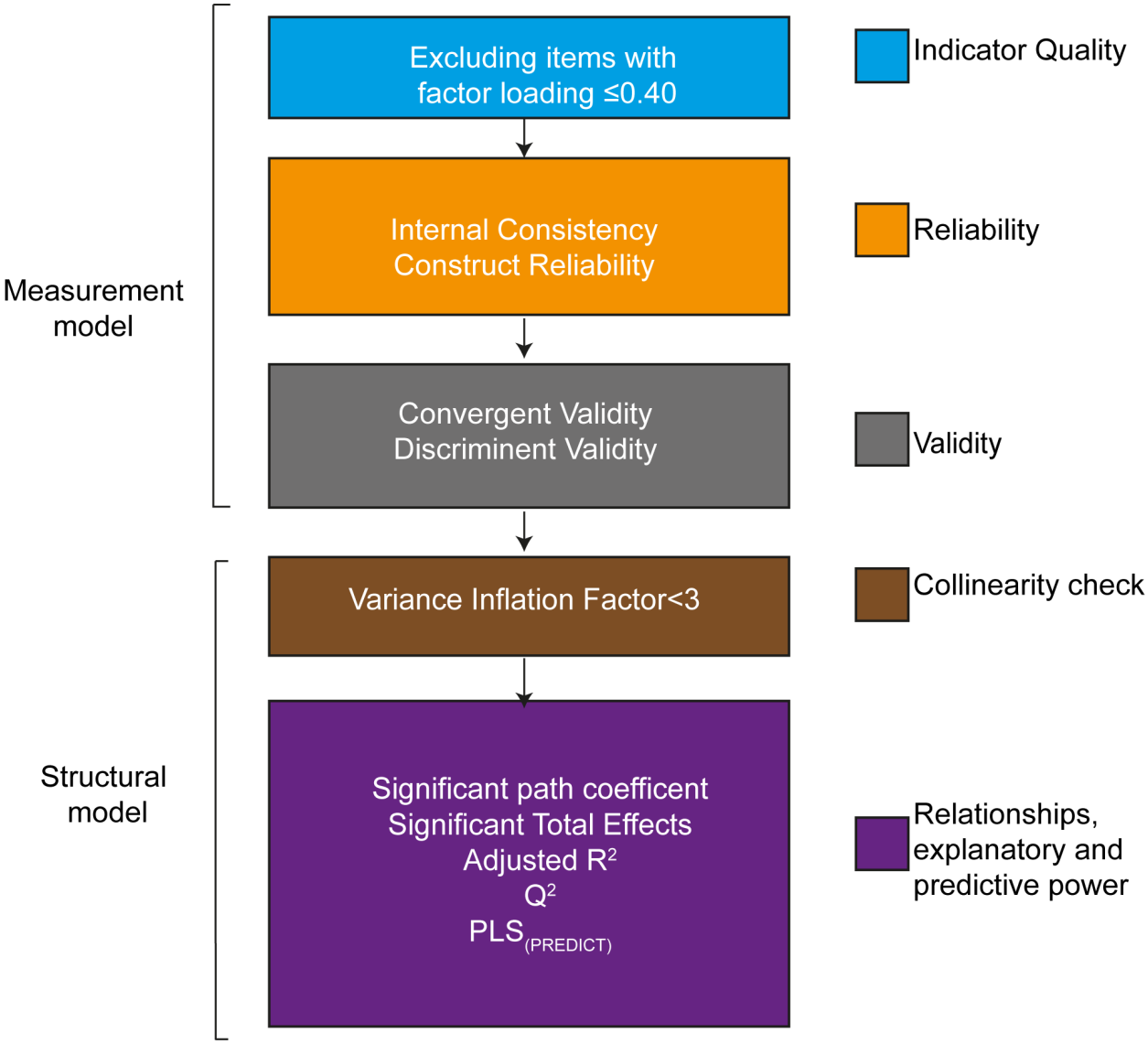

Figure 2. Analyses Steps

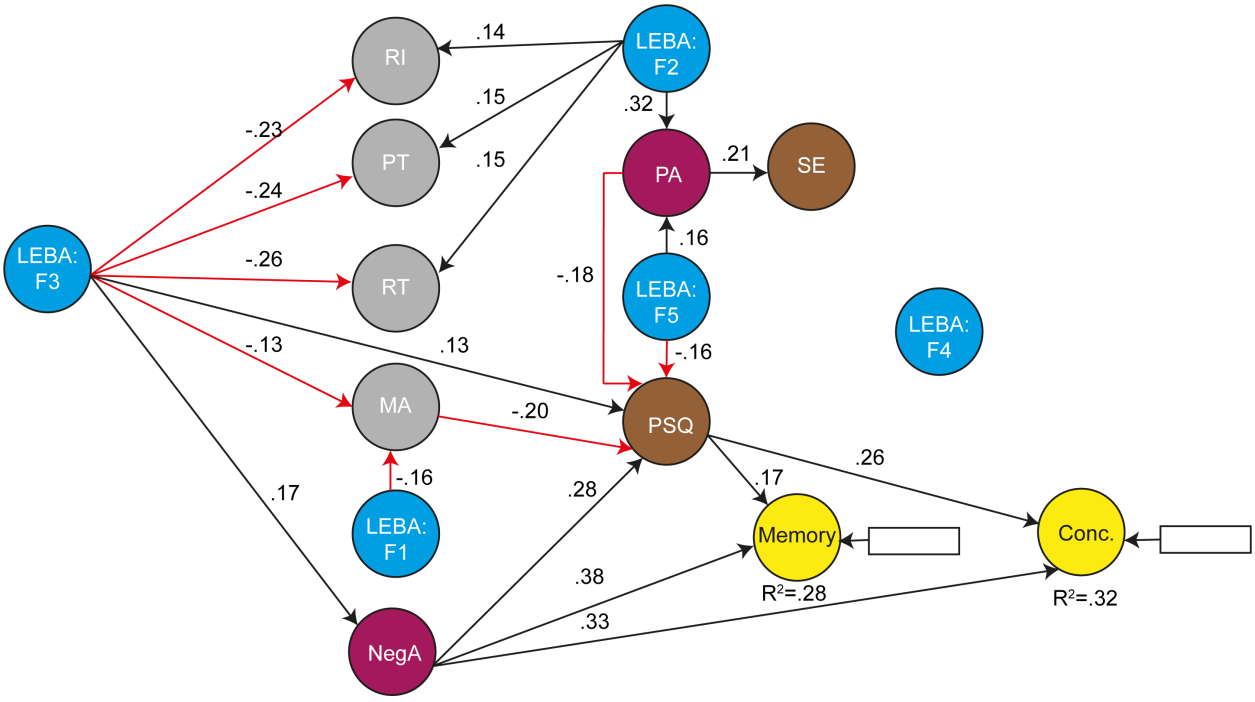

Figure 3. Analyses Steps