Light Exposure Behavior Assessment (LEBA): Development of a novel instrument to capture light exposure-related behaviours

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Abstract

Light exposure is an important driver of health and well-being. Many aspects of light exposure are modulated by our behaviour. How these light-related behaviours can be shaped to optimise personal light exposure is currently unknown. Here, we present a novel, self-reported and psychometrically validated instrument to capture light exposure-related behaviour, the Light Exposure Behavior Assessment (LEBA).

An expert panel prepared the initial 48 item pool spanning different light exposure related behaviors. Responses, consisting rating the frequency of engaging in the per-item behavior on a 5-point Likert type scale were collected in an online survey yielding responses from an international sample (690 completed responses, 74 countries, 28 time zones). Exploratory factor analysis (EFA) on an initial subset of our sample (n=428) rendered a five-factor solution with 25 items (Wearing blue light filters, spending time outdoors, using phone and smart-watch in bed, using light before bedtime, using light in the morning and during daytime). In a confirmatory factor analysis (CFA) performed on an independent subset of participants (n=262), we removed two further items to attain the best fit for the five-factor solution (CFI=0.97, TLI=0.96, RMSEA=0.05, SRMR=0.09). The internal consistency reliability coefficient for the total instrument was McDonald's omega_total=0.73. Measurement model invariance analysis between native and non-native English speakers showed our model attained the highest level of invariance (residual invariance; CFI=0.95, TLI =0.95, RMSEA=0.05). Lastly, a short form of LEBA (n=18) was developed using Item Response Theory on the complete sample (n=690).

The psychometric properties of the LEBA instrument indicate the usability to measure the light exposure-related behaviours across a variety of settings and may offer a scalable solution to characterise light exposure-related behaviours in remote samples. The LEBA instrument will be available under the open-access CC-BY-NC-ND license.

Keywords: light exposure, light-related behaviours, non-visual effects of light, psychometrics

Word count: X

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Introduction

- Light exposure is important
- Light exposure Behavior is important
- Table: Overview Existing Related Scales: items in total / items on light exposure (behaviour)
- Existing Scales: Review them in text
- None of these do light exposure behavior.

Methods

Data Collection

Data was collected in a quantitative cross-sectional approach via a fully anonymous online survey hosted on REDCap (Harris et al., 2019, 2009) by way of the University of Basel sciCORE. Participants were recruited via the website of a Comic co-released with the survey(Weinzaepflen & Spitschan, 2021), social media (i.e., LinkedIn, Twitter, Facebook), mailing lists, word of mouth, the investigators' personal contacts, and supported by distribution of the survey link via f.lux (F.lux Software LLC, 2021). Completing the online survey took approx. 15 to 20 minutes and was not compensated. The first page of the survey comprised a participant information sheet, where participants' informed consent to participate was obtained before any of the questions were displayed. Underaged participants (<18 years) were urged to obtain assent from their parents/legal guardians, before filling in the survey. Information on the first page included the objectives of the study, inclusion criteria, estimated duration, the use, storage and sharing of the data, compensation (none), and information about the type of questions in the survey. Moreover, participants needed to confirm that they were participating the survey for the first time. To ensure high data quality, five attention check items were included in the survey (e.g., "We want to make sure you are paying attention. What is 4+5?"). The data analysed in this study was collected between 17 May 2021 and 3 September 2021. Questions incorporating retrospective recall were all aligned to the period of "past four weeks," matching the presented LEBA instrument.

In addition to the LEBA questionnaire, which is subject of the current study, we assessed other variables and items which were not included in the present analysis. This comprised various sleep-related measures, i.e., sleep disturbances and sleep-related impairment (adult and pediatric versions) (Bevans et al., 2019; Daniel J. Buysse et al., 2010; Forrest et al., 2018; Harb, Hidalgo, & Martau, 2015; L. Yu et al., 2011), sleep duration, timing, and latency, chronotype, social jetlag, time in bed, work/sleep schedule and outdoor light exposure duration (MCTQ version for adults and adolescents Roenneberg, Wirz-Justice, & Merrow, 2003) plus sleep environment (Olivier et al., 2016). Furthermore, we included a light sensitivity questionnaire (photophobia vs. photophilia) (Wu & Hallett, 2017) and self-reported pubertal stage assessment (Petersen, Crockett, Richards, & Boxer, 1988) for participants younger than 18 years of age. Moreover, we incorporated custom items on meal timing and caffeine consumption in the "workday vs. free day" structure of the MCTQ sleep-wake regulation. Example items are: "On workdays I usually have my first meal at **:**" "On free days I usually have my last meal at **:**" and "On workdays I usually drink my first caffeinated drink at **:**"

Finally, we assessed age, sex, gender identity, occupational status, COVID-19 related occupational setting, time zone/country of residence and native language as single-item demographic variables. The demographic characteristics of our sample are given in Table **??**.

Item Construction & Item Selection

After reviewing the literature, we identified several light exposure related scale. However, no scales specifically measuring the behavioural component of light exposure were found. As such ,we developed a comprehensive item pool of 48 items with six point Likert response scale (0:Does not apply/I don't know; 1:Never, 2:Rarely; 3:Sometimes; 4:Often; 5:Always).The whole list of 48 items were then judged based on their relevance and representativeness of the construct "Light Exposure Related Behaviour" by an expert panel. The expert panel composed of all authors and researchers from the fields of chronobiology, light research, neuroscience and psychology. The panel members independently judged each of the items in terms of their relevance and representativeness and suggested required modification, if there is any. The author team acknowledged the auggestions and amended the items as required thus creating a 48-item scale

Analytic Strategies

Figure 1 summarizes the steps of our psychometric analysis. In our analysis we used R (version 4.1.0), with several R packages. Initially, our tool had six point Likert type response format (0:Does not apply/I don't know; 1:Never, 2:Rarely; 3:Sometimes; 4:Often; 5:Always). Our purpose was to capture light exposure related behavior and these two response options: "Does not apply/I don't know" and "Never" were providing similar information. As such we decided to collapse them into one, making it a 5 point Likert type response format. We conducted an initial item analysis and proceed to the EFA. Prior to the EFA,necessary assumptions of EFA, including sample adequacy, normality assumptions, quality of correlation matrix, were assessed. Our data violated both the univariate and multivariate normality assumptions. Due to these violations and the ordinal nature of our response data, we used polychoric correlation matrix

(Desjardins & Bulut, 2018) for the EFA. We employed principal axis (PA) as factor extraction method with varimax rotation. PA is robust to the normality assumption violations (Watkins, 2020). The obtained latent structure was confirmed by another factor extraction method: "the minimum residuals extraction" as well. We used a combination of factor identification method including scree plot (Cattell, 1966), minimum average partials method (Velicer, 1976), and hull method (Lorenzo-Seva, Timmerman, & Kiers, 2011) to identify factor numbers. Additionally, to determine the simple structure, we followed the common guidelines : (i) no factors with fewer than three items (ii) no factors with a factor loading <0.3 (iii) no items with cross-loading > .3 across factors (Bandalos & Finney, 2018). We also conducted a EFA on non-merged response options data (Supp. Table A9) and rejected the latent structure obtained as the factors were less interpretable.

For estimating reliability we used internal consistency reliability coefficient ordianl alpha. Though Cronbach's alpha coefficient is widely used for estimating internal consistency, it has a tendency to deflate the estimates for Likert type data since calculation is based on pearson-correlation matrix which requires response data to be continuous of nature (Gadermann, Guhn, & Zumbo, 2012; Zumbo, Gadermann, & Zeisser, 2007). Subsequently to get better estimates of reliability we reported ordinal alpha that used polychoric-correlation matrix and assumed that the responses data were ordered in nature instead of continuous (Zumbo et al., 2007). Ordinal alpha coefficient value ranges from 0 to 1 and higher value represents better reliability.

We conducted categorical confirmatory factor analysis with robust weighted least square (WLSMV) estimator since our response data was of ordinary nature (Desjardins & Bulut, 2018). We assessed the model fit using common model fit guidelines: (i) Reporting of χ^2 test statistics (A non-significant test statistics is required to reflect model fit) (ii) CFI and TLI (CFI/TLI close to .95 or above/ranging between 90-95 and above) (iii) RMSEA (close to .06 or below), (iv) SRMR (close to .08 or below) to estimate the model fit (Hu & Bentle, 1999; Schumacker & Lomax, 2004).However, the χ^2 test is sensitive to sample size (Brown, 2015) and SRMR does not work well with ordinal data (C. Yu, 2002) As such, we judged the model fit using CFI, TLI, SRMR and RMSEA.

With the validated latent structure obtained by CFA analysis we assessed the measurement invariance of our construct between native English speakers and non-non native English speakers. Measurement invariance (MI) evaluates whether a construct has the psychometric equivalence and same meaning across groups or measurement occasions (Kline, 2015; Putnick & Bornstein, 2016). We used structural equation modelling framework to assess the measurement invariance. We successively compared four nested models: configural, metric, scalar, and residual models using the χ^2 difference test ($\Delta\chi^2$). Here configural model is the least restrictive model and residual model is the most restrictive model. A non-significant $\Delta\chi^2$ test between two nested measurement invariance models indicates mode fit does not significantly decrease for the superior model (Dimitrov, 2010) thus allowing the superior invariance model to be accepted. (Widaman & Reise, 1997).

We also analysed possible semantic overlap of our developed tool using “Semantic Scale Network” (SSN) engine (Rosenbusch, Wanders, & Pit, 2020). The SSN detects semantically related scales and provides cosine similarity index ranging between -.66 to 1 (Rosenbusch et al., 2020). Pair of scales with a cosine similarity index value of 1 indicates they are perfectly semantically similar scales indicating redundancy. Additionally, To identify the educational grade level required to understand the items in our tool we subjected tool to Flesch-Kincaid Grade Level (Flesch, 1948)

Lastly, we sought “Item Response Theory” (IRT) based analysis on developing a short form of LEBA. We fitted each factor of LEBA using the graded response model (Samejima, Liden, & Hambleton, 1997) to the combined EFA and CFA sample (n =690). IRT assess the item quality by estimatingitem difficulty, item discrimination, a item information, and Test information (Baker, 2017). Item discrimination indicates the pattern of variation in the categorical responses with the changes in latent trait level (θ), and item information curve (IIC) indicates the amount of information an item carries along the latent trait continuum. Here, we reported the item discrimination parameter and categorize the items according to the suggestions of Baker (2017) : none = 0; very low =0.01 to 0.34; low = 0.35 to 0.64; moderate = 0.65 to 1.34 ; high = 1.35 to 1.69; very high >1.70. We discarded the items with relatively flat item information curve (information <.2) to develop the short form of LEBA. We also assessed the precision of the short LEBA using Test information curve (TIC). TIC indicates the amount of information an the full-scale carry along the latent trait continuum. Item fit and person-fit of the fitted model were also analyzed to gather more evidence on validity and meaningfulness of our Tool (Desjardins & Bulut, 2018). Item-fit was evaluated using the RMSEA value obtained from Signed-χ^2 index implementation, RMSEA value $\leq$.06 was consided adequate item fit. Person fit was estimated using standardized fit index Zh statistics (Drasgow, Levine, & Williams, 1985). Zh < -2 was be considered as a misfit (Drasgow et al., 1985).

Ethical approval

By reason of using fully anonymous online survey data, the present research project does not fall under the scope of the Human Research Act, making an authorisation from the ethics committee redundant. Nevertheless, the cantonal ethics commission (Ethikkommission Nordwest- und Zentralschweiz, EKNZ) reviewed our proposition (project ID Req-2021-00488) and issued an official clarification of responsibility (full document see Suppl. X in appendix).

Data Availability

The present article is a fully reproducible open-access “R Markdown” document. All code and data underlying this article – along with two versions of the LEBA questionnaire (full and short) and online survey implementation templates on common survey platforms

– will be available under open-access licence (CC-BY-NC-ND) on a public GitHub repository.

Results

Participants

Table **??** summarizes the survey participants' demographic characteristics. Only participants completing the full LEBA questionnaire were included, thus there are no missing values in the item analyses. XX participants were excluded from analysis due to not passing at least one of the "attention check" items. For exploring initial factor structure (EFA), a sample of 250-300 is recommended (Comrey & Lee, 1992; Schönbrodt & Perugini, 2013). For estimating the sample size for the confirmatory factor analysis (CFA) we followed the N:q rule (Bentler & Chou, 1987; Jackson, 2003; Kline, 2015; Worthington & Whittaker, 2006), where ten participants per parameter is required to earn trustworthiness of the result. Our sample size exceeds these requirements: Anonymous responses from a total of n = 690 participants were included in the analysis of the current study, split into samples for exploratory (EFA: n = 428) and confirmatory factor analysis (CFA: n = 262). The EFA sample included participants filling out the questionnaire from 17 May 2021 to XX XXX 2021, whereas participants who filled out the questionnaire from YY YYY 2021 to 3 September 2021 were included in the CFA analysis. Participants indicated filling out the online survey from a diverse range of geographic locations. The ten most common country and time zone combinations included:

- United States - America/New_York (UTC -04:00): 63 (9.1%)
- United Kingdom - Europe/London (UTC): 57 (8.3%)
- Germany - Europe/Berlin (UTC +01:00): 53 (7.7%)
- India - Asia/Kolkata (UTC +05:30): 38 (5.5%)
- United States - America/Los_Angeles (UTC -07:00): 37 (5.4%)

- United States - America/Chicago (UTC -05:00): 30 (4.3%)
- France - Europe/Paris (UTC +01:00): 22 (3.2%)
- Switzerland - Europe/Zurich (UTC +01:00): 21 (3.0%)
- Brazil - America/Sao_Paulo (UTC -03:00): 19 (2.8%)
- Netherlands - Europe/Amsterdam (UTC +01:00): 19 (2.8%)

For a complete list of geographic locations, see Suppl. Table A11.

Age among all participants ranged from 11 years to 84 years [EFA: *min* = 11, *max* = 84; CFA: *min* = 12, *max* = 74], with an overall mean of ~ 33 years of age [Overall: *M* = 32.95, *SD* = 14.57; EFA: *M* = 32.99, *SD* = 15.11; CFA: *M* = 32.89, *SD* = 13.66]. In total 325 (47%) of the participants indicated female sex [EFA: 189 (44%); CFA: 136 (52%)], 351 (51%) indicated male [EFA: 230 (54%); CFA: 121 (46%)] and 14 (2.0%) indicated other sex [EFA: 9 (2.1%), CFA: 5 (1.9%)]. Overall, 49 (7.2%) [EFA: 33 (7.8%); CFA: 16 (6.2%)] participants indicated a gender-variant identity. In a "Yes/No" question regarding native language, 320 (46%) of respondents [EFA: 191 (45%); CFA: 129 (49%)] indicated to be native English speakers. For their "Occupational Status," more than half of the overall sample reported that they currently work [Overall: 396 (57%); EFA: 235 (55%); CFA: 161 (61%)], whereas 174 (25%) [EFA: 122 (29%); CFA: 52 (20%)] reported that they go to school and 120 (17%) [EFA: 71 (17%); CFA: 49 (19%)] responded that they do "Neither." With respect to the COVID-19 pandemic we asked participants to indicate their occupational setting during the last four weeks: In the overall sample 303 (44%) [EFA: 194 (45%); CFA: 109 (42%)] of the participants indicated that they were in a home office/ home schooling setting, while 109 (16%) overall [EFA: 68 (16%) ; CFA: 41 (16%)] reported face-to-face work/schooling. Lastly, 147 (21%) overall [EFA: 94 (22%) ; CFA: 53 (20%)] reported a combination of home- and face-to-face work/schooling, whereas 131 (19%) overall [EFA: 72 (17%); CFA: 59 (23%)] filled in the "Neither (no work or school, or on vacation)" response option. We tested all demographic variables in Table 1 for significant group differences between the EFA and CFA sample, applying Wilcoxon rank sum test for the continuous variable “Age” and Pearson’s χ^2 test for all other categorical variables via the gtsummary R package’s “add_p” function (Sjoberg et al., 2021a) . The p-values were corrected for multiple testing applying false discovery rate (FDR) via the “add_q” function of the same package. After p-value (FDR) correction for multiple testing, none of the demographic variables were significantly different between the EFA sample and the CFA sample (all q-values $q \geq 0.2$).

Item Analysis

Table 3 summarizes the univariate descriptive statistics for the 48 items. Some of the items were skewed with high Kurtosis values. Our data violated both univariate normality (Shapiro-Wilk statistics; (Shapiro & Wilk, 1965)) and multivariate normality assumptions [Marida’s test;(Mardia, 1970)]. Multivariate skew was 583.80 ($p < 0.001$) and multivariate kurtosis was 2,749.15 ($p < 0.001$). Due to these violations and ordinal nature of the response data polychoric correlations over Pearson’s correlations was chosen (Desjardins & Bulut, 2018). The corrected item-total correlation ranges between .03 -.48. However, no item was discarded based on descriptive statistics or item analysis.

Exploratory Factor Analysis

Sampling adequacy was checked using Kaiser-Meyer-Olkin (KMO) measures of sampling adequacy (Kaiser, 1974) . The overall KMO vale for 48 items was 0.63 which was above the cutoff value (.50) indicating a mediocre sample (Hutcheson, 1999). Bartlett’s test of sphericity (Bartlett, 1954), χ^2 (1128) = 5042.86, $p < .001$ indicated the correlations between items are adequate for the EFA. However only 4.96% of the inter-item correlation coefficients were greater than .30. The absolute value of inter-item correlation ranged between -.44 to .91. Figure 2 depicts the correlation matrix.

Scree plot (Figure 3) suggested a six-factor solution. However, the minimum average partial (MAP) (Velicer, 1976) method (Table **??**) and Hull method (Lorenzo-Seva et al., 2011) (Figure 3) suggested a five-factor solution. As a result, we tested both five-factor and six-factor solutions.

With the initial 48 items we conducted three rounds of EFA and gradually discarded problematic items. (cross-loading items and poor factor loading (<.30) items). Finally, a five-factor EFA solution with 25 items was accepted with low RMSR = 0.08 (Brown, 2015), all factor-loading higher than .30 and no cross-loading greater than .30. We further confirmed this five-factor latent structure by another EFA using varimax rotation with a minimum residual extraction method (Sup.Table A7). Table 4 displays the factor-loading (structural coefficients) and communality of the items. The absolute value of the factor-loading ranged from .49 to .99 indicating strong coefficients. The commonalities ranged between .11 to .99. Figure 4(A) depicts the obtained five factor structure. However, the histogram of the absolute values of non-redundant residual-correlations (Figure 4(B)) showed 26% correlations were greater than the absolute value of .05, indicating a possible under-factoring. (Desjardins & Bulut, 2018). Subsequently, we fitted a six-factor solution. However, a factor emerged with only two salient variables, thus disqualifying the six-factor solution (Sup.Table A8).

In the five-factor solution, the first factor contained three items and explained 10.25% of the total variance with a internal reliability coefficient ordinal α = .94. All the items in this factor stemmed from the individual's preference to use blue light filters in different light environments. The second factor contained six items and explained 9.93% of the total variance with a internal reliability coefficient ordinal α = .76. Items under this factor commonly investigated an individual's hours spent outdoor. The third factor contained five items and explained 8.83% of the total variance. Items under this factor dealt with the specific behaviors pertaining to using phone and smart-watch in bed. The internal consistency reliability coefficient was, ordinal α = .75. The fourth factor contained five items and explained 8.44% of the total variance with an internal consistency coefficient, ordinal α = .72. These five items investigated the behaviors related to individual's light exposure before bedtime. Lastly, the fifth factor contained six items and explained 6.14% of the total variance. This factor captured individual's morning and daytime light exposure related behavior. The internal consistency reliability was, ordinal α = .62 . It is essential to attain a balance between psychometric properties and interpretability of the common themes when exploring the latent structure. As all of the emerged factors are highly interpretable and relevant towards our aim to capture light exposure related behavior, regardless of the apparent low reliability of the fifth factor, we retain all the five-factors with 23 items for our confirmatory factor analysis (CFA). Two items showed negative factor-loading (items 44 and 21). Upon inspection, it was understood that these items are negatively correlated to the common theme, and thus in the CFA analysis, we reversed the response code for these two items. Figure **??** depicts the data distribution and endorsement pattern for the included items in our LEBA tool for both the EFA and CFA sample.

Confirmatory Factor Analysis

Table 5 summarizes the CFA fit indices of our fitted model. Our fitted model attained acceptable fit (CFI =.94; TLI = .93); RMSEA = .06,[.05-.07, 90% CI]) with two imposed equity constrain on item pairs 32-33 [I dim my mobile phone screen within 1 hour before attempting to fall asleep.;I dim my computer screen within 1 hour before attempting to fall asleep.] and 16-17 [I wear blue-filtering, orange-tinted, and/or red-tinted glasses indoors during the day.;I wear blue-filtering, orange-tinted, and/or red-tinted glasses outdoors during the day.]. Items pair 32-33 stemed from the preference of dimming electric device's brightness before bed time and items pair 16 and 19 stemed from the preference of using blue filtering or colored glasses during the daytime. Nevertheless, SRMR value was higher than the guideline (SRMR = .12).

Further by allowing one pair of items (30-41) [I look at my smartwatch within 1 hour before attempting to fall asleep.;I look at my smartwatch when I wake up at night.] to covary their error variance and discarding two item (item 37 & 26) for very low r-square value, our model attained best fit (CFI =.95; TLI = .95); RMSEA = .06[.05-.06, 90% CI]) and SRMR value (SRMR = .11) was also close to the suggestions of Hu and Bentle (1999). Internal consistency ordinal α for the five factors of LEBA were .96, .83, .70, .69, .52 respectively. We also estimated the internal consistency reliability of the total scale using Mcdonald's ω_t coefficient which is a better reliability estimate for multidimensional constructs (Dunn, Baguley, & Brunsden, 2014; Sijtsma, 2009). McDonald's ω_t coefficient for the total scale was .68. Figure 7 depicts the obtained CFA structure.

Measurement Invariance

In our CFA sample we had 129 **native English speakers** and 133 **non-native English speakers** (For a detailed description these two groups see Sup. Table **??**). Table 6 indicates our fitted model had acceptable fit indices for all of the fitted MI models. The model fit did not significantly decrease across the nested models indicating the acceptability of the higheest measurement invariance model : residualmodel.

Semantic Analysis

To find out if our developed tool (23 items) is overlapping with existing instruments, we subjected the items of LEBA to the “Semantic Scale Network”(SSN) analysis (Rosenbusch et al., 2020). The SSN detects semantically related scales and provides cosine similarity index ranging between -.66 to 1 (Rosenbusch et al., 2020). Pair of scales with a cosine similarity index value of 1 indicates they are perfectly semantically similar scales indicating redundancy. LEBA appeared most strongly related to scales about sleep: “Sleep Disturbance Scale For Children” (Bruni et al., 1996) and “WHO-Composite International Diagnostic Interview (CIDI): Insomnia”(WHO, 1990).The cosine similarities lie between .47 to .51. Flesch-Kincaid Grade Level (Flesch, 1948) analysis on the the 23 items of our scale indicated required educational grade level was 3.33 and with a age above 8.33.

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Developing Short form of LEBA

We sought the Item Response Theory (IRT) to develop the short form of LEBA. IRT the conventional classical test theory-based analysis by gathering information on item quality by indices like item difficulty, item discrimination, and item information (Baker, 2017). Item is judged based on item information in relation to participants' latent trait level (θ). We fitted each factor of LEBA with the graded response model (Samejima et al., 1997) to the combined EFA and CFA sample (n =690). Item discrimination indicates the pattern of variation in the categorical responses with the changes in latent trait level (θ), and item information curve (IIC) indicates the amount of information an item carries along the latent trait continuum. Here, we reported the item discrimination parameter and only discarded the items with relatively flat item information curve (information <.2) to develop the short form of LEBA. Baker (2017) categorized the item discrimination in as none = 0; very low =0.01 to 0.34; low = 0.35 to 0.64; moderate = 0.65 to 1.34 ; high = 1.35 to 1.69; very high >1.70. Table 7 summarizes the IRT parameters of our tool. Item discrimination parameters of our tool fell in very high (10 items), high (4 items), moderate (4 items), and low (5 items) categorizes indicating a good range of discrimination along the latent trait level (θ). Examination of the item information curve (Sup.fig A1) indicated 5 items (1, 25, 38, 30, & 41) had relatively flat information curves ($I(\theta)$ <.20) thus discarded creating a short form of LEBA with 5 factors and 18 items.

Test information curve (TIC) (Figure 8) indicate the amount of information an the full-scale carry along the latent trait continuum. As we treated each factor of short-LEBA as an unidmensional construct we obtain 5 TICs (Figure 8). These information curves indicated except the first and fifth factors, the other three factor's TICs are roughly centered on the center of the trait continuum (θ).The first and fifth factor had a peak to the right side of the center of latent trait.Thus we conferred the LEBA tool estimated the light exposure related behavior with precision near the center of trait continuum for 2nd, 3rd and 4th factors and near the right side of the center of trait continuum for 1st and 5th factors (Baker, 2017).

Table 8 summarizes the item fit indexes of the items. All the items fitted well to the respective models as assessed by RMSEA value obtained from Signed-χ^2 index implementation. All of the items had RMSEA value $\leq$.06 indicating adequate fit. Sup.Figure A2 depicts the person fit of out fitted models. Person fit indicates the validity and meaningfulness of the fitted model at the participants latent trait level (Desjardins & Bulut, 2018). We estimated the person fit statistics using standardized fit index Zh statistics (Drasgow et al., 1985). Zh < -2 should be considered as a misfit. Fig indicates that Zh is larger than -2 for most participants, suggesting a good fit of the selected IRT models.

Discussion

We developed a self-reported tool to capture different light exposure related behavior and evaluated its psychometric properties using classical test theory and Item Response Theory based analysis.

48 items were generated by an expert panel and administered to a large sample (n = 428 to explore the latent structure. Exploratory Factor Analysis revealed a five factor solution with 25 items. ("Wearing blue light filters," "Spending time outdoors," "Using phone and smart-watch in bed," "Using light before bedtime," and "Using light in the morning and during daytime"). The internal consistency reliability coefficient ordinal

alpha ranged between .62.94. As all the retained factors were meaningful and contributed essentially towards our aim we retained all five factors.

A CFA on a separate sample ((n = 262 gave a five-factor solution (CFI =.95; TLI = .95); RMSEA = .06[.05-.06, 90% CI]) and SRMR = .11) after discarding two item. The internal consistency McDonald's ω_t of the five factors were satisfactory (.96, .83, .70, .69, .52) Internal consistency reliability of the total scale (23 items) was also satisfactory, McDonald's ω_t= .68. In the same sample, our measurement invariance analysis revealed that the latent structure attained the residual measurement invariance across subgroups: male and female (CFI: .98, TLI: .98, SRMR: .98).

The "Semantic Scale Network"(SSN) analysis (Rosenbusch et al., 2020) on the retained 23 items showed "LEBA" was related to "Sleep Disturbance Scale For Children" (SDSC) (Bruni et al., 1996) and "WHO-Composite International Diagnostic Interview (CIDI): Insomnia"(WHO, 1990). Upon inspecting the item contents we found items under "Using phone and smart-watch in bed" and "Using light before bedtime" have semantic overlap with the items of SDSC ans CIDI. Items in those two scales were looking into behaviors related to sleep. As such the similarity index obtained is expected. Flesch-Kincaid Grade Level (Flesch, 1948) analysis on the the 23 items of our scale indicated required educational grade level was 3.33 and with a age above 8.33.

Lastly, we developed a short-LEBA (n=23) using IRT analysis. We fitted a graded response model model to the combined EFA and CFA sample (n =690). We discarded 5 items with relatively flat item information curve [I(θ) <.20]. IRT analysis indicated short form of LEBA is a psychometrically sound measure. Item fit indexes and person fit index for all five fitted model were acceptable. Items had diverse slope parameters indicating a good range of discrimination- the ability to differentiate respondents with different levels of the light exposure related behavior. Test information curve also indicated a good coverage of underlying trait continuum with precision.

Conclusion

"The Light exposure behavior assessment"(LEBA) gave a five solution with 25 items in an EFA. A CFA with this 25-item scale again offered a five-factor solution, but this time two more item was discarded. The 23-item "LEBA" was found reliable and valid. A short-form of LEBA was developed using IRT analysis. IRT analysis gave a 18-item scale with a good range of coverage across the underlying trait continuum. All-in-all, we can recommend both forms to be used to capture individual's light exposure related behavior

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Table 1

List of instruments measuring related consttucts to LEBA

Name	Author	Description	Relevant Items	Scale type	Validity evidences
Visual Light Sensitivity Questionnaire-8	Verriotto et al., 2017	Eight-question survey to assess the presence and severity of photosensitivity symptoms	None	5-point Likert scale	Not available
Office Light Survey	Eklundet al., 1996	30 items survey to assess electrical lighting environment in office	Item 29	Mixed response format	Not available
Harvard Light Exposure Assessment Questionnaire	Bajaj et al., 2011	1 item semi-quantitative light questionnaire	None	Semi-quantitative	Correlation with physical measurememt
Hospital Lighting Survey	Dianat et el., 2013	23 items questionnaire to assess light environment in a hospital	Item 16,17	5-point Likert scale	Face and Content validity
Morningness-Eveningness Questionnaire	Horne et al., 1976	19 items questionnaire to understand your body clock	item 1,2,8,13,14	Mixed response format	Correlation with oral temperature

Table 1 continued

Name	Author	Description	Relevant Items	Scale type	Validity evidences
Munich Chronotype Questionnaire (MCTQ)	Roenneberg et al., 2003	17 items questionnaire to understand individuals phase of entrainment	Time spect outdoors	Mixed response format	Correlation with sleep-logs, actimetry, and physiological parameters
Sleep Practices and Attitudes Questionnaire (SPAQ)	Olivier et.al., 2016	16 Factor questionnaire measuring practice, behavior and attitude related sleep	Subscale 8&9	5-point Likert scale	Face and Construct validity
The Pittsburgh Sleep Quality Index (PSQI)	Buysse et al., 1989	9 items inventory to measure sleep quality and sleeping pattern	item 1-4	Mixed response format	Correlation with clinical measurements
Self-Rating of Biological Rhythm Disorder for Disorder for Adolescents (SBRDA)	Xie et al., 2021	29 Items questionnaire assessing four dimensions of biological rhythm disorder in adolescents	Item 3,6,22-25 and 29	5-point Likert scale	Construct validity
Photosensitivity Assessment Questionnaire (PAQ)	Bossini et al.,2006	16 dichotomous items questionnaire to assess ”photophobia” and ”photophilia”	All items	Binary response option	Not available

Table 2

Demographic Characteristics

Variable	Overall, N = 690	1. EFA Sample, N = 428	2. CFA Sample, N = 262	p-value	q-value
Age	32.95 (14.57)	32.99 (15.11)	32.89 (13.66)	0.5	0.5
Sex				0.14	0.4
Female	325 (47%)	189 (44%)	136 (52%)		
Male	351 (51%)	230 (54%)	121 (46%)		
Other	14 (2.0%)	9 (2.1%)	5 (1.9%)		
Gender-Variant Identity	49 (7.2%)	33 (7.8%)	16 (6.2%)	0.4	0.5
Native English Speaker	320 (46%)	191 (45%)	129 (49%)	0.2	0.5
Occupational Status				0.040	0.2
Work	396 (57%)	235 (55%)	161 (61%)		
School	174 (25%)	122 (29%)	52 (20%)		
Neither	120 (17%)	71 (17%)	49 (19%)		
Occupational setting				0.3	0.5
Home office/Home schooling	303 (44%)	194 (45%)	109 (42%)		
Face-to-face work/Face-to-face schooling	109 (16%)	68 (16%)	41 (16%)		
Combination of home- and face-to-face- work/schooling	147 (21%)	94 (22%)	53 (20%)		
Neither (no work or school, or in vacation)	131 (19%)	72 (17%)	59 (23%)		

[1] Mean (SD); n (%)

[2] False discovery rate correction for multiple testing

[3] Wilcoxon rank sum test

[4] Pearson’s Chi-squared test

Table 3

Descriptive Statistics

Item	Stem	Mean	SD	Skew	Kurtosis	SW Statistics	Item-total corelation
item01	I turn on the lights immediately after waking up.	2.27	1.39	0.74	-0.81	0.81*	0.19
item02	I open the curtains or blinds immediately after waking up.	2.87	1.59	0.08	-1.60	0.83*	0.28
item03	I look at my mobile phone screen immediately after waking up.	3.36	1.38	-0.48	-1.03	0.87*	0.23
item04	I use an alarm with a dawn simulation light.	1.47	1.18	2.38	4.00	0.43*	0.24
item05	I have breakfast within 3 meters from a window.	4.01	1.40	-1.22	0.07	0.70*	0.17
item06	I have breakfast in a brightly lit room (illuminated by electric light).	2.79	1.55	0.19	-1.48	0.85*	0.13
item07	I go for a walk or exercise outside within 2 hours after waking up.	2.26	1.25	0.70	-0.60	0.85*	0.32
item08	I spend 30 minutes or less per day (in total) outside.	2.97	1.20	-0.06	-0.94	0.91*	0.25
item09	I spend between 30 minutes and 1 hour per day (in total) outside.	2.94	1.03	-0.12	-0.40	0.91*	0.08
item10	I spend between 1 and 3 hours per day (in total) outside.	2.74	1.04	0.09	-0.74	0.91*	0.42
item11	I spend more than 3 hours per day (in total) outside.	2.18	0.90	0.60	0.12	0.86*	0.41
item12	I spend as much time outside as possible.	2.36	1.22	0.59	-0.62	0.87*	0.48
item13	I use sunglasses when I go outside in bright daylight.	2.73	1.46	0.20	-1.36	0.87*	0.25
item14	I wear a visor or cap when I go outside in bright daylight.	2.14	1.31	0.77	-0.78	0.80*	0.28
item15	I seek shade when I am outside in bright daylight.	3.26	1.09	-0.26	-0.45	0.91*	0.03
item16	I wear blue-filtering, orange-tinted, and/or red-tinted glasses indoors during the day.	1.56	1.23	2.00	2.45	0.50*	0.28
item17	I wear blue-filtering, orange-tinted, and/or red-tinted glasses outdoors during the day.	1.54	1.21	2.07	2.75	0.49*	0.21
item18	I use light therapy applying a white light box.	1.12	0.49	5.02	27.80	0.25*	0.18

Table 3 continued

Item	Stem	Mean	SD	Skew	Kurtosis	SW Statistics	Item-total corelation
item19	I use light therapy applying a blue light box.	1.05	0.36	7.23	52.98	0.13*	0.17
item20	I use light therapy applying a light visor.	1.04	0.33	8.99	85.28	0.10*	0.16
item21	I use light therapy applying another form of light device.	1.14	0.59	4.79	24.05	0.25*	0.21
item22	I spend most of my daytime in a brightly lit environment.	3.57	1.07	-0.65	-0.17	0.88*	0.20
item23	I close the curtains or blinds during the day if the light from outside is bright.	2.56	1.27	0.33	-1.00	0.89*	0.08
item24	I spend most of my indoor time within 3 meters from a window.	4.14	0.99	-1.23	1.14	0.79*	0.22
item25	I use a desk lamp when I do focused work.	2.59	1.41	0.27	-1.27	0.86*	0.15
item26	I turn on my ceiling room light when it is light outside.	2.25	1.27	0.69	-0.64	0.84*	0.08
item27	I use my mobile phone within 1 hour before attempting to fall asleep.	3.80	1.29	-0.87	-0.42	0.82*	0.17
item28	I use my computer/laptop/tablet within 1 hour before attempting to fall asleep.	3.76	1.14	-0.68	-0.45	0.86*	0.18
item29	I watch television within 1 hour before attempting to fall asleep.	2.44	1.31	0.38	-1.14	0.86*	0.13
item30	I look at my smartwatch within 1 hour before attempting to fall asleep.	1.48	1.11	2.18	3.35	0.48*	0.13
item31	I dim my room light within 1 hour before attempting to fall asleep.	3.00	1.62	-0.08	-1.61	0.83*	0.39
item32	I dim my mobile phone screen within 1 hour before attempting to fall asleep.	3.55	1.65	-0.60	-1.34	0.76*	0.33

Table 3 continued

Item	Stem	Mean	SD	Skew	Kurtosis	SW Statistics	Item-total corelation
item33	I dim my computer screen within 1 hour before attempting to fall asleep.	3.62	1.64	-0.68	-1.25	0.74*	0.37
item34	I use a blue-filter app on my mobile phone screen within 1 hour before attempting to fall asleep.	3.42	1.83	-0.45	-1.69	0.69*	0.20
item35	I use a blue-filter app on my computer screen within 1 hour before attempting to fall asleep.	3.86	1.67	-0.99	-0.85	0.65*	0.20
item36	I wear blue-filtering, orange-tinted, and/or red-tinted glasses within 1 hour before attempting to fall asleep.	1.54	1.25	2.13	2.86	0.46*	0.35
item37	I purposely leave a light on in my sleep environment while sleeping.	1.33	0.91	3.03	8.43	0.41*	0.09
item38	I use as little light as possible when I get up during the night.	4.30	1.08	-1.79	2.53	0.67*	0.32
item39	I turn on the lights when I get up during the night.	1.96	0.98	1.02	0.69	0.82*	0.07
item40	I check my phone when I wake up at night.	2.16	1.19	0.71	-0.54	0.84*	0.25
item41	I look at my smartwatch when I wake up at night.	1.31	0.81	2.75	6.92	0.43*	0.14
item42	I close curtains or blinds to prevent light from entering the bedroom if I want to sleep.	3.93	1.48	-1.06	-0.44	0.71*	0.15
item43	I use a sleep mask that covers my eyes.	1.64	1.18	1.79	2.02	0.60*	0.22
item44	I modify my light environment to match my current needs.	3.51	1.30	-0.70	-0.59	0.85*	0.40
item45	I use LEDs to create a healthy light environment.	2.22	1.48	0.71	-1.02	0.76*	0.29
item46	I use tunable lights to create a healthy light environment.	1.76	1.23	1.35	0.44	0.66*	0.39

Table 3 continued

Item	Stem	Mean	SD	Skew	Kurtosis	SW Statistics	Item-total corelation
item47	I discuss the effects of light on my body with other people.	2.11	1.17	0.77	-0.39	0.83*	0.37
item48	I seek out knowledge on how to improve my light exposure.	2.60	1.25	0.29	-0.86	0.89*	0.36

Note. *p<.001

Table 4

Factor loadings and communality of the retained items

item	PA1	PA2	PA3	PA4	PA5	Communality	Uniqueness
item16	0.99					0.993	0.007
item36	0.94					0.899	0.101
item17	0.8					0.658	0.342
item11		0.79				0.642	0.358
item10		0.76				0.592	0.408
item12		0.65				0.465	0.535
item07		0.5				0.267	0.733
item08		-0.49				0.252	0.748
item09		0.32				0.113	0.887
item27			0.8			0.658	0.342
item03			0.8			0.682	0.318
item40			0.65			0.464	0.536
item30			0.45			0.353	0.647
item41			0.36			0.329	0.671
item33				0.74		0.555	0.445
item32				0.73		0.624	0.376
item35				0.66		0.454	0.546
item37				-0.39		0.174	0.826
item38				0.38		0.178	0.822
item46					0.6	0.422	0.578
item45					0.59	0.374	0.626
item25					0.41	0.193	0.807
item04					0.41	0.219	0.781
item01					0.4	0.17	0.83
item26					0.35	0.165	0.835
% of Variance	0.1	0.1	0.09	0.08	0.06		

Note. Only loading higher than .30 is reported

Table 5

Confirmatory Factor Analysis model fit indices of the two model: five factor model with 25 items and five factor model with 23 items. The second model attained the best fit.

Model	Chi-Squre	df	CFI	TLI	RMSEA	RMSEA 90% Lower CI	RMSEA 90% Upper CI	SRMR
Five factor model:25	448.51	222.00	.94	0.93	0.06	0.05	0.07	0.12
Five factor model:23	415.45	231.00	.95	0.95	0.06	0.05	0.06	0.11

Note. df: Degrees of Freedom; CFI: Comparative Fit Index; TLI: Tucker Lewis Index;RMSEA:Root Mean Square Error of Approximation; CI: Confidence Interval; SRMR: Standardized Root Mean Square

Table 6

Measurment Invariance analysis on CFA sample (n=262) across native and non-native English speakers.

	Chi-Square	df	CFI	TLI	RMSEA	RMSEA 90% Lower CI	RMSEA 90% Upper	Chi-Square Difference	df difference*	p
Configural	632.20	442.00	0.95	0.94	0.06	0.05	0.07	-	-	-
Metric	644.58	458.00	0.95	0.95	0.06	0.05	0.07	18.019a	16	0.323
Scalar	714.19	522.00	0.95	0.95	0.05	0.04	0.06	67.961b	64	0.344
Residual	714.19	522.00	0.95	0.95	0.05	0.04	0.06	0c	0	NA

Note. a = Metric vs Configural; b = Scalar vs Metric; c = Residual vs Scalar; d = Structural vs Residual;* = df of model comparison

Table 7

Items discrimination and response category difficulty thresholds of 23 items in LEBA (n =690)

	a	b1	b2	b3	b4
item16	28.13	0.78	0.90	1.06	1.40
item36	4.49	0.94	1.08	1.23	1.40
item17	2.81	0.97	1.11	1.38	1.62
item11	3.27	-0.79	0.65	1.54	2.31
item10	3.07	-1.27	-0.09	0.82	2.00
item12	1.72	-0.67	0.44	1.28	2.11
item07	1.09	-0.50	0.73	1.63	2.97
Ritem08	1.19	-2.26	-0.48	0.64	1.91
item09	0.91	-2.63	-0.96	1.11	3.49
item27	2.21	-1.88	-1.19	-0.73	0.30
item03	3.03	-1.24	-0.77	-0.20	0.66
item40	1.55	-0.51	0.46	1.32	2.22
item30	0.49	3.27	3.74	4.64	6.52
item41	0.51	3.87	4.78	6.39	8.91
item32	1.62	-1.03	-0.78	-0.42	0.16
item35	1.37	-1.09	-0.98	-0.75	-0.40
item38	0.40	-7.48	-5.56	-4.23	-0.90
item33	12.31	-0.66	-0.48	-0.24	0.13
item46	2.22	0.68	0.89	1.38	2.17
item45	1.51	0.30	0.55	1.17	1.91
item25	0.52	-1.37	-0.04	1.89	4.22
item04	0.84	2.44	2.80	3.18	3.67
item01	0.39	-0.91	1.52	3.25	5.53

Note. a = item discrimination parameter; b(1-4) = response category difficulty parameter

Table 8

Item discrimination, response category difficulty thrsholds and fit statistics of the 18 items in short LEBA (n=690)

Items	a	b1	b2	b3	b4	Signed Chi-square	df	RMSEA	p
item16	28.13	0.78	0.90	1.06	1.40	2.02	6.00	0.00	0.92
item36	4.49	0.94	1.08	1.23	1.40	39.07	13.00	0.05	0.00
item17	2.81	0.97	1.11	1.38	1.62	25.58	13.00	0.04	0.02
item11	3.27	-0.79	0.65	1.54	2.31	55.03	27.00	0.04	0.00
item10	3.07	-1.27	-0.09	0.82	2.00	53.19	30.00	0.03	0.01
item12	1.72	-0.67	0.44	1.28	2.11	34.39	42.00	0.00	0.79
item07	1.09	-0.50	0.73	1.63	2.97	67.45	46.00	0.03	0.02
Ritem08	1.19	-2.26	-0.48	0.64	1.91	140.90	46.00	0.05	0.00
item09	0.91	-2.63	-0.96	1.11	3.49	131.19	45.00	0.05	0.00
item27	2.12	-1.91	-1.21	-0.74	0.31	16.41	11.00	0.03	0.13
item03	3.24	-1.22	-0.76	-0.20	0.65	15.09	11.00	0.02	0.18
item40	1.57	-0.50	0.45	1.30	2.20	9.92	9.00	0.01	0.36
item32	1.60	-1.04	-0.79	-0.42	0.16	41.33	15.00	0.05	0.00
item35	1.34	-1.10	-0.99	-0.76	-0.41	41.71	14.00	0.05	0.00
item33	15.66	-0.66	-0.48	-0.24	0.13	46.89	14.00	0.06	0.00
item46	2.34	0.66	0.88	1.36	2.12	19.00	15.00	0.02	0.21
item45	1.51	0.30	0.55	1.17	1.91	15.05	15.00	0.00	0.45
item25	0.49	-1.45	-0.04	1.99	4.46	31.60	15.00	0.04	0.01

Note. a = item discrimination parameter; b(1-4) = response category difficulty parameter

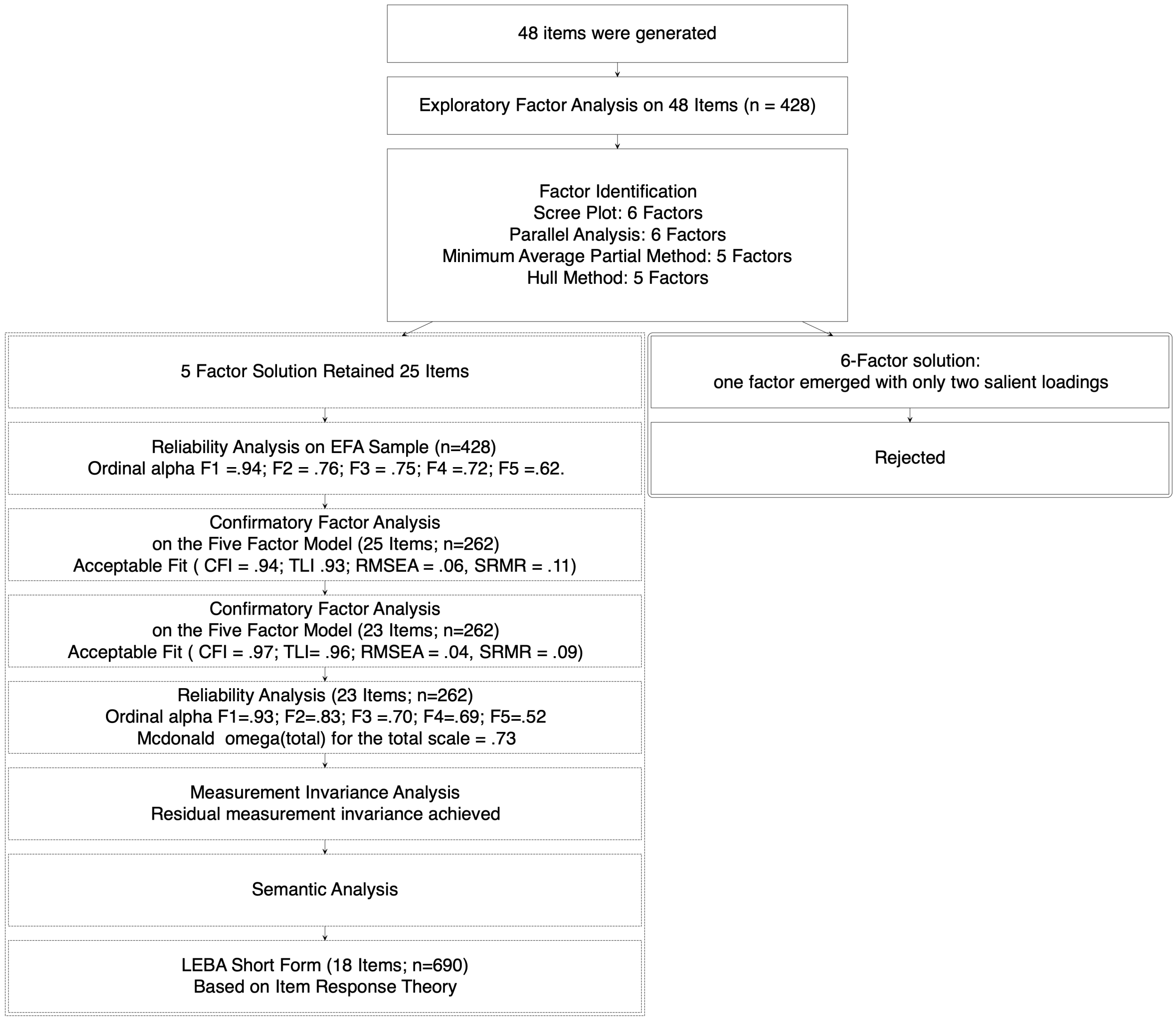

Figure 1. Development of long and short form of LEBA

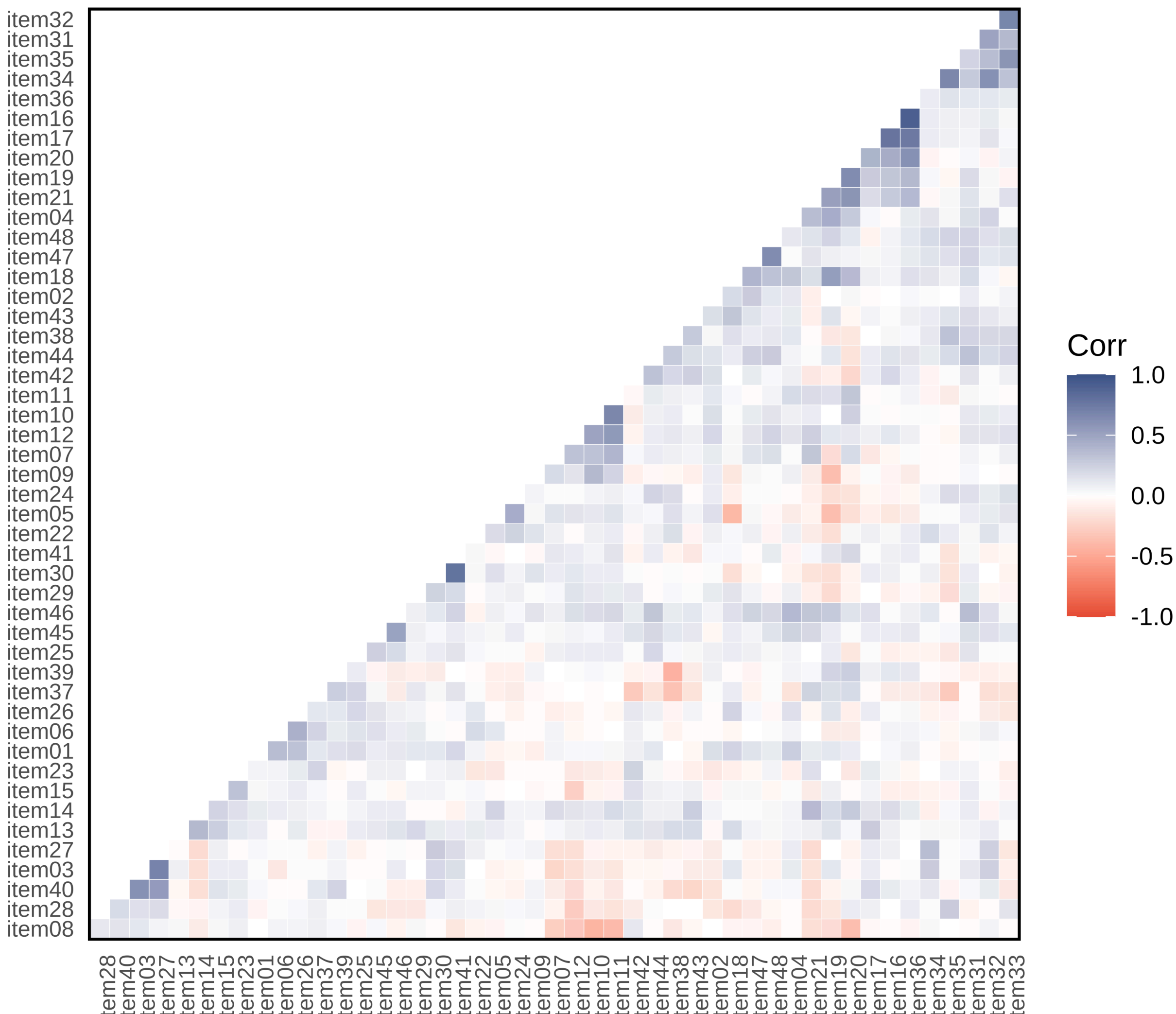

Figure 2. Inter item polychoric correlation coefficients for the 48 items. 4.9 % inter-item correlation coefficients were higher than .30

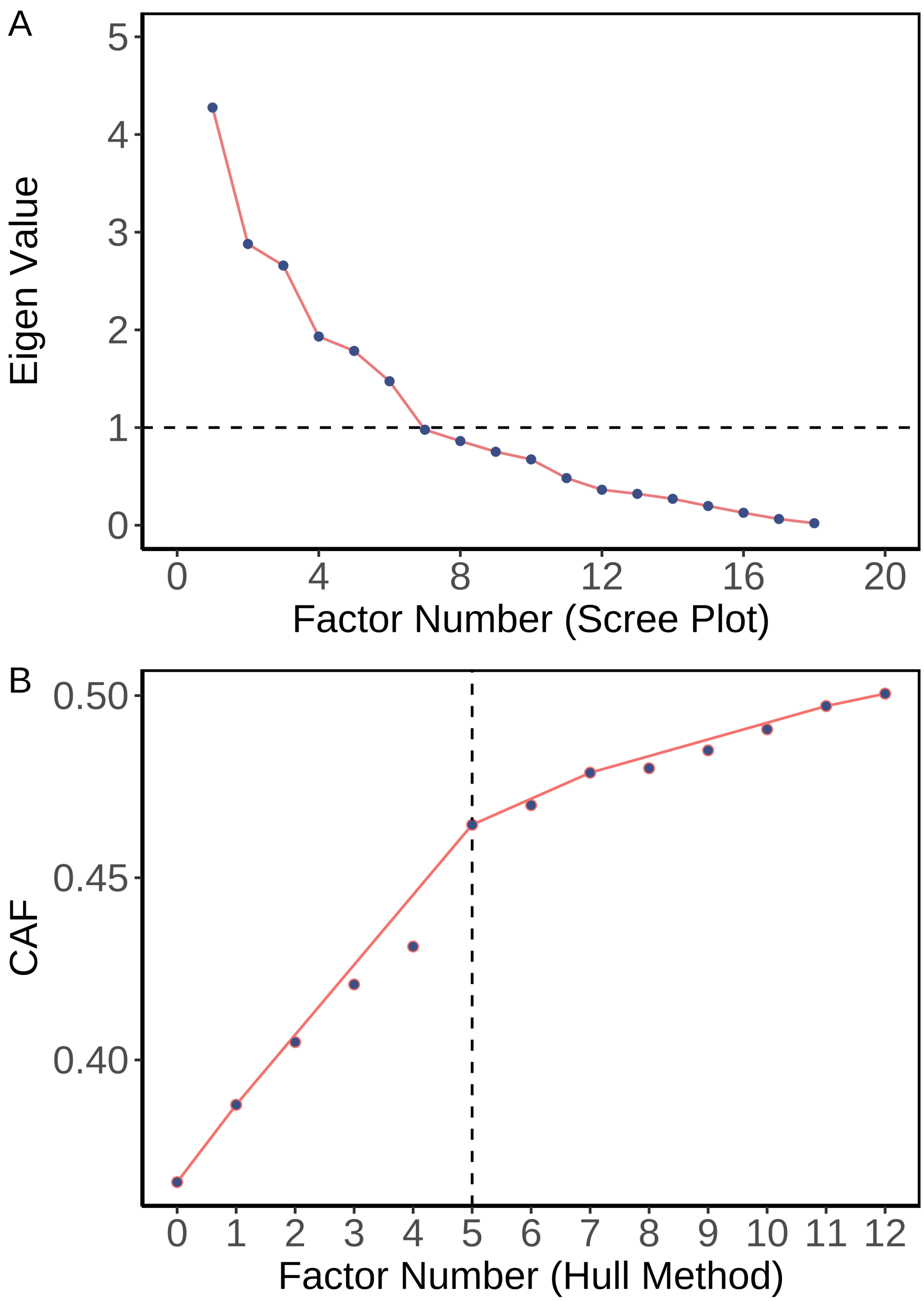

Figure 3. Factor Identification Methods (A) Scree plot suggested six factors. (B) Hull method indicated 5 factors were required to balance the model fit and number of parameters.

A

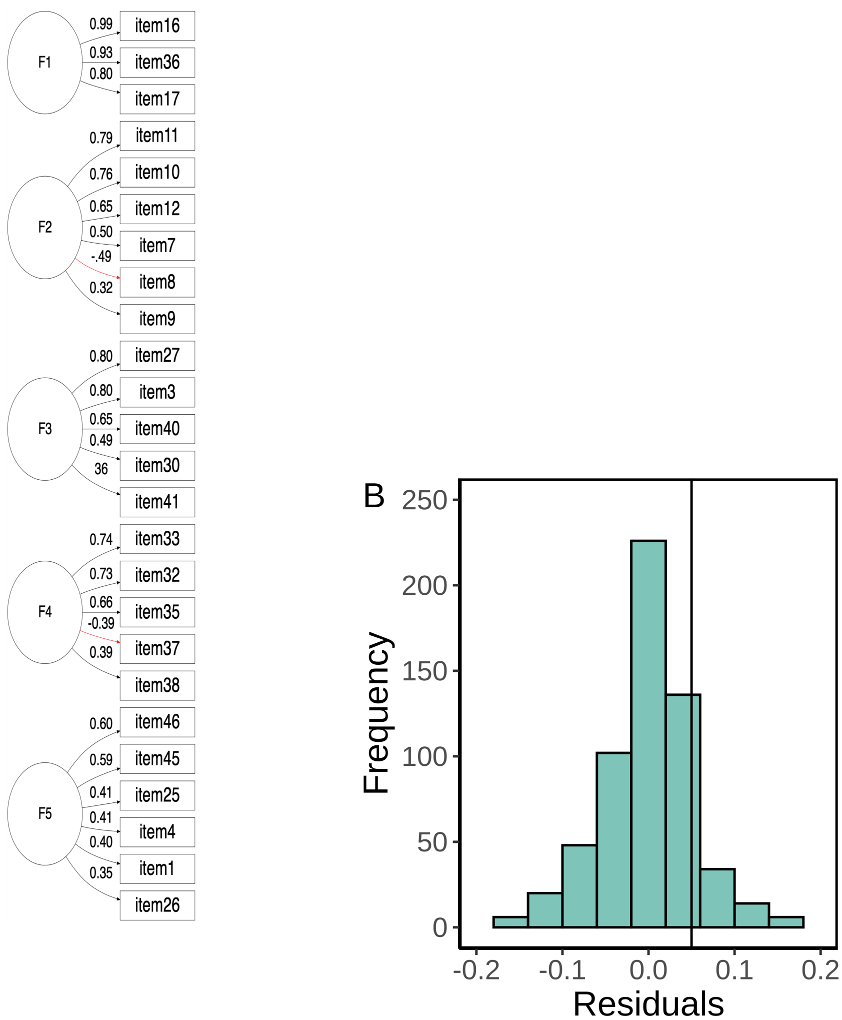

Figure 4. (A) Five Factor Solution obtained in Exploratory Factor Analysis (B) Histogram of nonredundent residula correlations

LEBA

Summary Descriptives EFA Sample (n =428)

Items	Summary Statistics				Graphics		Response Pattern				
LEBA Items	n	Mean	Median	SD	Histogram[1]	Density[2]	Never	Rarely	Sometimes	Often	Always
F1:Wearing blue light filters											
item16	428	1.6	1.0	1.2			79.67% (341)	4.21% (18)	3.97% (17)	4.67% (20)	7.48% (32)
item17	428	1.5	1.0	1.2			80.61% (345)	3.27% (14)	5.14% (22)	3.27% (14)	7.71% (33)
item36	428	1.5	1.0	1.3			82.24% (352)	3.04% (13)	3.04% (13)	2.34% (10)	9.35% (40)
F2:Spending time outdoors											
item07	428	2.3	2.0	1.2			35.98% (154)	27.80% (119)	17.29% (74)	12.38% (53)	6.54% (28)
item08	428	3.0	3.0	1.2			13.79% (59)	22.20% (95)	27.80% (119)	25.93% (111)	10.28% (44)
item09	428	2.9	3.0	1.0			10.28% (44)	19.63% (84)	41.82% (179)	22.43% (96)	5.84% (25)
item10	428	2.7	3.0	1.0			11.92% (51)	31.31% (134)	31.31% (134)	21.96% (94)	3.50% (15)
item11	428	2.2	2.0	0.9			22.43% (96)	46.26% (198)	23.13% (99)	7.01% (30)	1.17% (5)
item12	428	2.4	2.0	1.2			29.91% (128)	29.67% (127)	21.50% (92)	12.15% (52)	6.78% (29)
F3:Using phone and smart-watch in bed											
item03	428	3.4	4.0	1.4			15.89% (68)	11.45% (49)	17.29% (74)	31.07% (133)	24.30% (104)
item27	428	3.8	4.0	1.3			8.41% (36)	11.21% (48)	11.21% (48)	30.37% (130)	38.79% (166)
item30	428	1.5	1.0	1.1			81.78% (350)	3.27% (14)	4.91% (21)	5.37% (23)	4.67% (20)
item40	428	2.2	2.0	1.2			39.49% (169)	25.00% (107)	19.63% (84)	11.45% (49)	4.44% (19)
item41	428	1.3	1.0	0.8			85.05% (364)	4.67% (20)	6.07% (26)	3.04% (13)	1.17% (5)
F4:Using light before bedtime											
item32	428	3.6	4.0	1.6			23.13% (99)	7.01% (30)	8.18% (35)	14.95% (64)	46.73% (200)
item33	428	3.6	4.0	1.6			21.96% (94)	7.01% (30)	7.24% (31)	14.49% (62)	49.30% (211)
item35	428	3.9	5.0	1.7			22.90% (98)	1.87% (8)	3.74% (16)	9.35% (40)	62.15% (266)
item37	428	2.3	2.0	1.3			38.32% (164)	23.36% (100)	20.09% (86)	10.98% (47)	7.24% (31)
item38	428	4.3	5.0	1.1			5.37% (23)	3.50% (15)	5.37% (23)	27.57% (118)	58.18% (249)
F5:Using light in the morning and during daytime											
item01	428	2.3	2.0	1.4			42.29% (181)	22.20% (95)	12.62% (54)	12.38% (53)	10.51% (45)
item04	428	1.5	1.0	1.2			84.11% (360)	3.50% (15)	2.10% (9)	2.10% (9)	8.18% (35)
item25	428	2.6	3.0	1.4			34.35% (147)	13.79% (59)	22.20% (95)	17.99% (77)	11.68% (50)
item26	428	3.7	4.0	1.3			38.32% (164)	23.36% (100)	20.09% (86)	10.98% (47)	7.24% (31)
item45	428	2.2	1.0	1.5			53.04% (227)	7.01% (30)	16.36% (70)	11.92% (51)	11.68% (50)
item46	428	1.8	1.0	1.2			67.06% (287)	7.71% (33)	11.68% (50)	8.88% (38)	4.67% (20)

[1] **Histogram**

[2] **Density**

Figure 5. Summary Descriptives EFA Sample

LEBA

Summary Descriptives CFA Sample (Nn=262)

Items	Summary Statistics				Graphics		Response Pattern				
LEBA Items	n	Mean	Median	SD	Histogram[1]	Density[2]	Never	Rarely	Sometimes	Often	Always
F1:Wearing blue light filters											
item16	262	1.6	1.0	1.3			78.24% (205)	3.44% (9)	4.20% (11)	5.73% (15)	8.40% (22)
item17	262	1.6	1.0	1.2			80.15% (210)	3.44% (9)	5.34% (14)	2.67% (7)	8.40% (22)
item36	262	1.6	1.0	1.3			80.53% (211)	3.44% (9)	3.05% (8)	3.44% (9)	9.54% (25)
F2:Spending time outdoors											
item07	262	2.1	2.0	1.2			43.13% (113)	23.66% (62)	14.50% (38)	14.12% (37)	4.58% (12)
item08	262	3.0	3.0	1.2			14.12% (37)	22.90% (60)	20.99% (55)	32.06% (84)	9.92% (26)
item09	262	2.9	3.0	1.1			12.98% (34)	22.14% (58)	34.35% (90)	26.34% (69)	4.20% (11)
item10	262	2.6	3.0	1.1			17.56% (46)	29.39% (77)	29.01% (76)	21.37% (56)	2.67% (7)
item11	262	2.1	2.0	0.9			25.95% (68)	46.56% (122)	20.23% (53)	5.34% (14)	1.91% (5)
item12	262	2.3	2.0	1.2			32.06% (84)	30.92% (81)	19.08% (50)	11.45% (30)	6.49% (17)
F3:Using phone and smart-watch in bed											
item03	262	3.7	4.0	1.3			11.83% (31)	7.25% (19)	17.56% (46)	28.24% (74)	35.11% (92)
item27	262	4.0	4.0	1.2			6.11% (16)	7.25% (19)	8.02% (21)	33.59% (88)	45.04% (118)
item30	262	1.4	1.0	1.1			83.59% (219)	2.67% (7)	4.20% (11)	6.11% (16)	3.44% (9)
item40	262	2.5	2.0	1.3			30.92% (81)	27.10% (71)	18.70% (49)	12.21% (32)	11.07% (29)
item41	262	1.2	1.0	0.7			90.08% (236)	3.82% (10)	2.29% (6)	2.67% (7)	1.15% (3)
F4:Using light before bedtime											
item32	262	3.4	4.0	1.7			25.95% (68)	4.20% (11)	11.45% (30)	16.79% (44)	41.60% (109)
item33	262	3.1	3.0	1.7			32.44% (85)	6.11% (16)	11.83% (31)	14.12% (37)	35.50% (93)
item35	262	3.6	5.0	1.8			27.48% (72)	2.67% (7)	7.25% (19)	6.49% (17)	56.11% (147)
item38	262	4.3	5.0	1.1			4.20% (11)	7.63% (20)	6.49% (17)	21.37% (56)	60.31% (158)
F5:Using light in the morning and during daytime											
item01	262	2.3	2.0	1.4			40.46% (106)	22.52% (59)	14.50% (38)	10.69% (28)	11.83% (31)
item04	262	1.3	1.0	0.8			89.31% (234)	2.29% (6)	3.44% (9)	3.05% (8)	1.91% (5)
item25	262	2.5	2.0	1.4			32.82% (86)	18.32% (48)	21.76% (57)	16.79% (44)	10.31% (27)
item45	262	2.0	1.0	1.4			64.12% (168)	5.34% (14)	9.54% (25)	11.83% (31)	9.16% (24)
item46	262	1.6	1.0	1.2			75.57% (198)	2.67% (7)	8.02% (21)	9.54% (25)	4.20% (11)

[1] **Histogram**

[2] **Density**

Figure 6. Summary Descriptives of CFA Sample

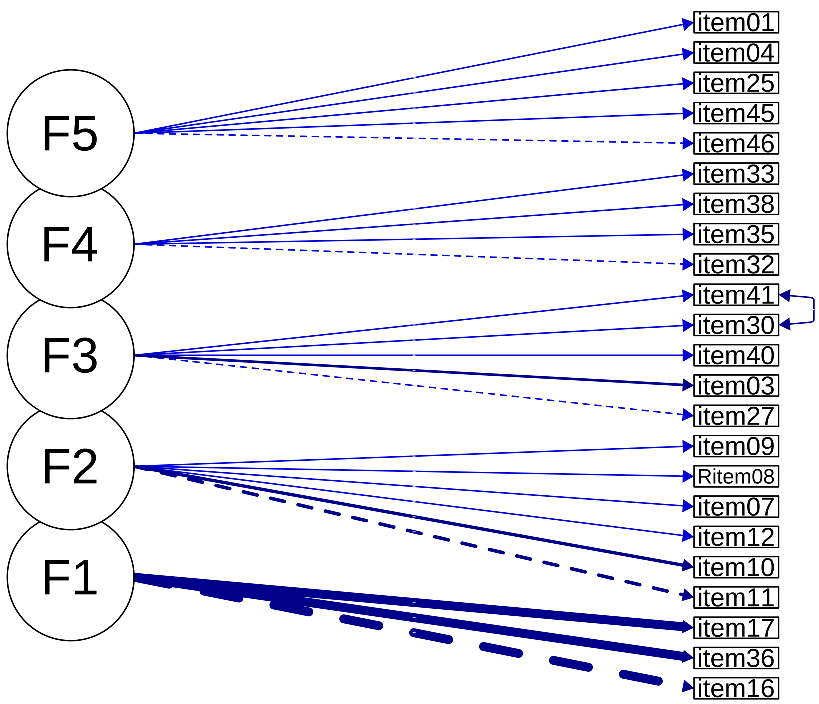

Figure 7. Five Factor Model of LEBA obtained by Confirmatory Factor Analysis. By allowing item pair 41 and 30 to covary their error variance our model attained the best fit.

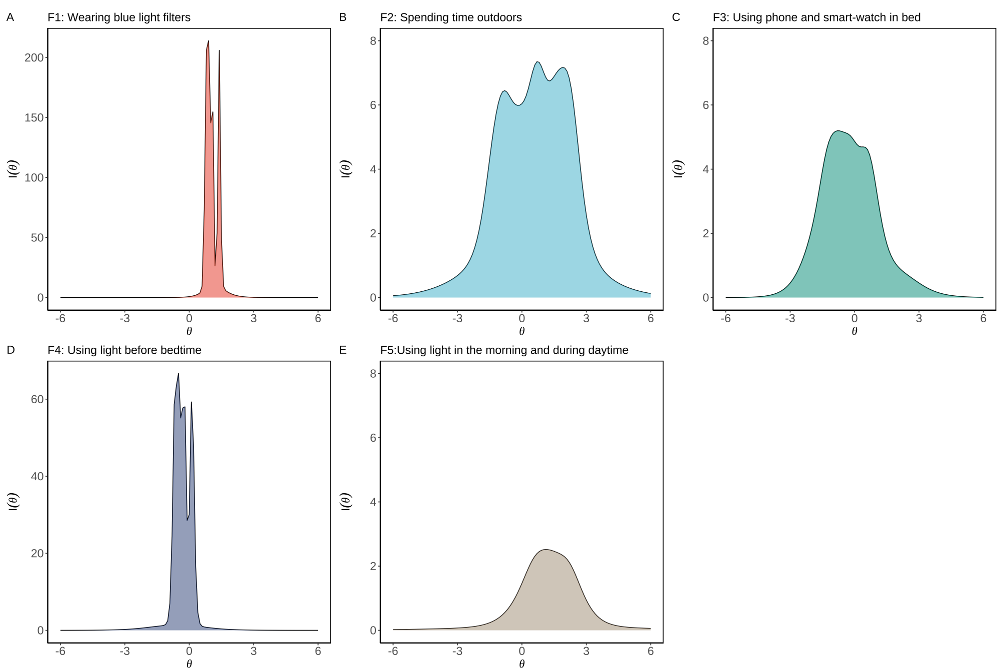

Figure 8. Test information curves (a) Wearing blue light filters (b) Spending time outdoors (c) Using phone and smartwatchin bed (d) Using light before bedtime (e) Using light in the morning andduring daytime

Appendix

Disclaimer: This is a non-public version of LEBA (dated February 6, 2022) and still a work in progress. Please do not distribute!

LEBA captures light exposure-related behaviours on a 5 point Likert type scale ranging from 1 to 5 (Never = 1; Rarely = 2; Sometimes = 3; Often = 4; Always = 5). The score of each factor is calculated by the summation of scores of items belonging to the corresponding factor.

Instruction:

“Please indicate how often you performed the following behaviours in the **past 4 weeks.**”

Table A1

LEBA Long Form (23 Items)

Items	Never	Rarely	Sometimes	Often	Always
01. I wear blue-filtering,orange-tinted,and/or red-tinted glasses indoors during the day.					
02. I wear blue-filtering, orange-tinted, and/or red-tinted glasses outdoors during the day.					
03. I wear blue-filtering, orange-tinted, and/or red-tinted glasses within 1 hour before attempting to fall asleep.					
04. I spend 30 minutes or less per day (in total) outside.					
05. I spend between 1 and 3 hours per day (in total) outside.					
06. I spend between 30 minutes and 1 hour per day (in total) outside.					
07.I spend more than 3 hours per day (in total) outside.					
08.I spend as much time outside as possible.					
09.I go for a walk or exercise outside within 2 hours after waking up.					
10.I use my mobile phone within 1 hour before attempting to fall asleep.					
11.I look at my mobile phone screen immediately after waking up.					
12. I check my phone when I wake up at night.					
13.I look at my smartwatch within 1 hour before attempting to fall asleep					
14.I look at my smartwatch when I wake up at night.					
15.I dim my mobile phone screen within 1 hour before attempting to fall asleep.					
16.I use a blue-filter app on my computer screen within 1 hour before attempting to fall asleep.					
17. I use as little light as possible when I get up during the night.					
18. I dim my computer screen within 1 hour before attempting to fall asleep.					
19. I use tunable lights to create a healthy light environment.					

Table A1 continued

Items	Never	Rarely	Sometimes	Often	Always
20. I use LEDs to create a healthy light environment.					
21. I use a desk lamp when I do focused work.					
22. I use an alarm with a dawn simulation light.					
23. I turn on the lights immediately after waking up.					

Table A2

LEBA Long Form (23 Items):Latent Structure and Reliability

Factor names	Items	Reliability Coefficients
F1: Wearing blue light filters	01-03	0.96
F2: Spending time outdoors	4-9 (Item 4 is reversed)	0.83
F3: Using phone and smartwatch in bed	10-14	0.7
F4: Using light before bedtime	15-18	0.69
F5: Using light in the morning and during daytime	19-23	0.52
McDonald’s Omega coefficient for the total scale		0.73

Table A3

LEBA Short Form (18 Items)

Items	Never	Rarely	Sometimes	Often	Always
01. I wear blue-filtering,orange-tinted,and/or red-tinted glasses indoors during the day.					
02. I wear blue-filtering, orange-tinted, and/or red-tinted glasses outdoors during the day.					
03. I wear blue-filtering, orange-tinted, and/or red-tinted glasses within 1 hour before attempting to fall asleep.					
04. I spend 30 minutes or less per day (in total) outside.					
05. I spend between 1 and 3 hours per day (in total) outside.					
06. I spend between 30 minutes and 1 hour per day (in total) outside.					
07.I spend more than 3 hours per day (in total) outside.					
08.I spend as much time outside as possible.					
09.I go for a walk or exercise outside within 2 hours after waking up.					
10.I use my mobile phone within 1 hour before attempting to fall asleep.					
11.I look at my mobile phone screen immediately after waking up.					
12. I check my phone when I wake up at night.					
13.I dim my mobile phone screen within 1 hour before attempting to fall asleep.					
14.I use a blue-filter app on my computer screen within 1 hour before attempting to fall asleep.					
15. I dim my computer screen within 1 hour before attempting to fall asleep.					
16. I use tunable lights to create a healthy light environment.					
17. I use LEDs to create a healthy light environment.					
18. I use an alarm with a dawn simulation light.					

Table A4

LEBA Short Form (18 Items):Latent Structure

Factor names	Items	Reliability Coefficients
F1: Wearing blue light filters	01-03	0.96
F2: Spending time outdoors	4-9 (Item 4 is reversed)	0.83
F3: Using phone and smartwatch in bed	10-14	0.7
F4: Using light before bedtime	15-18	0.69
F5: Using light in the morning and during daytime	19-23	0.52
McDonald's Omega coefficient for the total scale		0.73

Table A5

Minimum Average Partial (MAP) method of factor numder determination. MAP Statistics is the lowest in the 5th row indicating five factors are required.

MAP Statistics	dof	chisq	fit	RMSEA	BIC	eChisq	SRMR
.01125	1,080.00	4,344.31	0.18	0.08	-2,199.54	8,678.73	0.09
.01062	1,033.00	3,735.35	0.30	0.08	-2,523.72	6,414.94	0.08
.01077	987.00	3,065.44	0.38	0.07	-2,914.91	5,022.94	0.07
.01042	942.00	2,661.78	0.45	0.07	-3,045.92	3,969.03	0.06
.00938	898.00	2,237.56	0.51	0.06	-3,203.53	2,971.15	0.06
.00943	855.00	2,040.02	0.56	0.06	-3,140.53	2,441.92	0.05
.00973	813.00	1,861.69	0.59	0.05	-3,064.37	2,063.72	0.05
.00999	772.00	1,620.64	0.62	0.05	-3,057.00	1,707.87	0.04

Table A6

Demographic Characteristics: Native English Speakers

Variable	Overall, N = 262	Yes, N = 129	No, N = 133	p-value	q-value
Age	32.89 (13.66)	34.08 (15.32)	31.74 (11.77)	0.5	0.6
Sex				0.002	0.009
Female	136 (52%)	80 (62%)	56 (42%)		
Male	121 (46%)	48 (37%)	73 (55%)		
Other	5 (1.9%)	1 (0.8%)	4 (3.0%)		
Occupational Status				0.7	0.7
Work	161 (61%)	76 (59%)	85 (64%)		
School	52 (20%)	27 (21%)	25 (19%)		
Neither	49 (19%)	26 (20%)	23 (17%)		
Occupational setting				0.4	0.6
Home office/Home schooling	109 (42%)	50 (39%)	59 (44%)		
Face-to-face work/Face-to-face schooling	41 (16%)	22 (17%)	19 (14%)		
Combination of home- and face-to-face- work/schooling	53 (20%)	23 (18%)	30 (23%)		
Neither (no work or school, or in vacation)	59 (23%)	34 (26%)	25 (19%)		

[1] Mean (SD); n (%)

[2] False discovery rate correction for multiple testing

[3] Wilcoxon rank sum test

[4] Fisher's exact test

[5] Pearson's Chi-squared test

Table A7

Factor loadings and communality of the retained items (Minmum Residual)

item	MR1	MR2	MR3	MR4	MR5	Communality	Uniqueness
item16	1					0.996	0.004
item36	0.94					0.897	0.103
item17	0.8					0.658	0.342
item11		0.79				0.642	0.358
item10		0.76				0.592	0.408
item12		0.65				0.465	0.535
item07		0.5				0.267	0.733
item08		-0.49				0.252	0.748
item09		0.32				0.113	0.887
item27			0.8			0.659	0.341
item03			0.8			0.683	0.317
item40			0.65			0.464	0.536
item30			0.45			0.353	0.647
item41			0.36			0.329	0.671
item33				0.74		0.555	0.445
item32				0.73		0.623	0.377
item35				0.66		0.455	0.545
item37				-0.39		0.175	0.825
item38				0.38		0.178	0.822
item46					0.6	0.422	0.578
item45					0.59	0.374	0.626
item25					0.41	0.193	0.807
item04					0.41	0.219	0.781
item01					0.4	0.17	0.83
item26					0.35	0.165	0.835
% of Variance	0.1	0.1	0.09	0.08	0.06		

Note. Only loading higher than .30 is reported

Table A8

Factor loadings and communality of the retained items(six factor)

item	PA1	PA2	PA3	PA4	PA5	PA6	Communality	Uniqueness
item16	0.99						0.987	0.013
item36	0.94						0.896	0.104
item17	0.8						0.674	0.326
item11		0.82					0.698	0.302
item10		0.81					0.656	0.344
item12		0.64					0.467	0.533
item08		-0.48					0.254	0.746
item07		0.47					0.257	0.743
item09		0.33					0.122	0.878
item33			0.97				0.978	0.022
item32			0.77				0.69	0.31
item35			0.54			0.3	0.408	0.592
item31			0.49				0.332	0.668
item03				0.84			0.728	0.272
item27				0.81			0.666	0.334
item40				0.69			0.535	0.465
item46					0.65		0.525	0.475
item45					0.57		0.355	0.645
item04					0.48		0.332	0.668
item25					0.4		0.238	0.762
item01					0.35		0.134	0.866
item26					0.35		0.161	0.839
item37						-0.8	0.682	0.318
item38						0.39	0.245	0.755
% of Variance	0.11	0.1	0.09	0.09	0.06	0.05		

Table A8 continued

item	PA1	PA2	PA3	PA4	PA5	PA6	Communality	Uniqueness

Note. Only loading higher than .30 is reported; Sixth factor has only two salient loadings

Table A9

Factor loadings and communality of the retained items in five factor solution [Unmerged Responses]

item	PA1	PA2	PA5	PA3	PA4	Communality	Uniqueness
item19	0.99					1.007	-0.007
item20	0.91					0.874	0.126
item18	0.82					0.711	0.289
item21	0.8					0.683	0.317
item04	0.47					0.25	0.75
item11		0.83				0.687	0.313
item10		0.81				0.67	0.33
item12		0.56				0.371	0.629
item08		-0.44				0.206	0.794
item07		0.42				0.226	0.774
item09		0.33				0.115	0.885
item16			0.95			0.946	0.054
item17			0.74			0.595	0.405
item36	0.3		0.73			0.653	0.347
item03				0.85		0.746	0.254
item27				0.78		0.624	0.376
item40				0.71		0.512	0.488
item35					0.58	0.351	0.649
item48					0.57	0.354	0.646

Table A9 continued

item	PA1	PA2	PA5	PA3	PA4	Communality	Uniqueness
item33					0.55	0.32	0.68
item47					0.52	0.294	0.706
item44					0.45	0.216	0.784
item31					0.41	0.206	0.794
item38					0.33	0.129	0.871
% of Variance	0.15	0.09	0.09	0.08	0.08		

Note. Only loading higher than .30 is reported

Table A10

Factor loadings and communality of the retained items in six factor solution [Unmerged Responses]

item	PA1	PA2	PA3	PA4	PA6	PA5	Communality	Uniqueness
item19	0.98						0.995	0.005
item20	0.92						0.904	0.096
item21	0.79						0.666	0.334
item04	0.49						0.296	0.704
item43	0.32					0.31	0.282	0.718
item10		0.81					0.67	0.33
item11		0.81					0.668	0.332
item12		0.58					0.408	0.592
item08		-0.45					0.218	0.782
item07		0.42					0.229	0.771
item09		0.33					0.115	0.885
item03			0.85				0.731	0.269
item27			0.77				0.606	0.394
item40			0.72				0.533	0.467

Table A10 continued

item	PA1	PA2	PA3	PA4	PA6	PA5	Communality	Uniqueness
item35				0.64			0.426	0.574
item33				0.62			0.413	0.587
item48				0.52			0.305	0.695
item47				0.48			0.259	0.741
item31				0.39			0.206	0.794
item38				0.32			0.18	0.82
item17					0.85		0.786	0.214
item16					0.78		0.681	0.319
item13						0.57	0.336	0.664
item14						0.5	0.356	0.644
item15						0.48	0.277	0.723
item42						0.37	0.168	0.832
item26							0.064	0.936
% of Variance	0.11	0.08	0.07	0.06	0.06	0.05		

Note. Only loading higher than .30 is reported

Table A11

Geographical Location of the participants (n =690)

Timezone	Number of Participants
Africa/Ceuta (UTC +01:00)	2.00
Africa/Douala (UTC +01:00)	1.00
Africa/Johannesburg (UTC +02:00)	5.00
Africa/Khartoum (UTC +02:00)	2.00
Africa/Lagos (UTC +01:00)	1.00
America/Adak (UTC -09:00)	2.00
America/Anchorage (UTC -08:00)	3.00

Table A11 continued

Timezone	Number of Participants
America/Araguaina (UTC -03:00)	2.00
America/Argentina/Buenos_Aires (UTC -03:00)	5.00
America/Argentina/Cordoba (UTC -03:00)	2.00
America/Argentina/Jujuy (UTC -03:00)	1.00
America/Bahia (UTC -03:00)	2.00
America/Blanc-Sablon (UTC -04:00)	1.00
America/Bogota (UTC -05:00)	2.00
America/Boise (UTC -06:00)	4.00
America/Cayman (UTC -05:00)	1.00
America/Chicago (UTC -05:00)	30.00
America/Costa_Rica (UTC -06:00)	2.00
America/Cuiaba (UTC -04:00)	1.00
America/Denver (UTC -06:00)	6.00
America/Detroit (UTC -04:00)	6.00
America/Edmonton (UTC -06:00)	14.00
America/Fortaleza (UTC -03:00)	1.00
America/Guatemala (UTC -06:00)	1.00
America/Guayaquil (UTC -05:00)	2.00
America/Halifax (UTC -03:00)	1.00
America/Indiana/Indianapolis (UTC -04:00)	3.00
America/Indiana/Tell_City (UTC -05:00)	1.00
America/Kentucky/Louisville (UTC -04:00)	3.00
America/Los_Angeles (UTC -07:00)	37.00
America/Martinique (UTC -04:00)	1.00
America/Mexico_City (UTC -06:00)	2.00
America/Moncton (UTC -03:00)	2.00
America/Monterrey (UTC -06:00)	1.00
America/New_York (UTC -04:00)	63.00
America/North_Dakota/Center (UTC -05:00)	1.00

Table A11 continued

Timezone	Number of Participants
America/North_Dakota/New_Salem (UTC -05:00)	1.00
America/Panama (UTC -05:00)	1.00
America/Phoenix (UTC -07:00)	7.00
America/Resolute (UTC -05:00)	1.00
America/Santiago (UTC -03:00)	8.00
America/Sao_Paulo (UTC -03:00)	19.00
America/Toronto (UTC -04:00)	16.00
America/Vancouver (UTC -07:00)	6.00
Antarctica/Macquarie (UTC +11:00)	1.00
Asia /Taipei City (UTC +08:00)	3.00
Asia/Amman (UTC +03:00)	2.00
Asia/Barnaul (UTC +07:00)	1.00
Asia/Dhaka (UTC +06:00)	1.00
Asia/Famagusta (UTC +02:00)	1.00
Asia/Ho_Chi_Minh (UTC +07:00),British - America/Tortola (UTC -04:00)	2.00
Asia/Hong_Kong (UTC +08:00)	2.00
Asia/Jakarta (UTC +07:00)	9.00
Asia/Jerusalem (UTC +02:00)	4.00
Asia/Karachi (UTC +05:00)	1.00
Asia/Kathmandu (UTC +05:45)	2.00
Asia/Kolkata (UTC +05:30)	38.00
Asia/Kuala_Lumpur (UTC +08:00)	7.00
Asia/Kuching (UTC +08:00)	2.00
Asia/Manila (UTC +08:00)	6.00
Asia/Novosibirsk (UTC +07:00)	1.00
Asia/Riyadh (UTC +03:00)	1.00
Asia/Seoul (UTC +09:00)	1.00
Asia/Shanghai (UTC +08:00)	7.00
Asia/Singapore (UTC +08:00)	1.00

Table A11 continued

Timezone	Number of Participants
Asia/Tokyo (UTC +09:00)	3.00
Asia/Tomsk (UTC +07:00)	1.00
Asia/Ulaanbaatar (UTC +08:00)	1.00
Asia/Vladivostok (UTC +10:00)	1.00
Asia/Yangon (UTC +06:30)	1.00
Asia/Yekaterinburg (UTC +05:00)	1.00
Atlantic/Canary (UTC)	1.00
Australia/Adelaide (UTC +10:30)	2.00
Australia/Brisbane (UTC +10:00)	4.00
Australia/Darwin (UTC +09:30)	1.00
Australia/Melbourne (UTC +11:00)	5.00
Australia/Perth (UTC +08:00)	2.00
Australia/Sydney (UTC +11:00)	2.00
East Africa/Dodoma (UTC +03:00)	1.00
Europe/Amsterdam (UTC +01:00)	19.00
Europe/Athens (UTC +02:00)	3.00
Europe/Belgrade (UTC +01:00)	3.00
Europe/Berlin (UTC +01:00)	53.00
Europe/Bratislava (UTC +01:00)	2.00
Europe/Brussels (UTC +01:00)	4.00
Europe/Bucharest (UTC +02:00)	3.00
Europe/Budapest (UTC +01:00)	2.00
Europe/Busingen (UTC +01:00)	3.00
Europe/Copenhagen (UTC +01:00)	3.00
Europe/Dublin (UTC)	5.00
Europe/Helsinki (UTC +02:00)	9.00
Europe/Istanbul (UTC +03:00)	6.00
Europe/Kiev (UTC +02:00)	1.00
Europe/Lisbon (UTC)	2.00

Table A11 continued

Timezone	Number of Participants
Europe/Ljubljana (UTC +01:00)	3.00
Europe/London (UTC)	57.00
Europe/Madrid (UTC +01:00)	7.00
Europe/Moscow (UTC +03:00)	8.00
Europe/Oslo (UTC +01:00)	3.00
Europe/Paris (UTC +01:00)	22.00
Europe/Prague (UTC +01:00)	3.00
Europe/Riga (UTC +02:00)	2.00
Europe/Rome (UTC +01:00)	9.00
Europe/Sofia (UTC +02:00)	1.00
Europe/Stockholm (UTC +01:00)	4.00
Europe/Tallinn (UTC +02:00)	2.00
Europe/Tirane (UTC +01:00)	1.00
Europe/Vienna (UTC +01:00)	1.00
Europe/Vilnius (UTC +02:00)	5.00
Europe/Warsaw (UTC +01:00)	15.00
Europe/Zagreb (UTC +01:00)	2.00
Europe/Zurich (UTC +01:00)	21.00
European /Skopje (UTC +01:00)	1.00
Iran /Tehran (UTC +0:30)	3.00
Pacific/Auckland (UTC +13:00)	6.00
Pacific/Chatham (UTC +13:45)	1.00
Pacific/Easter (UTC -05:00)	1.00
Pacific/Honolulu (UTC -10:00)	2.00

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Table A12

F1
I use light therapy applying a blue light box.
I use light therapy applying a light visor.
I use light therapy applying a white light box.
I use light therapy applying another form of light device.
I use an alarm with a dawn simulation light.
F2
I spend more than 3 hours per day (in total) outside.
I spend between 1 and 3 hours per day (in total) outside.
I spend as much time outside as possible.
I spend 30 minutes or less per day (in total) outside.
I go for a walk or exercise outside within 2 hours after waking up.
I spend between 30 minutes and 1 hour per day (in total) outside.
F3
I look at my mobile phone screen immediately after waking up.
I use my mobile phone within 1 hour before attempting to fall asleep.
I check my phone when I wake up at night.
F4
I use a blue-filter app on my computer screen within 1 hour before attempting to fall asleep.
I seek out knowledge on how to improve my light exposure.
I dim my computer screen within 1 hour before attempting to fall asleep.
I discuss the effects of light on my body with other people.
I modify my light environment to match my current needs.
I dim my room light within 1 hour before attempting to fall asleep.
I use as little light as possible when I get up during the night.
F5
I wear blue-filtering, orange-tinted, and/or red-tinted glasses indoors during the day.
I wear blue-filtering, orange-tinted, and/or red-tinted glasses outdoors during the day.
I wear blue-filtering, orange-tinted, and/or red-tinted glasses within 1 hour before attempting to fall asleep.

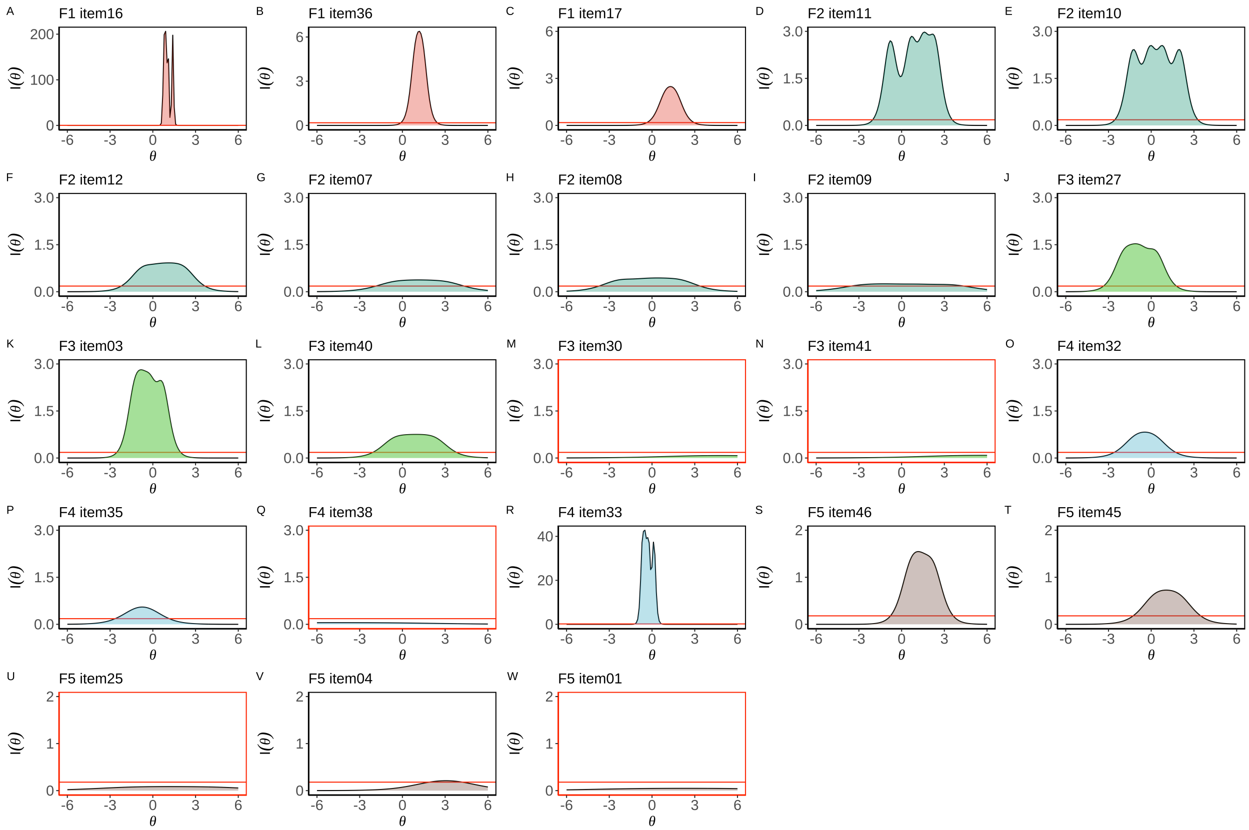

Figure A1. Item information curve

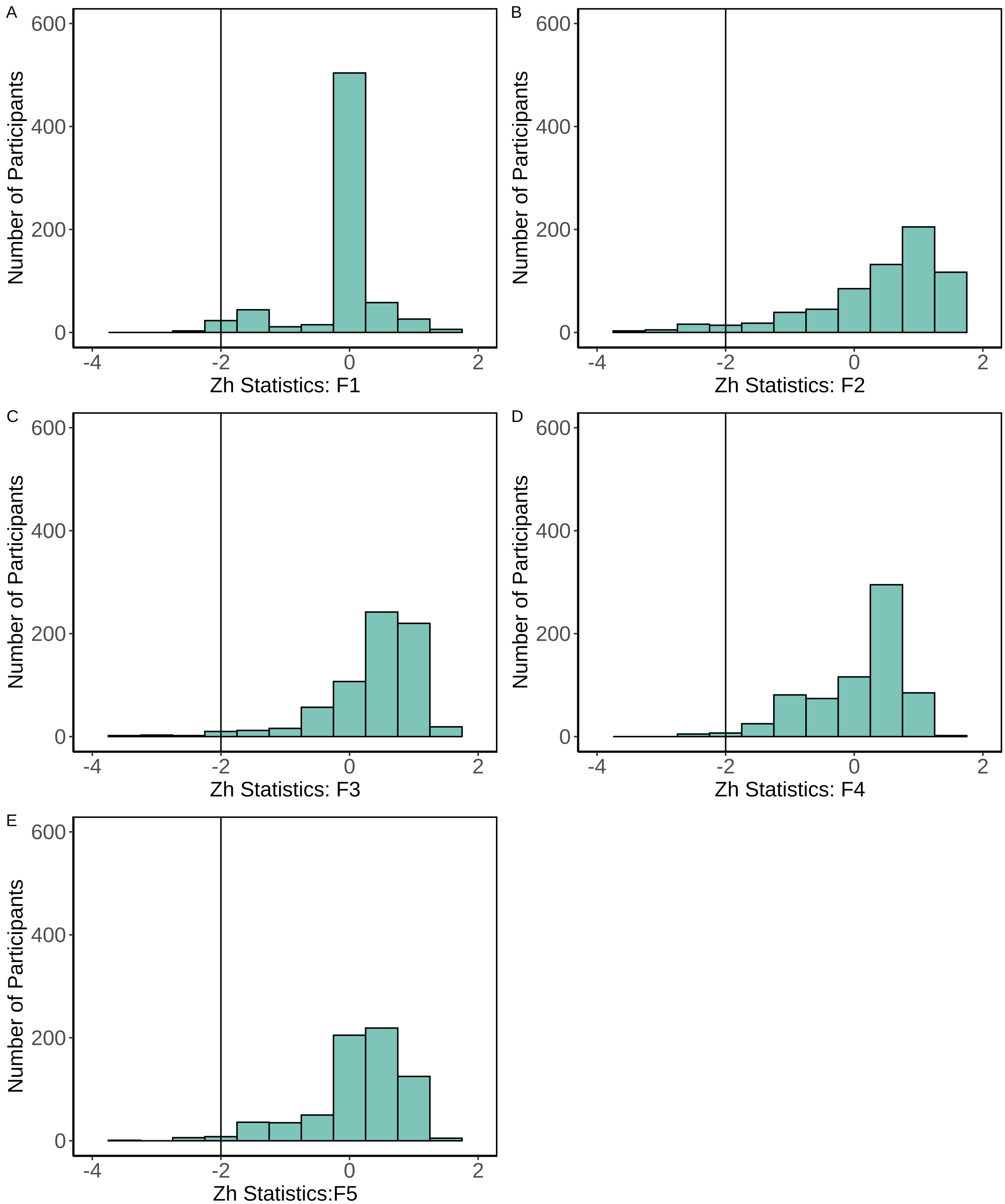

Figure A2. Person fit of the five fitted IRT models (a) Wearing blue light filters (b) Spending time outdoors (c) Using phone and smartwatchin bed (d) Using light before bedtime (e) Using light in the morning andduring daytime