

1 An inventory of human light exposure related behaviour

2

3

4 Abstract

5 Light exposure is an essential driver of health and well-being, and individual behaviours
6 during rest and activity modulate physiologically-relevant aspects of light exposure.
7 Further understanding the behaviours that influence individual photic exposure patterns
8 may provide insight into the volitional contributions to the physiological effects of light
9 and guide behavioral points of intervention. Here, we present a novel, self-reported and
10 psychometrically validated inventory to capture light exposure-related behaviour, the
11 Light Exposure Behaviour Assessment (LEBA).

12 An expert panel prepared the initial 48-item pool spanning different light exposure-related
13 behaviours. Responses, consisting of rating the frequency of engaging in the per-item
14 behaviour on a 5-point Likert type scale, were collected in an online survey yielding
15 responses from a geographically unconstrained sample (690 completed responses, 74
16 countries, 28 time zones). The exploratory factor analysis (EFA) on an initial subsample
17 ($n=428$) rendered a five-factor solution with 25 items (Wearing blue light filters, spending
18 time outdoors, using a phone and smartwatch in bed, using light before bedtime, using
19 light in the morning and during daytime). In a confirmatory factor analysis (CFA)
20 performed on an independent subset of participants ($n=262$), we removed two additional
21 items to attain the best fit for the five-factor solution ($CFI=0.95$, $TLI=0.95$, $RMSEA=0.06$).
22 The internal consistency reliability coefficient for the total instrument yielded McDonald's
23 $\Omega=0.68$. Measurement model invariance analysis between native and non-native
24 English speakers showed our model attained the highest level of invariance (residual
25 invariance $CFI=0.95$, $TLI=0.95$, $RMSEA=0.05$). Lastly, a short form of the LEBA ($n=18$)
26 was developed using Item Response Theory on the complete sample ($n=690$).

27 The psychometric properties of the LEBA indicate the usability to measure light
28 exposure-related behaviours. The instrument may offer a scalable solution to
29 characterize behaviours that influence individual photic exposure patterns in remote

³⁰ samples. The LEBA inventory is available under the open-access CC-BY-NC-ND
³¹ license.

³² Instrument webpage: <https://leba-instrument.org/> GitHub repository containing this
³³ manuscript: <https://github.com/leba-instrument/leba-manuscript>

³⁴ *Keywords:* light exposure, light-related behaviours, non-visual effects of light,
³⁵ psychometrics

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38 **Introduction**

39 Light exposure received by the eyes affects many facets of human health,
40 well-being, and performance beyond visual sensation and perception (Boyce, 2022).
41 The non-image-forming (NIF) effects of light comprise light's circadian and non-circadian
42 influence on several physiological and psychological functions, such as the secretion of
43 melatonin, sleep, mood, pupil size, body temperature, alertness, and higher cognitive
44 functions (Blume, Garbazza, & Spitschan, 2019).

45 With the introduction of artificial electric light, human behaviour has become
46 dissociated from the light-dark cycle given by solar radiation. People can now frequently
47 choose when to be exposed to light or darkness. For example, they can decide whether
48 to go outdoors and seek out sunlight, switch on/off light-emitting devices, use certain
49 types of lights at home, or avoid specific light environments altogether. Additionally,
50 when light sources cannot be directly manipulated, sought out, or avoided (for example,
51 at school, work, or in public places), there is still potential leeway to influence personal
52 light exposure behaviourally, for instance, by wearing sunglasses, directing one's gaze
53 away or supplementing the situation with additional light sources. Although clearly
54 yielding the potential for good, these behaviours are further associated with increased
55 electric light exposure at night and indoor time during the day, compromising the natural
56 temporal organisation of the light-dark cycle. For example, in the US, an average of 87%
57 of the time is spent in enclosed buildings (Klepeis et al., 2001), and more than 80% of
58 the population is exposed to a night sky that is brighter than nights with a full moon due
59 to electric light at night (Navara & Nelson, 2007).

60 An extensive body of scientific evidence suggests that improper light exposure may
61 be disruptive for health and well-being, giving rise to a series of adverse consequences,
62 including the alteration of hormonal rhythms, increased cancer rates, cardiovascular

63 diseases, and metabolic disorders, such as obesity and type II diabetes (Chellappa,
64 Vujovic, Williams, & Scheer, 2019; Lunn et al., 2017; Navara & Nelson, 2007). These
65 findings have sparked a significant call for assessment and guidance regarding healthy
66 light exposure as exemplified by a recently published set of consensus-based experts'
67 recommendations with specific requirements for indoor light environments during the
68 daytime, evening, and nighttime (T. M. Brown et al., 2022).

69 Furthermore, building on earlier attempts (e.g. Hubalek, Zöschg, & Schierz, 2006),
70 there was a recent push toward the development and use of portable light loggers to
71 improve ambulant light assessment and gain more insight into the NIF effects of light on
72 human health in field conditions (Hartmeyer, Webler, & Andersen, 2022; Spitschan et al.,
73 2022). Attached to different body parts (e.g., wrist; head, at eye level; chest), these light
74 loggers allow for the objective measurement of individual photic exposure patterns under
75 real-world conditions and thus are valuable tools for field studies. Nevertheless, these
76 devices also encompass limiting factors such as potentially being intrusive (e.g., when
77 eye-level worn), yielding the risk of getting covered (e.g., when wrist- or chest-worn) and
78 requiring (monetary) resources and expertise for acquisition and maintenance of the
79 devices. Moreover, it is important to note that portable light loggers alone do not collect
80 data on the specific behavioural patterns in relation to light exposure.

81 On the other hand, several attempts have been made to quantify received light
82 exposure subjectively with self-report questionnaires (**Supplementary Table 1**). However,
83 self-reporting light properties could be challenging for people who lack technical
84 knowledge of light sources. Moreover, it is worth considering that the human visual
85 system, unlike a photometer, continuously adapts to ambient brightness (Hurvich &
86 Jameson, 1966), while the signals underlying the non-visual effects of light are
87 independent from perception (Allen, Hazelhoff, Martial, Cajochen, & Lucas, 2018).
88 Retrospectively recalling the properties of a light source can further complicate such
89 subjective evaluations. Moreover, measuring light properties alone does not yield any

90 information about how individuals might behave differently regarding diverse light
91 environments such as work, home or outdoors.

92 To date, little effort has been made to understand and capture these activities.

93 Here, we present the development process of a novel self-reported inventory, the Light
94 Exposure Behaviour Assessment (LEBA), for characterizing diverse light
95 exposure-related behaviours. Notably, the focus of LEBA is not to estimate personal light
96 exposure. Instead, we aim to assess, in a scalable way, how people behave in relation to
97 light, focusing on habitual patterns that could guide behavioural interventions.

98 **Results**

99 Our results focus on the development of the LEBA inventory and its psychometric
100 validation using a large scale online sample data (n=690).

101 **Development of the initial item pool**

102 To capture the human light exposure related behaviours, 48 items were developed
103 by an expert panel (all authors – researchers from chronobiology, light research,
104 neuroscience and psychology in different geographical contexts). Face validity
105 examination by each panel member indicated all items were relevant and a few
106 modifications were suggested. The author team discussed the suggestions and
107 amended the items as indicated, thus creating a 48-item inventory.

108 **Measurement of light exposure behaviour in an online sample**

109 We conducted two rounds of large scale online survey between 17 May 2021 and 3
110 September 2021 to generate data from 690 participants with varied geographic locations
111 (countries=74; time-zone=28). For a complete list of geographic locations, see
112 **Supplementary Table 2**. Table 1 presents the survey participants' demographic

characteristics. Only participants completing the full LEBA inventory were included. We used the data from first round for the exploratory factor analysis (EFA sample; n=428) and data from the second round was used in the confirmatory factor analysis (CFA sample; n=262). Participants in our survey were aged between 11 to 84 years, with an overall mean of ~ 32.95 years of age [Overall: 32.95 ± 14.57 ; EFA: 32.99 ± 15.11 ; CFA: 32.89 ± 13.66]. In the entire sample, 351 (51%) were male, 325 (47%) were female, 14 (2.0%) reported other sex, and 49 (7.2%) reported 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 (396 (57%)) reported that they currently work, whereas 174 (25%) reported that they go to school, and 120 (17%) 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 entire sample, 303 (44%) of the participants indicated that they were in a home office/ home schooling setting, 109 (16%) reported face-to-face work/schooling, 147 (21%) reported a combination of home- and face-to-face work/schooling, and 131 (19%) filled in the “Neither (no work or school, or on vacation)” response option.

Psychometric analysis: Development of the long form

Descriptive statistics and item analysis. We observed that the response patterns of LEBA inventory for the entire sample (n=690) were not normally distributed (Figures 1 and 2). All items violated both univariate (Shapiro & Wilk, 1965) and multivariate normality (Mardia, 1970). The multivariate skewness was 488.40 ($p < 0.001$) and the multivariate kurtosis was 2,808.17 ($p < 0.001$).

Similarly, non-normal distribution of response pattern was also observed in the EFA sample. Supplementary Figure 1 depicts the univariate descriptive statistics for the EFA sample (n=428). Further, We observed that each item's correlation with the aggregated

139 sum of the 48-item's score varied largely (corrected item-total correlation= 0.03 -0.48)
140 indicating the possibility of multi-factor structure of the LEBA inventory.

141 **Exploratory factor analysis and reliability analysis.** Exploratory analysis revealed
142 that items of LEBA inventory can be categorized into five major factors: (i) wearing blue
143 light filters; (ii) spending time out doors; (iii) using phone and smartwatch in bed; (iv)
144 using light before bedtime (v) using light in the morning and during daytime. In this stage
145 of analysis, we retained 25 items. the first factor had three items and encapsulated the
146 individual's preference for using blue light filters in different light environments. The
147 second factor contained six items that incorporated the individuals' hours spent
148 outdoors. The third factor contained five items that looked into specific behaviours of
149 using a phone and smartwatch in bed. The fourth factor comprised five items
150 investigated the other behaviours related to the individual's electric light exposure before
151 bedtime. Lastly, the fifth factor encompassed six items capturing the individual's morning
152 and daytime light exposure-related behaviour.

153 Prior to conducting the EFA, we have checked the post-hoc sampling adequacy by
154 applying Kaiser-Meyer-Olkin (KMO) measures of sampling adequacy on the EFA sample
155 ($n=428$) (Kaiser, 1974) and the quality of the correlation matrix by Bartlett's test of
156 sphericity (Bartlett, 1954). KMO>0.50 would indicate adequate sample size (Hutcheson,
157 1999) and a significant test of sphericity would indicate satisfactory quality of the
158 correlation matrix . Results indicated that we had an adequate sample size (KMO=0.63)
159 and correlation matrix ($\chi^2_{1128}=5042.86$, $p< 0.001$). However, 4.96% of the inter-item
160 correlation coefficients were greater than |0.30|, and the inter-item correlation
161 coefficients ranged between -0.44 to 0.91. Figure 3-A depicts the respective correlation
162 matrix. To identify how many factors are required to optimally express human light
163 exposure related behaviours we used a combination of methods. the Scree plot (Figure
164 3-B) revealed a six-factor solution, whereas the minimum average partial (MAP) method
165 (Velicer, 1976) (Supplementary Table 3) and Hull method (Lorenzo-Seva, Timmerman, &

Kiers, 2011) implied a five-factor solution (Figure 3-C). Hence, we tested both five-factor and six-factor solutions using iterative EFA where we gradually identified and discarded problematic items (factor-loading <0.30 and cross-loading >0.30). In this process, we found a five-factor structure for LEBA inventory with 25 items. Table 2 displays the factor-loading (λ) and communality of the items. Both factor loadings and commonalities advocate to accept this five-factor solution ($|\lambda|=0.32-0.99$; commonalities=0.11-0.99). These five factors explains 10.25%, 9.93%, 8.83%, 8.44%, 6.14% of the total variance in individual's light exposure related behaviours respectively. All factors exhibited excellent to satisfactory reliability (ordinal $\alpha=0.94, 0.76, 0.75, 0.72, 0.62$ respectively). The entire inventory also exhibited satisfactory reliability ($\omega_t=0.77$).

However, the histogram of the absolute values of nonredundant residual correlations (Figure 3-D) displayed that 26% of correlations were greater $>|0.05|$, indicating a possible under-factoring. (Desjardins & Bulut, 2018). Subsequently, we fitted a six-factor solution, where a factor with only two salient variables emerged, thus disqualifying the six-factor solution (Supplementary Table 4). While making the judgement of accepting this five-factor solution we considered both factor's interpretability and their psychometric properties. We deemed the five derived factors as highly interpretable and relevant concerning our aim to capture light exposure-related behaviour, we retained all of them with 25 items. Two of the items showed negative factor-loading (item 08: I spend 30 minutes or less per day (in total) outside. and item 37: I use a blue-filter app on my computer screen within 1 hour before attempting to fall asleep.). Upon re-inspection, we recognized these items to be negatively correlated to the respective factor, and thus, we reverse-scored these two items.

Confirmatory factor analysis. To investigate the structural validity of the five-factor structure obtained in EFA, we conducted a confirmatory factor analysis (CFA) on the CFA sample. The five-factor structure with 25 items showed acceptable fit (Table 3) providing evidence of structural validity ($CFI=0.92$; $TLI=0.91$; $RMSEA=0.07$ [0.06-0.07],

193 90% CI]). Two equity constraints were imposed on item pairs 32-33 (item 32: I dim my
194 mobile phone screen within 1 hour before attempting to fall asleep; item 33: I dim my
195 computer screen within 1 hour before attempting to fall asleep) and 16-17 (item 16: I
196 wear blue-filtering, orange-tinted, and/or red-tinted glasses indoors during the day; item
197 17: I wear blue-filtering, orange-tinted, and/or red-tinted glasses outdoors during the
198 day). Item pair 32-33 describes the preference for dimming the electric devices'
199 brightness before bedtime, whereas item pair 16-17 represents the use of blue filtering
200 or coloured glasses during the daytime. Given the similar nature of captured behaviours
201 within each item pair, we accepted the imposed equity constraints. Nevertheless, the
202 SRMR value exceeded the guideline recommendation (SRMR=0.12). In order to
203 improve the model fit, we conducted a post-hoc model modification. Firstly, the
204 modification indices suggested cross-loadings between item 37 and 26 (item 37: I
205 purposely leave a light on in my sleep environment while sleeping; item 26: I turn on my
206 ceiling room light when it is light outside), which were hence discarded. Secondly, items
207 30 and 41 (item 30: I look at my smartwatch within 1 hour before attempting to fall
208 asleep; item 41: I look at my smartwatch when I wake up at night) showed a tendency to
209 co-vary in their error variance ($MI=141.127$, $p<0.001$). By allowing the latter pair of items
210 (30 & 41) to co-vary, the model's error variance attained an improved fit ($CFI=0.95$;
211 $TLI=0.95$; $RMSEA=0.06$ [0.05-0.06, 90% CI]; $SRMR=0.11$).

212 Accordingly, we accept the five-factor model with 23 items, finalizing the long Form
213 of LEBA inventory (see **Supplementary File 1**). Internal consistency ordinal α for the five
214 factors of the LEBA were 0.96, 0.83, 0.70, 0.69, 0.52, respectively. The reliability of the
215 total inventory was satisfactory ($\omega_t=0.68$). Figure 4 depicts the obtained CFA structure,
216 while **Supplementary Figure 2** depicts the data distribution and endorsement pattern of
217 the retained 23 items in our CFA sample.

218 **Measurement invariance.** We reported the measurement invariance (MI) analysis
219 on the CFA sample based on native ($n=129$) and non-native English speakers ($n=133$).

220 A detailed demographic description are provided in Supplementary Table 5. Our MI
221 results (Table 4) indicated that LEBA inventory demonstrated highest level of (residual
222 model) psychometric equivalence across native and non-native English speaking
223 participants, thus permitting group-mean based comparisons. The four fitted MI models
224 generated acceptable fit indices and the model fit did not significantly decrease across
225 the nested models ($\Delta\text{CFI}>-0.01$; $\Delta\text{RMSEA}<0.01$).

226 **Secondary analysis: Grade level identification and semantic scale network analysis**

227 We investigated the language-based accessibility of LEBA using Flesch-Kincaid
228 grade level analysis (Flesch, 1948). Results indicated that at least a language
229 proficiency of educational grade level-four (US education system) with age above eight
230 years are required to comprehend the items used in LEBA inventory. Semantic Scale
231 analysis (Rosenbusch, Wanders, & Pit, 2020) was administered to assess the LEBA's
232 (23 items) semantic relation to other questionnaires. LEBA inventory was most strongly
233 semantically related to scales about sleep: The "Sleep Disturbance Scale For Children"
234 (Bruni et al., 1996) and the "Composite International Diagnostic Interview (CIDI):
235 Insomnia"(Robins et al., 1988). The cosine similarity index ranged between 0.47 to 0.51.

236 **Developing a short form of LEBA: IRT-based analysis**

237 Our aim was to provide a data-driven approach to reducing the number of items for
238 cases where a small reduction of items is necessary. In order to derive a short form of
239 the LEBA inventory, we fitted each factor of the LEBA with the graded response model
240 (Samejima, Liden, & Hambleton, 1997) to the combined EFA and CFA sample (n=690).
241 The resulting item discrimination parameters of the inventory fell into categories of "very
242 high" (10 items), "high" (4 items), "moderate" (4 items), and "low" (5 items), indicating a
243 good range of discrimination along the latent trait level (θ) (Supplementary Table 6). An
244 examination of the item information curve (Supplementary Figure 3) revealed five items

245 (1, 25, 30, 38, & 41) provided very low information regarding light exposure related
246 behaviours with relatively flat curves ($I(\theta) < 0.20$). We discarded those items, culminating
247 in a short form of LEBA with five factors and 18 items (Supplementary File 2).

248 Subsequently, we obtained five test information curves (TICs). As Figure 5
249 illustrates, the TICs of the first and fifth factors peaked on the right side of the centre of
250 their latent traits, while the TICs of the other three factors were roughly centred on the
251 respective trait continuum (θ). This points out that the LEBA short-form estimates the
252 light exposure-related behaviour most precisely near the centre of the trait continuum for
253 the second, third and fourth factors. In contrast, for the first and fifth factors the TICs
254 were left skewed indicating their increased sensitivity in identifying people who are
255 engaging more in those particular light exposure related behaviour dimensions (Baker &
256 Kim, 2017).

257 Finally, Supplementary Table 7 summarises the item fit indexes of the LEBA short
258 form. All 18 items yielded RMSEA value ≤ 0.06 , indicating an adequate fit to the fitted
259 IRT model. Furthermore, Supplementary Figure 4 depicts the person fit Zh statistics
260 histogram for the five IRT models. Zh statistics are larger than -2 for most participants,
261 suggesting a good person fit regarding the selected IRT models.

262 Discussion

263 We have developed two versions of a self-report inventory, LEBA, that can capture
264 light exposure-related behaviours in multiple dimensions. The 48 generated items were
265 applied in a large-scale, geographically unconstrained, cross-sectional study, yielding
266 690 completed surveys. To assure high data quality, participant responses were only
267 included when the five “attention check items” throughout the survey were passed.
268 Ultimately, data was recorded from 74 countries and 28 time zones, including native and
269 non-native English speakers from a sex-balanced and age-diverse sample (see Table 1).

270 The acquired study population complied with our objective to avoid bias from a selective
271 sample, which is crucial when relying on voluntary uncompensated participation.

272 Data collected in the first round was used to explore the latent structure (EFA
273 sample; n=428). The exploratory factor analysis revealed a highly interpretable
274 five-factor solution (“Wearing blue light filters”, “Spending time outdoors”, “Using phone
275 and smartwatch in bed”, “Using light before bedtime”, and “Using light in the morning and
276 during daytime”) with 25 items. Our CFA analysis (CFA sample; n=262) confirmed the
277 five-factor structure we obtained in our EFA, thus providing evidence for structural
278 validity.(CFI=0.95; TLI=0.95; RMSEA=0.06). In this model, we discarded two more items
279 (item 26 & 37) for possible cross-loadings. As a rule of thumb, reliability coefficients
280 higher than .70 are regarded as “satisfactory”. However, at the early developmental
281 stage, a value of .50 is considered acceptable (Dall’Oglio et al., 2010; Field, 2015;
282 Nunnally, 1978). Thus, we confer, the internal consistency coefficients ordinal alpha for
283 the five factors and the total inventory were satisfactory (Ordinal alpha ranged between
284 0.52 to 0.96; McDonald’s ω_t =0.68).

285 The results of the measurement invariance analysis indicate that the construct
286 “Light exposure-related behaviour” is equivalent across native and non-native English
287 speakers and thus suitable for assessment in both groups. Furthermore, according to
288 the grade level identification method, the LEBA appears understandable for students at
289 least 8.33 years of age visiting grade four or higher. Interestingly, the semantic similarity
290 analysis (“Semantic Scale Network” database Rosenbusch et al. (2020)) revealed that
291 the “LEBA” is semantically related to the “Sleep Disturbance Scale For Children” (SDSC)
292 (Bruni et al., 1996) and the “Composite International Diagnostic Interview (CIDI):
293 Insomnia”(Robins et al., 1988). Upon inspecting the questionnaire contents, we found
294 that some items in the factors “Using phone and smartwatch in bed” and “Using light
295 before bedtime” have semantic overlap with the SDSC’s and CIDI’s items. However,
296 while the CIDI and the SDSC capture various clinically relevant sleep problems and

related activities, the LEBA aims to assess light-exposure-related behaviour. Since light exposure at night has been shown to influence sleep negatively (T. M. Brown et al., 2022; Santhi & Ball, 2020), this overlap confirms our aim to measure the physiologically relevant aspects of light-exposure-related behaviour. Nevertheless, the general objectives of the complete questionnaires and the LEBA differ evidently.

While developing and validating LEBA, we have complemented conventional approaches with an Item Response Theory (IRT) analysis. IRT provides a framework to interpret respondents' obtained scores in the light of latent ability (i.e. light exposure behaviour) and the characteristics of the respondents – how they interpret the items (Thomas, 2019). The benefit of implementing IRT analysis was twofold. First, we derived a shorter form of LEBA (18 items). We fitted a graded response model to the combined EFA and CFA sample ($n=690$) and discarded five items (1, 25, 30, 38, & 41) with relatively flat item information curve [$I(\theta) < .20$]. The resulting test information curves suggest that the short-LEBA is a psychometrically sound measure with adequate coverage of underlying traits and can be applied to capture the frequency of different light exposure related behaviours reliably. Often, psychological measurements require application of several questionnaires simultaneously. Responding to several lengthy questionnaires increases the participants losing focus and becoming tired. Thus, in some circumstances, reducing the number of items even slightly may be necessary to employ the LEBA questionnaire. Our aim was to provide a data-driven approach to reducing the number of items, apart from the possibility of excluding a specific factor from the 23-item questionnaire. Nonetheless, where possible, we strongly recommend using the extended form of the questionnaire to avoid limiting the range of gained information.

The IRT analysis enabled us to capture individual differences in responding to the items of LEBA. Findings from the item and person fit index analysis demonstrate that all five fitted models were acceptable and provide evidence of validity for the factors. In addition, the diverse item discrimination parameters indicate an appropriate range of

324 discrimination – the ability to differentiate respondents with different levels of light
325 exposure-related behaviour while acknowledging the interpersonal variability in
326 understanding the item.

327 **Known limitations**

328 We acknowledge that this work is limited concerning the following aspects:

329 The fifth factor, “using light in the morning and during daytime”, exhibited low
330 internal consistency both in the exploratory and confirmatory factor analysis (EFA: 0.62;
331 CFA:0.52). Since, it was above .50, considering the developmental phase of this
332 inventory we accepted the fifth factor. This particular factor captures our behaviour
333 related to usages of light in the morning and daytime. Since, light exposure during
334 morning and daytime influences our alertness and cognition (Lok, Smolders, Beersma, &
335 de Kort, 2018; Siraji, Kalavally, Schaefer, & Haque, 2021), we deemed capturing these
336 behaviours is essential for the sake of completeness of our inventory. However, the
337 possibility of improving the reliability should be investigated further by adding more
338 appropriate and relevant items to this factor.

339 The habitual patterns queried in the developed inventory might not exhaustively
340 represent all relevant light-exposure-related behaviours. For instance, it is conceivable
341 that additional light-related activities not included in the LEBA depend on the
342 respondents’ profession/occupation, geographical context, and socio-economic status.
343 However, we generated the initial item pool with an international team of researchers
344 and followed a thorough psychometric analysis. Therefore, we are confident that the
345 developed LEBA inventory can serve as a good starting point for exploring the light
346 exposure related behaviours in more depth and inform room for modification of light
347 exposure-related behaviour to improve light hygiene.

348 As with all studies relying on retrospective self-report data, individuals filling in the

349 LEBA may have difficulties precisely recalling the inquired light-related behaviours. In
350 the interest of bypassing a substantial memory component, we limited the recall period
351 to four weeks and chose response options that do not require exact memory recall. In
352 contrast to directly assessing light properties via self-report, we assume that reporting
353 behaviours might be more manageable for inexperienced laypeople, as the latter does
354 not rely on existing knowledge about light sources. The comprehensibility of the LEBA is
355 also reflected by the Flesch-Kincaid grade level identification method (Flesch, 1948) that
356 suggested a minimum age of 8.33 years and an educational grade of four or higher (US
357 grading system). We argue that measuring light-related behaviours via self-report is
358 crucial because these behaviours will hardly be as observable by anyone else or
359 measurable with other methods (like behavioural observations) with reasonable effort.

360 It is important to note that LEBA utilizes a five-point Likert-type response scale
361 which may be susceptible to central tendency bias, i.e. responses are biased towards
362 the central value of the response scale. Future work should evaluate other methods of
363 obtaining responses, such as using a visual-analogue scale.

364 Finally, there is limited evidence for convergent validity. LEBA being the first of its
365 kind in characterising light exposure *behaviour* at present lacks a gold standard against
366 which its convergent validity evidence could be established. A recent study (Siraji,
367 Spitschan, Kalavally, & Haque, 2023) demonstrated the predictive validity of LEBA by
368 successfully relating its factors to self-reported chronotype, mood, sleep quality, and
369 cognitive function. The results of their study confirmed that light-related behaviours, as
370 captured by LEBA, could lead to different light exposure experiences that differentially
371 influence health, wellness and performance. Further work will need to establish
372 convergent validity of LEBA further.

373 Future directions

374 To our knowledge, the LEBA is the first inventory characterising light
375 exposure-related behaviour in a scalable manner. Further evidence for the validity of the
376 LEBA could be obtained by administering it conjointly with objective field measurements
377 of light exposure (e.g. with portable light loggers/wearables), smartphone readouts, as
378 well as subjective data in the form of 24-hour recalls. Such a study could relate the
379 relationship between (subjectively measured) light exposure-related behavioural patterns
380 translate into (objectively measured) received light exposure, smartphone use, and how
381 closely the retrospective questionnaire relates to daily reports of these behaviours.

382 Conclusion

383 Here, we developed a novel, internally consistent and structurally valid 23-item
384 self-report inventory for capturing light exposure-related behaviour in five scalable
385 factors. In addition, an 18-item short-form of the LEBA was derived using IRT analysis,
386 yielding adequate coverage across the underlying trait continuum. Applying the LEBA
387 inventory can provide insights into light exposure-related habits on a population-based
388 level. Furthermore, it can serve as a good starting point to profile individuals based on
389 their light exposure-related behaviour and to assess their light consumption and timing.

390 Methods**391 Data collection**

392 A quantitative cross-sectional, fully anonymous, geographically unconstrained
393 online survey was conducted via REDCap (Harris et al., 2019, 2009) by way of the
394 University of Basel sciCORE. Participants were recruited via the website
395 (<https://enlightenyourclock.org/participate-in-research>) of the science-communication

396 comic book “Enlighten your clock”, co-released with the survey (Weinzaepflen &
397 Spitschan, 2021), social media (i.e., LinkedIn, Twitter, Facebook), mailing lists, word of
398 mouth, the investigators’ personal contacts, and supported by the distribution of the
399 survey link via f.lux (F.lux Software LLC, 2021). The initial page of the online survey
400 provided information about the study, including that participation was voluntary and that
401 respondents could withdraw from participation at any time without being penalised.
402 Subsequently, consent was recorded digitally for the adult participants (>18 years), while
403 under-aged participants (<18 years) were prompted to obtain additional assent from their
404 parents/legal guardians. Filling in all questionnaires was estimated to take less than 30
405 minutes, and participation was not compensated.

406 As a part of the demographic data, participants provided information regarding age,
407 sex, gender identity, occupational status, COVID-19-related occupational setting, time
408 zone/country of residence and native language. The demographic characteristics of our
409 sample are given in Table 1. Participants were further asked to confirm that they
410 participated in the survey for the first time. All questions incorporating retrospective
411 recall were aligned to a “past four weeks” period. Additionally, four attention check items
412 were included among the questionnaires to ensure high data quality, with the following
413 phrasing: - We want to make sure you are paying attention. What is 4+5? - [...] Please
414 select “Strongly disagree” here. - [...] Please type in “nineteen” as a number. - [...]
415 Please select “Does not apply/I don’t know.” here.

416 Analytic strategy

417 Figure 6 summarises the steps we followed while developing the LEBA. We
418 conducted all analyses with the statistical software environment R.

419 (1) We set an item pool of 48 items with a six-point Likert-type response format
420 (0-Does not apply/I don’t know, 1-Never, 2-Rarely 3-Sometimes, 4-Often,

421 5-Always) for our initial inventory. Our purpose was to capture light
422 exposure-related behaviour. In that context, the first two response options: “Does
423 not apply/I don’t know” and “Never”, provided similar information. As such, we
424 collapsed them into one, making it a 5-point Likert-type response format (1-Never,
425 2-Rarely, 3-Sometimes, 4-Often, 5-Always).

426 (2) Two rounds of data collection were administered. In the first round (EFA sample;
427 n=428) we collected data for the exploratory factor analysis (EFA). A sample of at
428 least 250-300 is recommended for EFA (Comrey & Lee, 2013; Schönbrodt &
429 Perugini, 2013). The EFA sample exceeded this recommendation. The second
430 round data (CFA sample; n=262) was subjected to confirmatory factor analysis
431 (CFA). To assess sampling adequacy for CFA, we followed the N:q rule (Bentler &
432 Chou, 1987; Jackson, 2003; Kline, 2016; Worthington & Whittaker, 2006), where at
433 least ten participants per item are required to earn trustworthiness of the result.
434 Again, our CFA sample exceeded this guidelines.

435 (3) We conducted descriptive and item analyses and proceeded to EFA on the EFA
436 sample. Prior to the EFA, the necessary assumptions, including sample adequacy,
437 normality assumptions, and quality of correlation matrix, were assessed. As our
438 data violated both the univariate and multivariate normality assumption and yielded
439 ordinal response data, we used a polychoric correlation matrix in the EFA and
440 employed “principal axis” (PA) as the factor extraction method (Desjardins & Bulut,
441 2018; Watkins, 2020). We applied a combination of methods, including a Scree
442 plot (Cattell, 1966), minimum average partials method (Velicer, 1976), and Hull
443 method (Lorenzo-Seva et al., 2011) to identify factor numbers. To determine the
444 latent structure, we followed the common guidelines: (i) no factors with fewer than
445 three items (ii) no factors with a factor loading <0.3 (iii) no items with cross-loading
446 > .3 across factors (Bandalos & Finney, 2018).

Though Cronbach's internal consistency coefficient alpha is widely used for estimating internal consistency, it tends to deflate the estimates for Likert-type data since the calculation is based on the Pearson-correlation matrix, which requires response data to be continuous in nature (Gadermann, Guhn, & Zumbo, 2012; Zumbo, Gadermann, & Zeisser, 2007). Subsequently, we reported ordinal alpha for each factor obtained in the EFA which was suggested as a better reliability estimates for ordinal data (Zumbo et al., 2007). We also estimated the internal consistency reliability of the total inventory using McDonald's ω_t coefficient, which was suggested as a better reliability estimate for multidimensional constructs (Dunn, Baguley, & Brunsden, 2014; Sijtsma, 2009). Both ordinal alpha and McDonald's ω_t coefficient values range between 0 to 1, where higher values represent better reliability.

To validate the latent structure obtained in the EFA, we conducted a categorical confirmatory factor analysis (CFA) with the weighted least squares means and variance adjusted (WLSMV) estimation (Desjardins & Bulut, 2018) on the CFA sample. We assessed the model fit using standard model fit guidelines: (i) χ^2 test statistics: a non-significant test statistics is required to accept the model (ii) comparative fit index (CFI) and Tucker Lewis index (TLI): close to 0.95 or above/ between 0.90-0.95 and above (iii) root mean square error of approximation (RMSEA): close to 0.06 or below, (iv) Standardized root mean square (SRMR): close to 0.08 or below (Hu & Bentle, 1999; Schumacker & Lomax, 2004). However, the χ^2 test is sensitive to sample size (T. A. Brown, 2015), and SRMR does not work well with ordinal data (Yu, 2002). Consequently, we judged the model fit using CFI, TLI and RMSEA.

In order to evaluate whether the construct demonstrated psychometric equivalence and the same meaning across native English speakers ($n=129$) and non-native English speakers ($n=133$) in the CFA sample ($n=262$) (Kline, 2016; Putnick & Bornstein, 2016) measurement invariance analysis was used. We used structural equation modelling framework to assess the measurement invariance. We successively compared four

474 nested models: configural, metric, scalar, and residual models using the χ^2 difference
475 test ($\Delta\chi^2$). Among MI models, the configural model is the least restrictive, and the
476 residual model is the most restrictive. A non-significant $\Delta\chi^2$ test between two nested
477 measurement invariance models indicates mode fit does not significantly decrease for
478 the superior model, thus allowing the superior invariance model to be accepted
479 (Dimitrov, 2010; Widaman & Reise, 1997).

480 (4) In a secondary analysis, we identified the educational grade level (US education
481 system) required to understand the items in our inventory with the Flesch-Kincaid
482 grade level identification method (Flesch, 1948). Correspondingly, we analysed
483 possible semantic overlap of our developed inventory using the “Semantic Scale
484 Network” (SSN) engine (Rosenbusch et al., 2020). The SSN detects semantically
485 related scales and provides a cosine similarity index ranging between -.66 to 1
486 (Rosenbusch et al., 2020). Pairs of scales with a cosine similarity index value of 1
487 indicate full semantical similarity, suggesting redundancy.

488 (5) We derived a short form of the LEBA employing an Item Response Theory (IRT)
489 based analysis. We fitted each factor of the LEBA to the combined EFA and CFA
490 sample (n=690) using the graded response model (Samejima et al., 1997). IRT
491 assesses the item quality by estimating the item discrimination, item difficulty, item
492 information curve, and test information curve (Baker & Kim, 2017). Item
493 discrimination indicates how well a particular item can differentiate between
494 participants across the given latent trait continuum (θ). Item difficulty corresponds
495 to the latent trait level at which the probability of endorsing a particular response
496 option is 50%. The item information curve (IIC) indicates the amount of information
497 an item carries along the latent trait continuum. Here, we reported the item
498 difficulty and discrimination parameter and categorized the items based on their
499 item discrimination index: (i) none=0; (ii) very low=0.01 to 0.34; (iii) low=0.35 to

500 0.64; (iv) moderate=0.65 to 1.34 ; (v) high=1.35 to 1.69; (vi) very high >1.70 (Baker
501 & Kim, 2017). We discarded the items with a relatively flat item information curve
502 (information <.2) to derive the short form of LEBA. We also assessed the precision
503 of the short LEBA utilizing the test information curve (TIC). TIC indicates the
504 amount of information a particular scale carries along the latent trait continuum.
505 Additionally, the item and person fit of the fitted IRT models were analysed to
506 gather more evidence on the validity and meaningfulness of our scale (Desjardins
507 & Bulut, 2018). The item fit was evaluated using the RMSEA value obtained from
508 Signed- χ^2 index implementation, where an RMSEA value $\leq .06$ was considered
509 an adequate item fit. The person fit was estimated employing the standardized fit
510 index Z_h statistics (Drasgow, Levine, & Williams, 1985). Here, $Z_h < -2$ was
511 considered as a misfit (Drasgow et al., 1985).

512 Ethical approval

513 The current research project utilizes fully anonymous online survey data and
514 therefore does not fall under the scope of the Human Research Act, making an
515 authorisation from the ethics committee redundant. Nevertheless, the cantonal ethics
516 commission (Ethikkommission Nordwest- und Zentralschweiz, EKNZ) reviewed our
517 proposition (project ID Req-2021-00488) and issued an official clarification of
518 responsibility.

519 Code, materials and data availability

520 The present article is a fully reproducible open access “R Markdown” document. All
521 code and data underlying this article is available on a public GitHub repository. The
522 English version of long and short form of LEBA inventory and online survey
523 implementation templates on common survey platforms (Qualtrics and REDCap) – is

- ⁵²⁴ available on another public GitHub repository as well as on the dedicated website of the
⁵²⁵ LEBA inventory under an open-access licence (Creative Commons CC-BY-NC-ND).

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Table 1

Demographic Characteristics of Participants (n=690).

Variable	Overall, N = 690	1. EFA Sample, N = 428	2. CFA Sample, N = 262
Age	32.95 (14.57)	32.99 (15.11)	32.89 (13.66)
Sex			
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%)
Native English Speaker	320 (46%)	191 (45%)	129 (49%)
Occupational Status			
Work	396 (57%)	235 (55%)	161 (61%)
School	174 (25%)	122 (29%)	52 (20%)
Neither	120 (17%)	71 (17%)	49 (19%)
Occupational setting			
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 (%)

Table 2

Factor loadings and communality of the retained items in EFA using principal axis extraction method (n=482).

item	Stem	PA1	PA2	PA3	PA4	PA5	Communality
item16	I wear blue-filtering, orange-tinted, and/or red-tinted glasses indoors during the day.	0.99					0.99
item36	I wear blue-filtering, orange-tinted, and/or red-tinted glasses within 1 hour before attempting to fall asleep.	0.94					0.90
item17	I wear blue-filtering, orange-tinted, and/or red-tinted glasses outdoors during the day.	0.8					0.66
item11	I spend more than 3 hours per day (in total) outside.		0.79				0.64
item10	I spend between 1 and 3 hours per day (in total) outside.		0.76				0.59
item12	I spend as much time outside as possible.		0.65				0.47
item07	I go for a walk or exercise outside within 2 hours after waking up.		0.5				0.27
item08	I spend 30 minutes or less per day (in total) outside.		-0.49				0.25
item09	I spend between 30 minutes and 1 hour per day (in total) outside.		0.32				0.11
item27	I use my mobile phone within 1 hour before attempting to fall asleep.		0.8				0.66
item03	I look at my mobile phone screen immediately after waking up.		0.8				0.68
item40	I check my phone when I wake up at night.		0.65				0.46
item30	I look at my smartwatch within 1 hour before attempting to fall asleep.		0.45				0.35
item41	I look at my smartwatch when I wake up at night.		0.36				0.33

Table 2 continued

item	Stem	PA1	PA2	PA3	PA4	PA5	Communality
item33	I dim my computer screen within 1 hour before attempting to fall asleep.				0.74		0.56
item32	I dim my mobile phone screen within 1 hour before attempting to fall asleep.				0.73		0.62
item35	I use a blue-filter app on my computer screen within 1 hour before attempting to fall asleep.				0.66		0.45
item37	I purposely leave a light on in my sleep environment while sleeping.				-0.39		0.17
item38	I use as little light as possible when I get up during the night.				0.38		0.18
item46	I use tunable lights to create a healthy light environment.				0.6		0.42
item45	I use LEDs to create a healthy light environment.				0.59		0.37
item25	I use a desk lamp when I do focused work.				0.41		0.19
item04	I use an alarm with a dawn simulation light.				0.41		0.22
item01	I turn on the lights immediately after waking up.				0.4		0.17
item26	I turn on my ceiling room light when it is light outside.				0.35		0.16

Note. Only loading > .30 is reported.

Table 3

*Confirmatory Factor Analysis model fit indices of the two model: (a) Model 1: five factor model with 25 items
 (b) Model 2: five factor model with 23 items. Model 2 attained the best fit.*

Model	χ^2	df	CFI	TLI	RMSEA	RMSEA 90% Lower CI	RMSEA 90% Upper CI	SRMR
1	675.55	267.00	0.92	0.91	0.07	0.06	0.07	0.12
2	561.25	231.00	0.95	0.95	0.07	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 4

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

	χ^2	df	CFI	TLI	RMSEA	RMSEA 90% Lower CI	RMSEA 90% Upper	$\Delta \chi^2$	Δdf^*	p
Configural	632.20	442.00	0.95	0.94	0.06	0.05	0.07	-	-	-
Metric	643.06	458.00	0.95	0.95	0.06	0.04	0.07	18.254a	16	0.309
Scalar	711.87	522.00	0.95	0.95	0.05	0.04	0.06	68.221b	64	0.336
Residual	711.87	522.00	0.95	0.95	0.05	0.04	0.06	0c	0	NA

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

Summary Descriptives (n=690)											
Items 01-24											
Items	Item Stem	Summary Statistics			Graphics		Response Pattern				
		Mean	SD	SW ⁷	Histogram	Density	Never	Rarely	Sometimes	Often	Always
●item01	I turn on the lights immediately after waking up.	2.3	1.4	0.82*			41.59% (287)	22.32% (154)	13.33% (92)	11.74% (81)	11.01% (76)
●item02	I open the curtains or blinds immediately after waking up.	2.8	1.6	0.84*			32.61% (225)	15.22% (105)	11.30% (78)	19.28% (133)	21.59% (149)
●item03	I look at my mobile phone screen immediately after waking up.	3.5	1.4	0.86*			14.35% (99)	9.86% (68)	17.39% (120)	30.00% (207)	28.41% (196)
●item04	I use an alarm with a dawn simulation light.	1.4	1.1	0.40*			86.09% (594)	3.04% (21)	2.61% (18)	2.46% (17)	5.80% (40)
●item05	I have breakfast within 3 meters from a window.	3.9	1.4	0.74*			14.35% (99)	4.78% (33)	11.01% (76)	18.26% (126)	51.59% (356)
●item06	I have breakfast in a brightly lit room (illuminated by electric light).	2.7	1.5	0.85*			33.19% (229)	15.36% (106)	16.38% (113)	16.09% (111)	18.99% (131)
●item07	I go for a walk or exercise outside within 2 hours after waking up.	2.2	1.2	0.84*			38.70% (267)	26.23% (181)	16.23% (112)	13.04% (90)	5.80% (40)
●item08	I spend 30 minutes or less per day (in total) outside.	3.0	1.2	0.91*			13.91% (96)	22.46% (155)	25.22% (174)	28.26% (195)	10.14% (70)
●item09	I spend between 30 minutes and 1 hour per day (in total) outside.	2.9	1.0	0.91*			11.30% (78)	20.58% (142)	38.99% (269)	23.91% (165)	5.22% (36)
●item10	I spend between 1 and 3 hours per day (in total) outside.	2.7	1.1	0.91*			14.06% (97)	30.58% (211)	30.43% (210)	21.74% (150)	3.19% (22)
●item11	I spend more than 3 hours per day (in total) outside.	2.2	0.9	0.86*			23.77% (164)	46.38% (320)	22.03% (152)	6.38% (44)	1.45% (10)
●item12	I spend as much time outside as possible.	2.3	1.2	0.87*			30.72% (212)	30.14% (208)	20.58% (142)	11.88% (82)	6.67% (46)
●item13	I use sunglasses when I go outside in bright daylight.	2.7	1.5	0.87*			30.14% (208)	17.54% (121)	17.83% (123)	18.70% (129)	15.80% (109)
●item14	I wear a visor or cap when I go outside in bright daylight.	2.1	1.3	0.79*			47.54% (328)	18.84% (130)	12.90% (89)	15.22% (105)	5.51% (38)
●item15	I seek shade when I am outside in bright daylight.	3.3	1.1	0.91*			7.97% (55)	13.91% (96)	35.36% (244)	27.97% (193)	14.78% (102)
●item16	I wear blue-filtering, orange-tinted, and/or red-tinted glasses indoors during the day.	1.6	1.3	0.51*			79.13% (546)	3.91% (27)	4.06% (28)	5.07% (35)	7.83% (54)
●item17	I wear blue-filtering, orange-tinted, and/or red-tinted glasses outdoors during the day.	1.5	1.2	0.49*			80.43% (555)	3.33% (23)	5.22% (36)	3.04% (21)	7.97% (55)
●item18	I use light therapy applying a white light box.	1.1	0.5	0.27*			92.90% (641)	3.48% (24)	2.75% (19)	0.58% (4)	0.29% (2)
●item19	I use light therapy applying a blue light box.	1.0	0.3	0.12*			97.68% (674)	0.87% (6)	0.72% (5)	0.72% (5)	0.00% (0)
●item20	I use light therapy applying a light visor.	1.0	0.3	0.08*			98.70% (681)	0.14% (1)	0.58% (4)	0.43% (3)	0.14% (1)
●item21	I use light therapy applying another form of light device.	1.1	0.6	0.24*			94.06% (649)	1.45% (10)	3.04% (21)	0.58% (4)	0.87% (6)
●item22	I spend most of my daytime in a brightly lit environment.	3.5	1.1	0.88*			5.36% (37)	13.33% (92)	21.74% (150)	41.59% (287)	17.97% (124)
●item23	I close the curtains or blinds during the day if the light from outside is bright.	2.6	1.3	0.89*			26.38% (182)	24.93% (172)	23.33% (161)	17.25% (119)	8.12% (56)
●item24	I spend most of my indoor time within 3 meters from a window.	4.1	1.0	0.79*			2.90% (20)	5.65% (39)	11.45% (79)	37.83% (261)	42.17% (291)

⁷ Shapiro-Wilk test

Figure 1. Summary descriptives and response pattern observed in the large-scale survey for item 01-24. All items violated normality assumption.

Summary Descriptives (n=690)

Items 25-48

LEBA Items	Stem	Summary Statistics			Graphics		Response Pattern				
		Mean	SD	SW ¹	Histogram	Density	Never	Rarely	Sometimes	Often	Always
●item25	I use a desk lamp when I do focused work.	2.6	1.4	0.86*			33.77% (233)	15.51% (107)	22.03% (152)	17.54% (121)	11.16% (77)
●item26	I turn on my ceiling room light when it is light outside.	3.7	1.3	0.85*			37.54% (259)	22.03% (152)	20.58% (142)	12.17% (84)	7.68% (53)
●item27	I use my mobile phone within 1 hour before attempting to fall asleep.	3.9	1.3	0.80*			7.54% (52)	9.71% (67)	10.00% (69)	31.59% (218)	41.16% (284)
●item28	I use my computer/laptop/tablet within 1 hour before attempting to fall asleep.	3.7	1.2	0.87*			5.07% (35)	13.19% (91)	17.39% (120)	35.36% (244)	28.99% (200)
●item29	I watch television within 1 hour before attempting to fall asleep.	2.5	1.3	0.87*			33.04% (228)	18.12% (125)	20.29% (140)	20.72% (143)	7.83% (54)
●item30	I look at my smartwatch within 1 hour before attempting to fall asleep.	1.5	1.1	0.47*			82.46% (569)	3.04% (21)	4.64% (32)	5.65% (39)	4.20% (29)
●item31	I dim my room light within 1 hour before attempting to fall asleep.	3.0	1.6	0.83*			31.30% (216)	10.43% (72)	12.03% (83)	20.14% (139)	26.09% (180)
●item32	I dim my mobile phone screen within 1 hour before attempting to fall asleep.	3.5	1.6	0.76*			24.20% (167)	5.94% (41)	9.42% (65)	15.65% (108)	44.78% (309)
●item33	I dim my computer screen within 1 hour before attempting to fall asleep.	3.4	1.7	0.77*			25.94% (179)	6.67% (46)	8.99% (62)	14.35% (99)	44.06% (304)
●item34	I use a blue-filter app on my mobile phone screen within 1 hour before attempting to fall asleep.	3.4	1.8	0.70*			34.06% (235)	2.90% (20)	4.20% (29)	7.83% (54)	51.01% (352)
●item35	I use a blue-filter app on my computer screen within 1 hour before attempting to fall asleep.	3.8	1.7	0.67*			24.64% (170)	2.17% (15)	5.07% (35)	8.26% (57)	59.86% (413)
●item36	I wear blue-filtering, orange-tinted, and/or red-tinted glasses within 1 hour before attempting to fall asleep.	1.6	1.3	0.47*			81.59% (563)	3.19% (22)	3.04% (21)	2.75% (19)	9.42% (65)
●item37	I purposely leave a light on in my sleep environment while sleeping.	2.3	1.3	0.44*			37.54% (259)	22.03% (152)	20.58% (142)	12.17% (84)	7.68% (53)
●item38	I use as little light as possible when I get up during the night.	4.3	1.1	0.68*			4.93% (34)	5.07% (35)	5.80% (40)	25.22% (174)	58.99% (407)
●item39	I turn on the lights when I get up during the night.	2.0	1.1	0.82*			37.97% (262)	37.10% (256)	14.78% (102)	6.52% (45)	3.62% (25)
●item40	I check my phone when I wake up at night.	2.3	1.3	0.85*			36.23% (250)	25.80% (178)	19.28% (133)	11.74% (81)	6.96% (48)
●item41	I look at my smartwatch when I wake up at night.	1.3	0.8	0.39*			86.96% (600)	4.35% (30)	4.64% (32)	2.90% (20)	1.16% (8)
●item42	I close curtains or blinds to prevent light from entering the bedroom if I want to sleep.	4.0	1.4	0.70*			13.62% (94)	5.07% (35)	8.41% (58)	15.51% (107)	57.39% (396)
●item43	I use a sleep mask that covers my eyes.	1.7	1.2	0.62*			69.86% (482)	9.28% (64)	10.00% (69)	4.20% (29)	6.67% (46)
●item44	I modify my light environment to match my current needs.	3.4	1.3	0.86*			14.49% (100)	7.68% (53)	20.29% (140)	34.93% (241)	22.61% (156)
●item45	I use LEDs to create a healthy light environment.	2.1	1.5	0.74*			57.25% (395)	6.38% (44)	13.77% (95)	11.88% (82)	10.72% (74)
●item46	I use tunable lights to create a healthy light environment.	1.7	1.2	0.63*			70.29% (485)	5.80% (40)	10.29% (71)	9.13% (63)	4.49% (31)
●item47	I discuss the effects of light on my body with other people.	2.1	1.2	0.84*			40.43% (279)	24.06% (166)	21.30% (147)	9.57% (66)	4.64% (32)
●item48	I seek out knowledge on how to improve my light exposure.	2.5	1.3	0.89*			26.81% (185)	23.33% (161)	28.12% (194)	12.46% (86)	9.28% (64)

¹ Shapiro-Wilk test

Figure 2. Summary descriptives and response pattern observed in the large-scale survey for item 25-48. All items violated normality assumption.

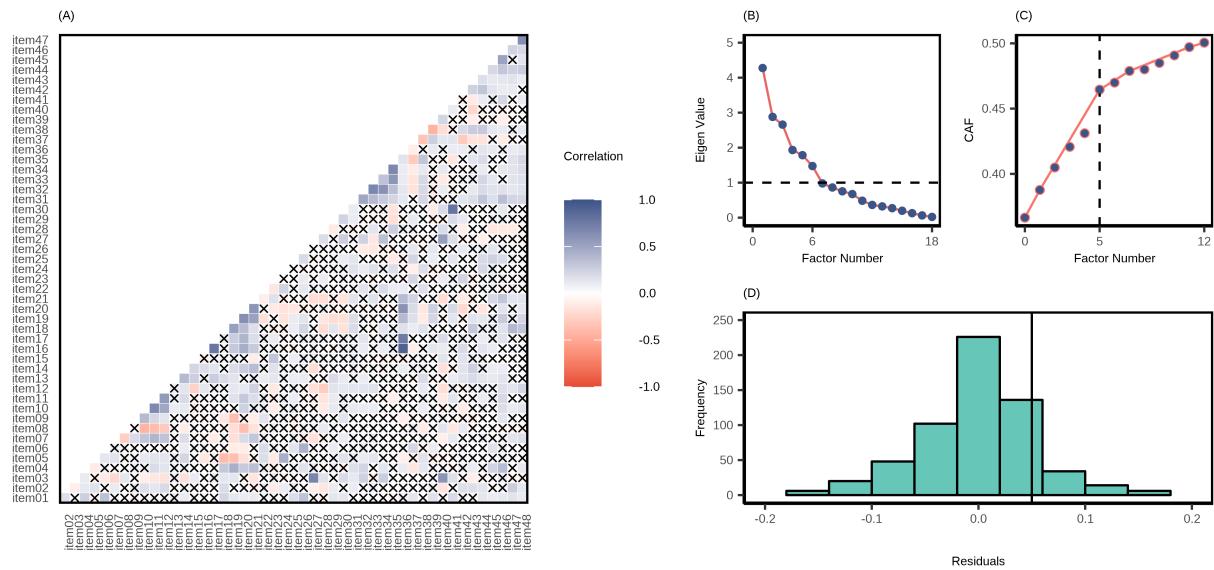


Figure 3. (A) Inter-item polychoric correlation coefficients for the 48 items. 4.9 % inter-item correlation coefficients were higher than $|.30|$. 'x' denotes non-significant correlation. (B) The Scree plot suggested six factors. (C) Hull method indicated that five factors were required to balance the model fit and number of parameters. (D) The histogram of nonredundant residual correlations in the five-factor model indicated that 26% of inter-item correlations were higher than .05, hinting at a possible under-factoring.



Figure 4. Five factor model of LEBA obtained by confirmatory factor analysis. By allowing item pair 41 and 30 to co-vary their error variance our model attained the best fit.

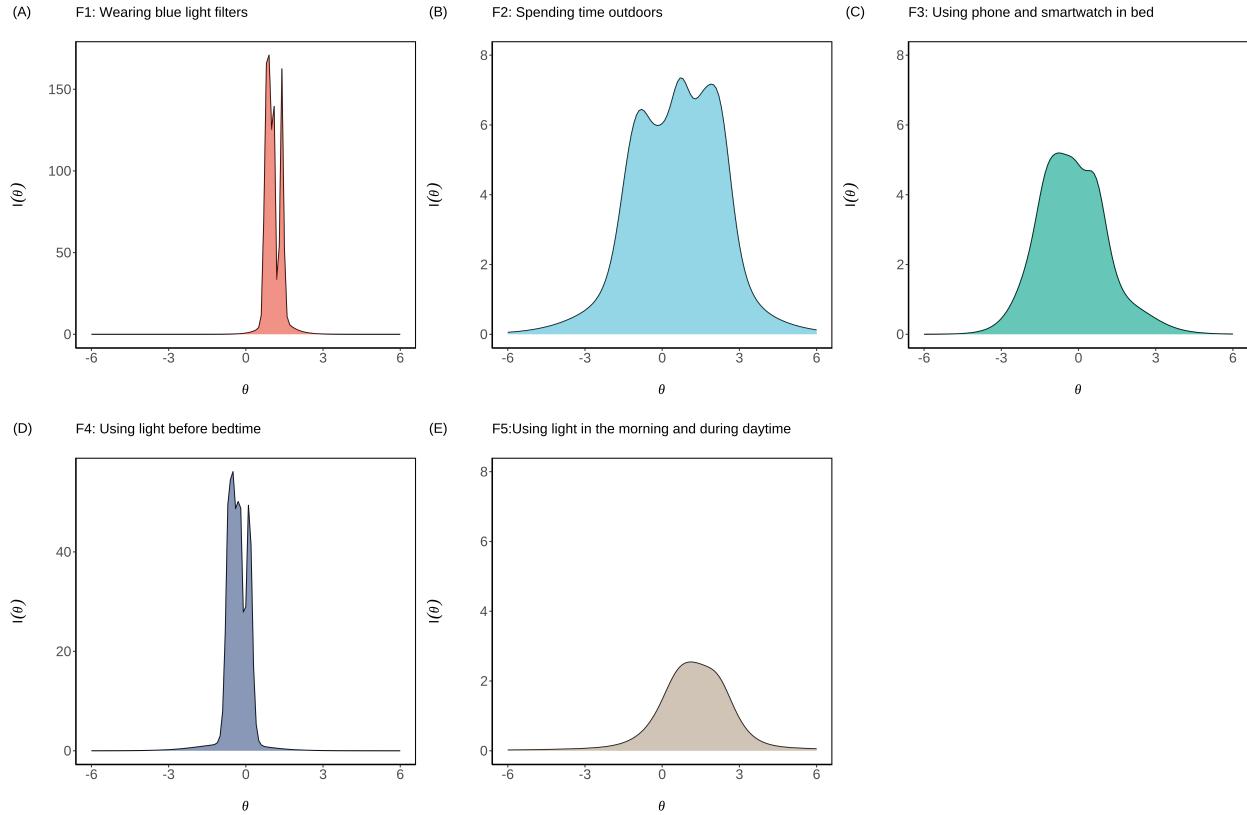


Figure 5. Test information curves for the five factors of LEBA: (A) wearing blue light filters (B) spending time outdoors (C) using a phone and smartwatch in bed (D) using light before bedtime (E) using light in the morning and during daytime. Along the x-axis, we plotted the underlying latent trait continuum for each factor. Along the y-axis, we plotted how much information a particular factor is carrying across its latent trait continuum

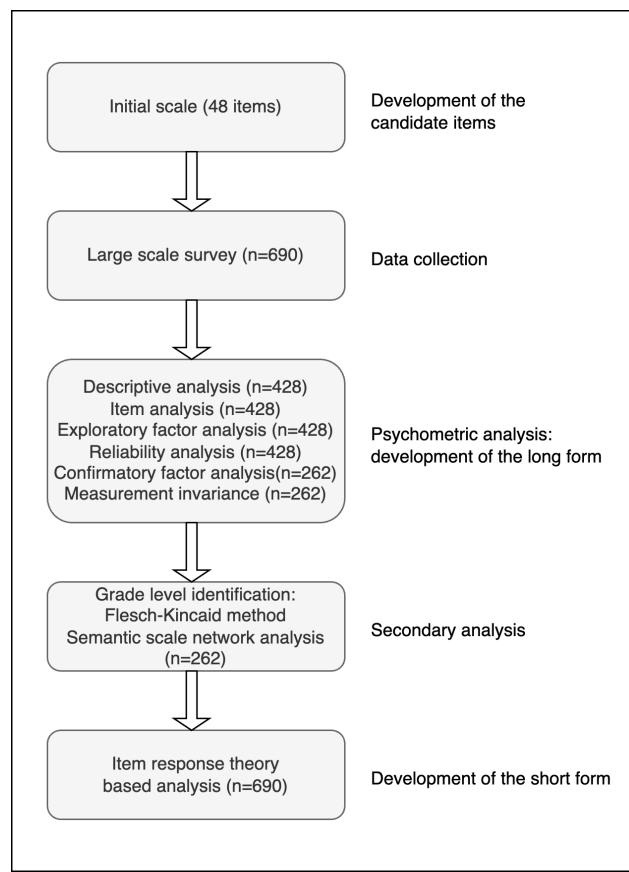


Figure 6. Flow chart of the LEBA (long and short form) development and evaluation.

Supplementary File 1
Light Exposure Behaviour Assessment (LEBA): Long Form

Instructions to Participant

Please indicate how often you performed the following behaviours in the **past four weeks**

	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. <i>(Reverse-scored)</i>					
05	I spend between 30 minutes and 1 hour per day (in total) outside.					
06	I spend between 1 and 3 hours 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.					
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.					

LEBA: Supplementary Materials

Scoring

(Note: R = reverse-scored item)

LEBA captures light exposure-related behaviours on a 5-point Likert-type scale ranging from 1 to 5 (1 = never; 2 = rarely; 3 = sometimes; 4 = often; 5 = always; for reversed-scored item: 1 = always; 2 = often; 3 = sometimes; 4 = rarely; 5 = never). The score of each factor is calculated by using the mean score of the corresponding items.

Factor Name	Score
F1: Wearing blue light filters	Mean score of items 01, 02, 03
F2: Spending time outdoors	Mean score of items 04(R), 05, 06, 07, 08, 09
F3: Using phone and smartwatch in bed	Mean score of items 10, 11, 12, 13, 14
F4: Using light before bedtime	Mean score of items 15, 16, 17, 18
F5: Using light in the morning and during daytime	Mean score of items 19, 20, 21, 22, 23

Supplementary File 2
Light Exposure Behaviour Assessment (LEBA): Short Form

Instructions to Participant

Please indicate how often you performed the following behaviours in the **past four weeks**.

	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. <i>(Reverse-scored)</i>					
05	I spend between 30 minutes and 1 hour per day (in total) outside.					
06	I spend between 1 and 3 hours 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.					
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.					
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.					
20	I use LEDs to create a healthy light environment.					
22	I use an alarm with a dawn simulation light.					

LEBA: Supplementary Materials

Scoring

(Note: R = reverse-scored item)

LEBA captures light exposure-related behaviours on a 5-point Likert-type scale ranging from 1 to 5 (1 = never; 2 = rarely; 3 = sometimes; 4 = often; 5 = always; for reversed-scored item: 1 = always; 2 = often; 3 = sometimes; 4 = rarely; 5 = never). The score of each factor is calculated by using the mean score of the corresponding items.

Factor Name	Score
F1: Wearing blue light filters	Mean score of items 01, 02, 03
F2: Spending time outdoors	Mean score of items 04(R), 05, 06, 07, 08, 09
F3: Using phone and smartwatch in bed	Mean score of items 10, 11, 12
F4: Using light before bedtime	Mean score of items 15, 16, 18
F5: Using light in the morning and during daytime	Mean score of items 19, 20, 22

Supplementary Tables**Supplementary Table 1**

List of instruments measuring related constructs to LEBA.

Name	Number of all items	Description	Relevant items	Scale type
Visual Light Sensitivity Questionnaire-8 (Verriotto et al., 2017)	8	To assess the presence and severity of photosensitivity symptoms	None	5-point Likert scale
Office Light Survey (Eklund & Boyce, 1996)	30	To assess electrical lighting environment in office	Item 29	Mixed response format
Harvard Light Exposure Assessment Questionnaire (Bajaj et al., 2011)	1	To assess an individual's daily light exposure	None	Semi-quantitative
Hospital Lighting Survey (Dianat et al., 2013)	23	To assess light environment in a hospital	Items 16, 17	5-point Likert scale
Morningness-Eveningness Questionnaire (Horne & Ostberg, 1976)	19	To assess an individual's chronotype	items 1, 2, 8, 13, 14	Mixed response format
Munich Chronotype Questionnaire (Roenneberg et al., 2003)	17	To understand an individual's phase of entrainment	Time spent outdoors	Mixed response format
Sleep Practices and Attitudes Questionnaire (Grandner et al., 2014)	16	To assess practice, behaviour and attitude related to sleep	Activities in bed and sleep environment subscales	5-point Likert scale
The Pittsburgh Sleep Quality Index (Buysse et al., 1989)	9	To assess sleep quality and sleeping pattern	items 1-4	Mixed response format
Self-Rating of Biological Rhythm Disorder for Adolescents (Xie et al., 2022)	29	To assess four dimensions of biological rhythm disorder in adolescents	Items 3, 6, 22-25, 29	5-point Likert scale
Photosensitivity Assessment Questionnaire (PAQ) (Bossini et al., 2006)	16	To assess "photophobia" and "photophilia"	All items	Binary response option

Supplementary Table 2

Geographical location of the participants (n = 690).

	Time zone and country name	Number of Participants
1	Africa/Ceuta (UTC +01:00)	2
2	Africa/Douala (UTC +01:00)	1
3	Africa/Johannesburg (UTC +02:00)	5
4	Africa/Khartoum (UTC +02:00)	2
5	Africa/Lagos (UTC +01:00)	1
6	America/Adak (UTC -09:00)	2
7	America/Anchorage (UTC -08:00)	3
8	America/Araguaina (UTC -03:00)	2
9	America/Argentina/Buenos_Aires (UTC -03:00)	5
10	America/Argentina/Cordoba (UTC -03:00)	2
11	America/Argentina/Jujuy (UTC -03:00)	1
12	America/Bahia (UTC -03:00)	2
13	America/Blanc-Sablon (UTC -04:00)	1
14	America/Bogota (UTC -05:00)	2
15	America/Boise (UTC -06:00)	4
16	America/Cayman (UTC -05:00)	1
17	America/Chicago (UTC -05:00)	30
18	America/Costa_Rica (UTC -06:00)	2
19	America/Cuiaba (UTC -04:00)	1
20	America/Denver (UTC -06:00)	6
21	America/Detroit (UTC -04:00)	6
22	America/Edmonton (UTC -06:00)	14
23	America/Fortaleza (UTC -03:00)	1
24	America/Guatemala (UTC -06:00)	1
25	America/Guayaquil (UTC -05:00)	2
26	America/Halifax (UTC -03:00)	1
27	America/Indiana/Indianapolis (UTC -04:00)	3
28	America/Indiana/Tell_City (UTC -05:00)	1
29	America/Kentucky/Louisville (UTC -04:00)	3
30	America/Los_Angeles (UTC -07:00)	37
31	America/Martinique (UTC -04:00)	1
32	America/Mexico_City (UTC -06:00)	2
33	America/Moncton (UTC -03:00)	2
34	America/Monterrey (UTC -06:00)	1
35	America/New_York (UTC -04:00)	63
36	America/North_Dakota/Center (UTC -05:00)	1

LEBA: Supplementary Materials

37	America/North_Dakota/New_Salem (UTC -05:00)	1
38	America/Panama (UTC -05:00)	1
39	America/Phoenix (UTC -07:00)	7
40	America/Resolute (UTC -05:00)	1
41	America/Santiago (UTC -03:00)	8
42	America/Sao_Paulo (UTC -03:00)	19
43	America/Toronto (UTC -04:00)	16
44	America/Vancouver (UTC -07:00)	6
45	Antarctica/Macquarie (UTC +11:00)	1
46	Asia /Taipei City (UTC +08:00)	3
47	Asia/Amman (UTC +03:00)	2
48	Asia/Barnaul (UTC +07:00)	1
49	Asia/Dhaka (UTC +06:00)	1
50	Asia/Famagusta (UTC +02:00)	1
51	Asia/Ho_Chi_Minh (UTC +07:00),British - America/Tortola (UTC -04:00)	2
52	Asia/Hong_Kong (UTC +08:00)	2
53	Asia/Jakarta (UTC +07:00)	9
54	Asia/Jerusalem (UTC +02:00)	4
55	Asia/Karachi (UTC +05:00)	1
56	Asia/Kathmandu (UTC +05:45)	2
57	Asia/Kolkata (UTC +05:30)	38
58	Asia/Kuala_Lumpur (UTC +08:00)	7
59	Asia/Kuching (UTC +08:00)	2
60	Asia/Manila (UTC +08:00)	6
61	Asia/Novosibirsk (UTC +07:00)	1
62	Asia/Riyadh (UTC +03:00)	1
63	Asia/Seoul (UTC +09:00)	1
64	Asia/Shanghai (UTC +08:00)	7
65	Asia/Singapore (UTC +08:00)	1
66	Asia/Tokyo (UTC +09:00)	3
67	Asia/Tomsk (UTC +07:00)	1
68	Asia/Ulaanbaatar (UTC +08:00)	1
69	Asia/Vladivostok (UTC +10:00)	1
70	Asia/Yangon (UTC +06:30)	1
71	Asia/Yekaterinburg (UTC +05:00)	1
72	Atlantic/Canary (UTC)	1
73	Australia/Adelaide (UTC +10:30)	2
74	Australia/Brisbane (UTC +10:00)	4
75	Australia/Darwin (UTC +09:30)	1
76	Australia/Melbourne (UTC +11:00)	5
77	Australia/Perth (UTC +08:00)	2
78	Australia/Sydney (UTC +11:00)	2

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79	East Africa/Dodoma (UTC +03:00)	1
80	Europe/Amsterdam (UTC +01:00)	19
81	Europe/Athens (UTC +02:00)	3
82	Europe/Belgrade (UTC +01:00)	3
83	Europe/Berlin (UTC +01:00)	53
84	Europe/Bratislava (UTC +01:00)	2
85	Europe/Brussels (UTC +01:00)	4
86	Europe/Bucharest (UTC +02:00)	3
87	Europe/Budapest (UTC +01:00)	2
88	Europe/Busingen (UTC +01:00)	3
89	Europe/Copenhagen (UTC +01:00)	3
90	Europe/Dublin (UTC)	5
91	Europe/Helsinki (UTC +02:00)	9
92	Europe/Istanbul (UTC +03:00)	6
93	Europe/Kiev (UTC +02:00)	1
94	Europe/Lisbon (UTC)	2
95	Europe/Ljubljana (UTC +01:00)	3
96	Europe/London (UTC)	57
97	Europe/Madrid (UTC +01:00)	7
98	Europe/Moscow (UTC +03:00)	8
99	Europe/Oslo (UTC +01:00)	3
100	Europe/Paris (UTC +01:00)	22
101	Europe/Prague (UTC +01:00)	3
102	Europe/Riga (UTC +02:00)	2
103	Europe/Rome (UTC +01:00)	9
104	Europe/Sofia (UTC +02:00)	1
105	Europe/Stockholm (UTC +01:00)	4
106	Europe/Tallinn (UTC +02:00)	2
107	Europe/Tirane (UTC +01:00)	1
108	Europe/Vienna (UTC +01:00)	1
109	Europe/Vilnius (UTC +02:00)	5
110	Europe/Warsaw (UTC +01:00)	15
111	Europe/Zagreb (UTC +01:00)	2
112	Europe/Zurich (UTC +01:00)	21
113	European /Skopje (UTC +01:00)	1
114	Iran /Tehran (UTC +0:30)	3
115	Pacific/Auckland (UTC +13:00)	6
116	Pacific/Chatham (UTC +13:45)	1
117	Pacific/Easter (UTC -05:00)	1
118	Pacific/Honolulu (UTC -10:00)	2

Supplementary Table 3.

Minimum average partial (MAP) method of factor number determination. MAP Statistics is the lowest in the 5th row indicating five factors are required.

MAP Statistic ¹	df	χ^2	RMSEA	BIC	SRMR
0.01125	1080	4344.31	0.08	-2199.54	0.09
0.01062	1033	3735.35	0.08	-2523.72	0.08
0.01077	987	3065.44	0.07	-2914.91	0.07
0.01042	942	2661.78	0.07	-3045.92	0.06
0.0093	898	2237.56	0.06	-3203.53	0.06
0.0094	855	2040.02	0.06	-3140.53	0.05
0.0097	813	1861.69	0.05	-3064.37	0.04
0.0100	772	1620.64	0.05	-3057.00	0.04

Note. ¹ Minimum average partial.

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Supplementary Table 4

Factor loadings and communality of the retained in EFA with six factors. One factor emerged with only two items (n = 428).

Items	PA1	PA2	PA3	PA4	PA5	PA6	Communality
Item 16	.99						.01
Item 36	.94						.10
Item 17	.80						.33
Item 11		.82					.30
Item 10		.81					.34
Item 12		.64					.53
Item 08		-.48					.75
Item 07		.47					.74
Item 09		.33					.88
Item 33			.97				.02
Item 32			.77				.31
Item 35			.54				.59
Item 31			.49				.67
Item 03				.84			.27
Item 27				.81			.33
Item 40				.69			.47
Item 46					.65		.48
Item 45					.57		.65
Item 04					.48		.67
Item 25					.40		.76
Item 01					.35		.87
Item 26					.35		.84
Item 37						-.8	.32
Item 38						.39	.76
% Of Variance	11	10	9	9	6	5	-

Note. Only loading higher than .30 is reported.

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Supplementary Table 5

Demographics Characteristics of the native and non-native English Speakers (n = 262).

Variable	Overall ¹ (n = 262)	Native English Speakers ¹ (n = 129)	Non-native English Speakers ¹ (n = 133)
Age	32.89 (13.66)	34.08 (15.32)	31.74 (11.77)
Sex			
Female	136 (52%)	80 (62%)	56 (42%)
Male	121 (46%)	48 (37%)	73 (55%)
Other	5 (1.9%)	1 (.08%)	4 (3.0%)
Occupational Status			
Work	161 (61%)	76 (59%)	85 (64%)
School	52 (20%)	27 (21%)	25 (19%)
Neither	49 (19%)	26 (20%)	23 (17%)
Occupational Setting			
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 (%).

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Supplementary Table 6

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

Items	a	b ₁	b ₂	b ₃	b ₄	Item Discrimination Category
F1: Wearing blue light filters						
Item 16	28.13	0.78	0.90	1.06	1.40	Very High
Item 36	4.49	0.94	1.08	1.23	1.40	Very High
Item 17	2.81	0.97	1.11	1.38	1.62	Very High
F2: Spending time outdoors						
Item 11	3.27	-0.79	0.65	1.54	2.31	Very High
Item 10	3.07	-1.27	-0.09	0.82	2.00	Very High
Item 12	1.72	-0.67	0.44	1.28	2.11	Very High
Item 07	1.09	-0.50	0.73	1.63	2.97	Moderate
Item 08	1.19	-2.26	-0.48	0.64	1.91	Moderate
Item 09	0.91	-2.63	-0.96	1.11	3.49	Moderate
F3: Using phone and smartwatch in bed						
Item 27	2.21	-1.88	-1.19	-0.73	0.30	Very High
Item 03	3.03	-1.24	-0.77	-0.20	0.66	Very High
Item 40	1.55	-0.51	0.46	1.32	2.22	High
Item 30	0.49	3.27	3.74	4.64	6.52	Low
Item 41	0.51	3.87	4.78	6.39	8.91	Low
F4: Using light before bedtime						
Item 32	1.62	-1.03	-0.78	-0.42	0.16	High
Item 35	1.37	-1.09	-0.98	-0.75	-0.40	High
Item 38	0.40	-7.48	-5.56	-4.23	-0.90	Low
Item 33	12.31	-0.66	-0.48	-0.24	0.13	Very High
F5: Using light in the morning and during daytime						
Item 46	2.22	0.68	0.89	1.38	2.17	Very High
Item 45	1.51	0.30	0.55	1.17	1.91	High
Item 25	0.52	-1.37	-0.04	1.89	4.22	Low
Item 04	0.84	2.44	2.80	3.18	3.67	Moderate
Item 01	0.39	-0.91	1.52	3.25	5.53	Low

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

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Supplementary Table 7

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

Items	a	b ₁	b ₂	b ₃	b ₄	Signed χ^2	df	RMSEA	p	Item Discrimination Category
F1: Wearing blue light filters										
Item 16	28.13	0.78	0.90	1.06	1.40	2.02	6	0.00	0.92	Very High
Item 36	4.49	0.94	1.08	1.23	1.40	39.07	13	0.05	0.00	Very High
Item 17	2.81	0.97	1.11	1.38	1.62	25.58	13	0.04	0.02	Very High
F2: Spending time outdoors										
Item 11	3.27	-0.79	0.65	1.54	2.31	55.03	27	0.04	0.00	Very High
Item 10	3.07	-1.27	-0.09	0.82	2.00	53.19	30	0.03	0.01	Very High
Item 12	1.72	-0.67	0.44	1.28	2.11	34.39	42	0.00	0.79	Very High
Item 07	1.09	-0.50	0.73	1.63	2.97	67.45	46	0.03	0.02	Moderate
Item 08	1.19	-2.26	-0.48	0.64	1.91	140.90	46	0.05	0.00	Moderate
Item 09	0.91	-2.63	-0.96	1.11	3.49	131.19	45	0.05	0.00	Moderate
F3: Using phone and smartwatch in bed										
Item 27	2.12	-1.91	-1.21	-0.74	0.31	16.41	11	0.03	0.13	Very High
Item 03	3.24	-1.22	-0.76	-0.20	0.65	15.09	11	0.02	0.18	Very High
Item 40	1.57	-0.50	0.45	1.30	2.20	9.92	9	0.01	0.36	High
F4: Using light before bedtime										
Item 32	1.60	-1.04	-0.79	-0.42	0.16	41.33	15	0.05	0.00	High
Item 35	1.34	-1.10	-0.99	-0.76	-0.41	41.71	14	0.05	0.00	High
Item 33	15.66	-0.66	-0.48	-0.24	0.13	46.89	14	0.06	0.00	Very High
F5: Using light in the morning and during daytime										
Item 46	2.34	0.66	0.88	1.36	2.12	19.00	15	0.02	0.21	Very High
Item 45	1.51	0.30	0.55	1.17	1.91	15.05	15	0.00	0.45	High
Item 25	0.49	-1.45	-0.04	1.99	4.46	31.60	15	0.04	0.01	Low

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

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Supplementary Figures

Light Exposure Behavior Assessment
Summary Descriptives EFA Sample (n =428)

Items	Summary Statistics					Item Total Correlation	Graphics		Response Pattern				
	Mean	SD	Skew	Kurtosis	SW ^a		Histogram	Density	Never	Rarely	Sometimes	Often	Always
● item01	2.27	1.39	0.74	-0.81	0.81*	0.19			42.29% (181)	22.20% (95)	12.62% (54)	12.38% (53)	10.51% (45)
● item02	2.87	1.59	0.08	-1.60	0.83*	0.28			31.78% (136)	15.65% (67)	9.35% (40)	20.09% (86)	23.13% (99)
● item03	3.36	1.38	-0.48	-1.03	0.87*	0.23			15.89% (68)	11.45% (49)	17.29% (74)	31.07% (133)	24.30% (104)
● item04	1.47	1.18	2.38	4.00	0.43*	0.24			84.11% (360)	3.50% (15)	2.10% (9)	2.10% (9)	8.18% (35)
● item05	4.01	1.40	-1.22	0.07	0.70*	0.17			12.85% (55)	3.50% (15)	9.58% (41)	17.52% (75)	56.54% (242)
● item06	2.79	1.55	0.19	-1.48	0.85*	0.13			32.01% (137)	15.42% (66)	15.89% (68)	15.42% (66)	21.26% (91)
● item07	2.26	1.25	0.70	-0.60	0.85*	0.32			35.98% (154)	27.80% (119)	17.29% (74)	12.38% (53)	6.54% (28)
● item08	2.97	1.20	-0.06	-0.94	0.91*	0.25			13.79% (59)	22.20% (95)	27.80% (119)	25.93% (111)	10.28% (44)
● item09	2.94	1.03	-0.12	-0.40	0.91*	0.08			10.28% (44)	19.63% (84)	41.82% (179)	22.43% (96)	5.84% (25)
● item10	2.74	1.04	0.09	-0.74	0.91*	0.42			11.92% (51)	31.31% (134)	31.31% (134)	21.96% (94)	3.50% (15)
● item11	2.18	0.90	0.60	0.12	0.86*	0.41			22.43% (96)	46.26% (198)	23.13% (99)	7.01% (30)	1.17% (5)
● item12	2.36	1.22	0.59	-0.62	0.87*	0.48			29.91% (128)	29.67% (127)	21.50% (92)	12.15% (52)	6.78% (29)
● item13	2.73	1.46	0.20	-1.36	0.87*	0.25			30.14% (129)	17.52% (75)	17.76% (76)	18.69% (80)	15.89% (68)
● item14	2.14	1.31	0.77	-0.78	0.80*	0.28			47.20% (202)	18.93% (81)	12.62% (54)	15.65% (67)	5.61% (24)
● item15	3.26	1.09	-0.26	-0.45	0.91*	0.03			7.48% (32)	13.79% (59)	37.15% (159)	28.04% (120)	13.55% (58)
● item16	1.56	1.23	2.00	2.45	0.50*	0.28			79.67% (341)	4.21% (18)	3.97% (17)	4.67% (20)	7.48% (32)
● item17	1.54	1.21	2.07	2.75	0.49*	0.21			80.61% (345)	3.27% (14)	5.14% (22)	3.27% (14)	7.71% (33)
● item18	1.12	0.49	5.02	27.80	0.25*	0.18			93.22% (399)	3.50% (15)	2.10% (9)	0.70% (3)	0.47% (2)
● item19	1.05	0.36	7.23	52.98	0.13*	0.17			97.43% (417)	0.93% (4)	0.47% (2)	1.17% (5)	0.00% (0)
● item20	1.04	0.33	8.99	85.28	0.10*	0.16			98.36% (421)	0.23% (1)	0.70% (3)	0.47% (2)	0.23% (1)
● item21	1.14	0.59	4.79	24.05	0.25*	0.21			93.69% (401)	1.64% (7)	3.04% (13)	0.47% (2)	1.17% (5)
● item22	3.57	1.07	-0.65	-0.17	0.88*	0.20			4.91% (21)	11.92% (51)	21.96% (94)	43.22% (185)	17.99% (77)
● item23	2.56	1.27	0.33	-1.00	0.89*	0.08			26.40% (113)	25.23% (108)	22.66% (97)	17.76% (76)	7.94% (34)
● item24	4.14	0.99	-1.23	1.14	0.79*	0.22			2.34% (10)	5.84% (25)	10.98% (47)	37.38% (160)	43.46% (186)
● item25	2.59	1.41	0.27	-1.27	0.86*	0.15			34.35% (147)	13.79% (59)	22.20% (95)	17.99% (77)	11.68% (50)
● item26	2.25	1.27	0.69	-0.64	0.84*	0.08			38.32% (164)	23.36% (100)	20.09% (86)	10.98% (47)	7.24% (31)
● item27	3.80	1.29	-0.87	-0.42	0.82*	0.17			8.41% (36)	11.21% (48)	11.21% (48)	30.37% (130)	38.79% (166)
● item28	3.76	1.14	-0.68	-0.45	0.86*	0.18			3.97% (17)	13.08% (56)	17.06% (73)	34.81% (149)	31.07% (133)
● item29	2.44	1.31	0.38	-1.14	0.86*	0.13			34.35% (147)	20.33% (87)	19.39% (83)	19.16% (82)	6.78% (29)
● item30	1.48	1.11	2.18	3.35	0.48*	0.13			81.78% (350)	3.27% (14)	4.91% (21)	5.37% (23)	4.67% (20)
● item31	3.00	1.62	-0.08	-1.61	0.83*	0.39			31.31% (134)	10.05% (43)	11.68% (50)	20.79% (89)	26.17% (112)
● item32	3.55	1.65	-0.60	-1.34	0.76*	0.33			23.13% (99)	7.01% (30)	8.18% (35)	14.95% (64)	46.73% (200)
● item33	3.62	1.64	-0.68	-1.25	0.74*	0.37			21.96% (94)	7.01% (30)	7.24% (31)	14.49% (62)	49.30% (211)
● item34	3.42	1.83	-0.45	-1.69	0.69*	0.20			33.64% (144)	3.04% (13)	3.04% (13)	8.64% (37)	51.64% (221)
● item35	3.86	1.67	-0.99	-0.85	0.65*	0.20			22.90% (98)	1.87% (8)	3.74% (16)	9.35% (40)	62.15% (266)
● item36	1.54	1.25	2.13	2.86	0.46*	0.35			82.24% (352)	3.04% (13)	3.04% (13)	2.34% (10)	9.35% (40)
● item37	1.33	0.91	3.03	8.43	0.41*	0.09			84.58% (362)	7.01% (30)	3.04% (13)	1.64% (7)	3.74% (16)
● item38	4.30	1.08	-1.79	2.53	0.67*	0.32			5.37% (23)	3.50% (15)	5.37% (23)	27.57% (118)	58.18% (249)
● item39	1.96	0.98	1.02	0.69	0.82*	0.07			37.62% (161)	38.79% (166)	15.65% (67)	5.61% (24)	2.34% (10)
● item40	2.16	1.19	0.71	-0.54	0.84*	0.25			39.49% (169)	25.00% (107)	19.63% (84)	11.45% (49)	4.44% (19)
● item41	1.31	0.81	2.75	6.92	0.43*	0.14			85.05% (364)	4.67% (20)	6.07% (26)	3.04% (13)	1.17% (5)
● item42	3.93	1.48	-1.06	-0.44	0.71*	0.15			14.72% (63)	5.84% (25)	7.94% (34)	14.95% (64)	56.54% (242)
● item43	1.64	1.18	1.79	2.02	0.60*	0.22			71.26% (305)	9.35% (40)	10.05% (43)	2.80% (12)	6.54% (28)
● item44	3.51	1.30	-0.70	-0.59	0.85*	0.40			13.55% (58)	7.24% (31)	18.69% (80)	35.98% (154)	24.53% (105)
● item45	2.22	1.48	0.71	-1.02	0.76*	0.29			53.04% (227)	7.01% (30)	16.36% (70)	11.92% (51)	11.68% (50)
● item46	1.76	1.23	1.35	0.44	0.66*	0.39			67.06% (287)	7.71% (33)	11.68% (50)	8.88% (38)	4.67% (20)
● item47	2.11	1.17	0.77	-0.39	0.83*	0.37			41.12% (176)	24.77% (106)	20.09% (86)	9.81% (42)	4.21% (18)
● item48	2.60	1.25	0.29	-0.86	0.89*	0.36			25.00% (107)	21.50% (92)	30.84% (132)	13.79% (59)	8.88% (38)

^aShapiro-Wilk test

Sup.Fig. 1. Summary descriptive statistics and response pattern of EFA sample (n = 428). All items violated normality assumptions

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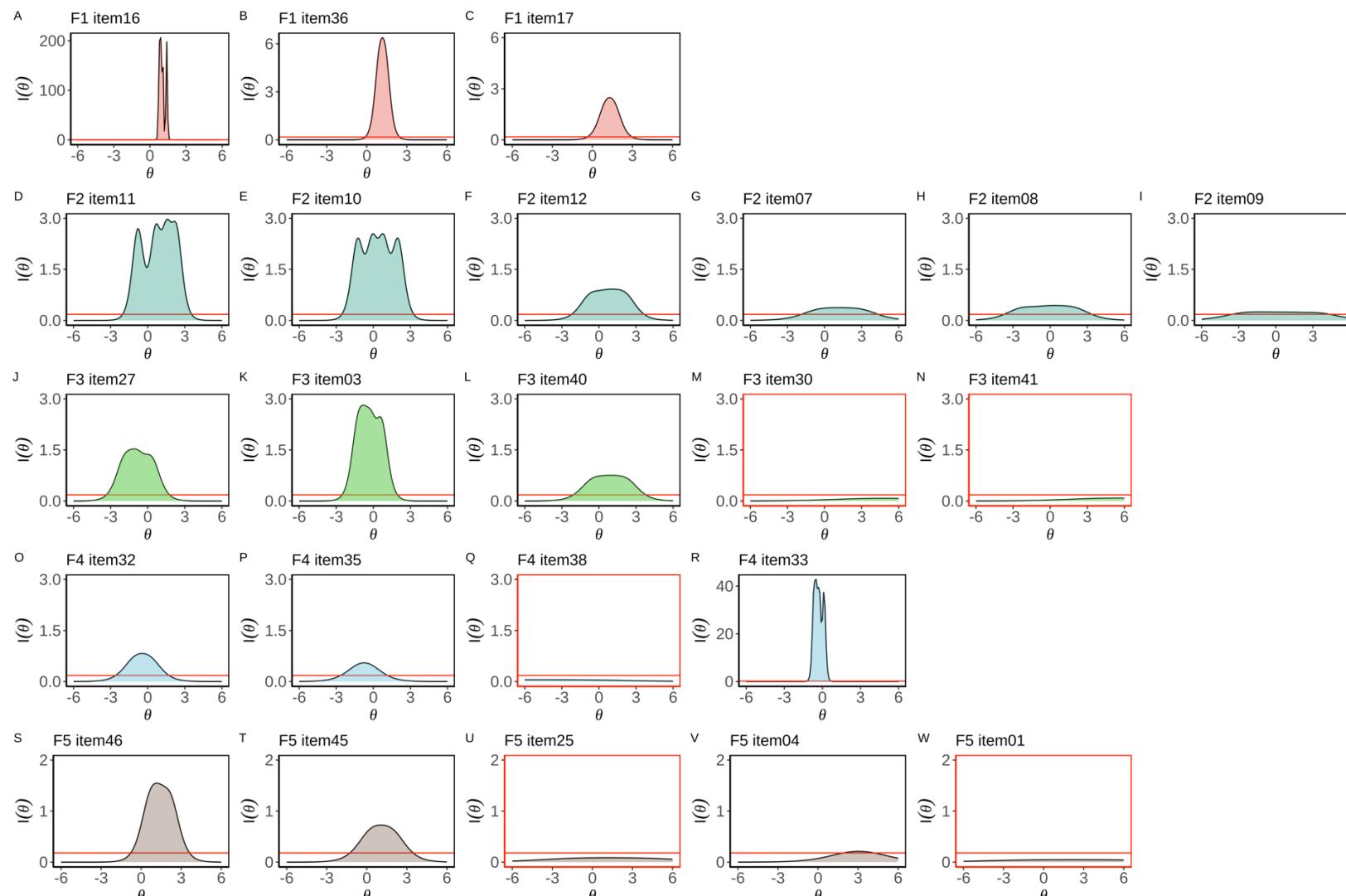
Light Exposure Behavior Assessment

Summary Descriptives CFA Sample (n=262)

Items	Summary Statistics			Graphics		Response Pattern					
	n	Mean	Median	SD	Histogram	Density	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)

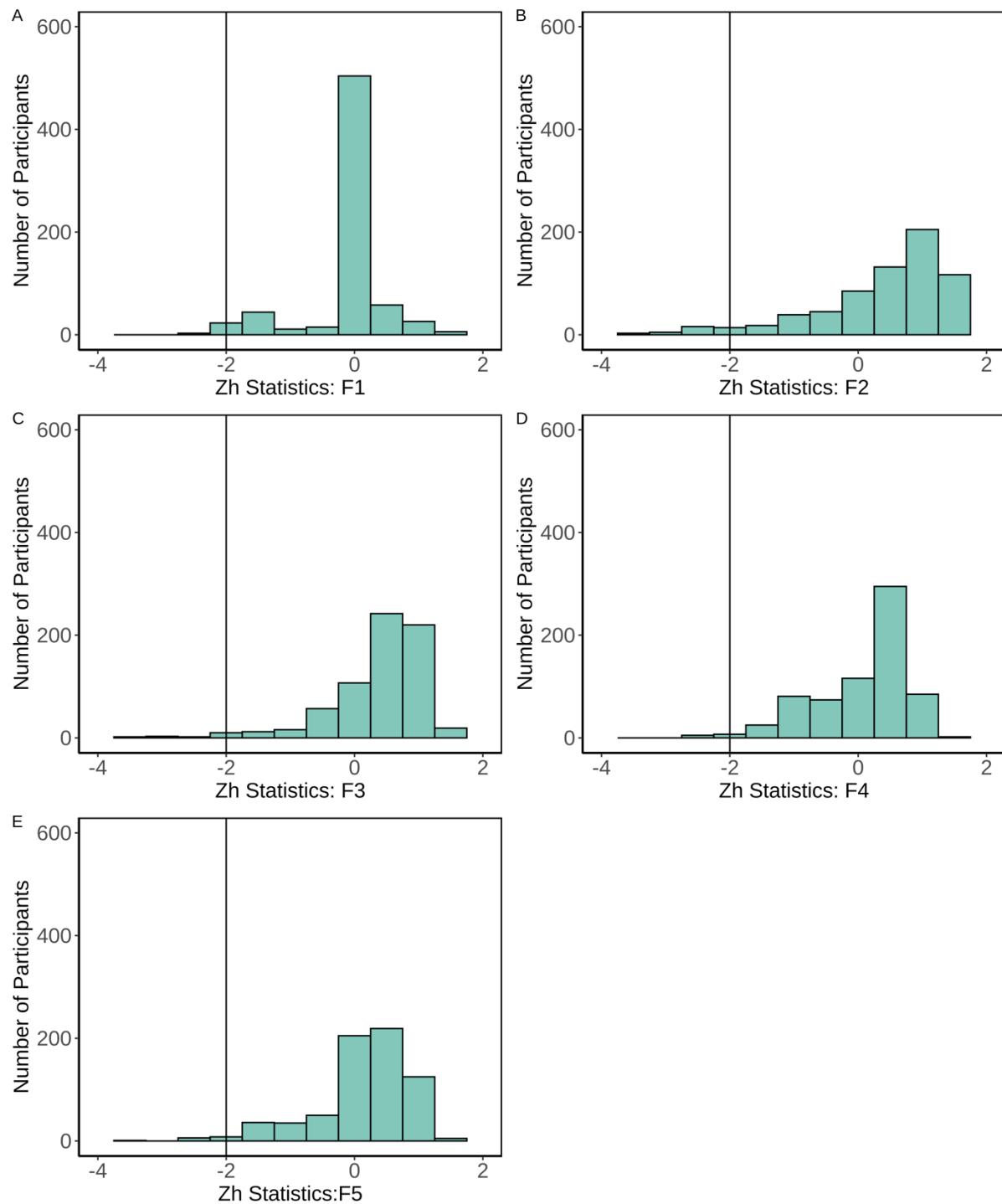
Sup.Fig.2. Summary descriptive statistics and response pattern of CFA sample (n = 262).

LEBA: Supplementary Materials



Sup. Fig.3. Item information curves for all items of LEBA. The red boxed five items (1, 25, 30, 38, 41) had relatively flat information curves.

LEBA: Supplementary Materials



Sup.Fig.4. Person fit of the five fitted IRT models (a) wearing blue light filters (b) spending time outdoors (c) using phone and smart-watch in bed (d) using light before bedtime (e) using light in the morning and during daytime. Most of the Zh values are higher than -2.