

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.

80 On the other hand, several attempts have been made to quantify received light
81 exposure subjectively with self-report questionnaires (**Supplementary Table 1**),
82 bypassing the cost and intrusiveness issues. However, subjective light intensity
83 assessments pose a new set of challenges: The human visual system constantly adapts
84 to brightness (Hurwicz & Jameson, 1966), while the signals underlying the non-visual
85 effects of light are independent from perception (Allen, Hazelhoff, Martial, Cajochen, &
86 Lucas, 2018), making the self-report assessment of light properties challenging.
87 Retrospectively recalling the properties of a light source can further complicate such
88 subjective evaluations. Moreover, measuring light properties alone does not yield any
89 information about how individuals might behave differently regarding diverse light

90 environments such as work, home or outdoors.

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

92 Here, we present the development process of a novel self-reported inventory, the Light
93 Exposure Behaviour Assessment (LEBA), for characterizing diverse light
94 exposure-related behaviours.

95 Results

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

98 Development of the initial item pool

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

105 Measurement of light exposure behaviour in an online sample

106 We conducted two rounds of large scale online survey between 17 May 2021 and 3
107 September 2021 to generate data from 690 participants with varied geographic locations
108 (countries=74; time-zone=28). For a complete list of geographic locations, see
109 **Supplementary Table 2.** Table 1 presents the survey participants' demographic
110 characteristics. Only participants completing the full LEBA inventory were included. We
111 used the data from first round for the exploratory factor analysis (EFA sample; n=428)
112 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.

127 **Psychometric analysis: Development of the long form**

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

133 Similarly, non-normal distribution of response pattern was also observed in the EFA
134 sample. **Supplementary Figure 1** depicts the univariate descriptive statistics for the
135 EFA sample (n=428). Further, We observed that each item’s correlation with the
136 aggregated sum of the 48-item’s score varied largely (corrected item-total correlation=
137 0.03 -0.48) indicating the possibility of multi-factor structure of the LEBA inventory.

Exploratory factor analysis and reliability analysis.

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

Prior to conducting the EFA, we have checked the post-hoc sampling adequacy by

applying Kaiser-Meyer-Olkin (KMO) measures of sampling adequacy on the EFA sample ($n=428$) (Kaiser, 1974) and the quality of the correlation matrix by Bartlett's test of sphericity (Bartlett, 1954). KMO>0.50 would indicate adequate sample size (Hutcheson, 1999) and a significant test of sphericity would indicate satisfactory quality of the correlation matrix . Results indicated that we had an adequate sample size (KMO=0.63) and correlation matrix ($\chi^2_{1128}=5042.86$, $p< 0.001$). However, 4.96% of the inter-item correlation coefficients were greater than |0.30|, and the inter-item correlation coefficients ranged between -0.44 to 0.91. Figure 3-A depicts the respective correlation matrix. To identify how many factors are required to optimally express human light exposure related behaviors we used a combination of methods. the Scree plot (Figure 3-B) revealed a six-factor solution, whereas the minimum average partial (MAP) method (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

165 discarded problematic items (factor-loading <0.30 and cross-loading >0.30). In this
166 process, we found a five-factor structure for LEBA inventory with 25 items. Table 2
167 displays the factor-loading (λ) and communality of the items. Both factor loadings and
168 commonalities advocate to accept this five-factor solution ($|\lambda|=0.32-0.99$;
169 commonalities=0.11-0.99). These five factors explains 10.25%, 9.93%, 8.83%, 8.44%,
170 6.14% of the total variance in individual's light exposure related behaviours respectively.
171 All factors exhibited excellent to satisfactory reliability (ordinal $\alpha=0.94, 0.76, 0.75, 0.72,$
172 0.62 respectively). The entire inventory also exhibited satisfactory reliability ($\omega_t=0.77$).

173 However, the histogram of the absolute values of nonredundant residual
174 correlations (Figure 3-D) displayed that 26% of correlations were greater $>|.05|$,
175 indicating a possible under-factoring. (Desjardins & Bulut, 2018). Subsequently, we fitted
176 a six-factor solution, where a factor with only two salient variables emerged, thus
177 disqualifying the six-factor solution (**Supplementary Table 4**). While making the
178 judgement of accepting this five-factor solution we considered both factor's
179 interpretability and their psychometric properties. We deemed the five derived factors as
180 highly interpretable and relevant concerning our aim to capture light exposure-related
181 behaviour, we retained all of them with 25 items. Two of the items showed negative
182 factor-loading (item 08: I spend 30 minutes or less per day (in total) outside. and item
183 37: I use a blue-filter app on my computer screen within 1 hour before attempting to fall
184 asleep.). Upon re-inspection, we recognized these items to be negatively correlated to
185 the respective factor, and thus, we reverse-scored these two items.

186 **Confirmatory factor analysis.** To investigate the structural validity of the
187 five-factor structure obtained in EFA, we conducted a confirmatory factor analysis (CFA)
188 on the CFA sample. The five-factor structure with 25 items showed acceptable fit (Table
189 3) providing evidence of structural validity ($CFI=0.92$; $TLI=0.91$; $RMSEA=0.07$
190 [0.06-0.07, 90% CI]). Two equity constraints were imposed on item pairs 32-33 (item 32:
191 I dim my mobile phone screen within 1 hour before attempting to fall asleep; item 33: I

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

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

215 **Measurement invariance.** We reported the measurement invariance (MI)
216 analysis on the CFA sample based on native ($n=129$) and non-native English speakers
217 ($n=133$). A detailed demographic description are provided in **Supplementary Table 5**.
218 Our MI results (Table 4) indicated that LEBA inventory demonstrated highest level of

219 (residual model) psychometric equivalence across native and non-native English
220 speaking participants, thus permitting group-mean based comparisons. The four fitted
221 MI models generated acceptable fit indices and the model fit did not significantly
222 decrease across the nested models ($\Delta\text{CFI}>-0.01$; $\Delta\text{RMSEA}<0.01$).

223 **Secondary analysis: Grade level identification and semantic scale network
224 analysis**

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

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

235 In order to derive a short form of the LEBA inventory, we fitted each factor of the
236 LEBA with the graded response model (Samejima, Liden, & Hambleton, 1997) to the
237 combined EFA and CFA sample (n=690). The resulting item discrimination parameters
238 of the inventory fell into categories of "very high" (10 items), "high" (4 items), "moderate"
239 (4 items), and "low" (5 items), indicating a good range of discrimination along the latent
240 trait level (θ) (**Supplementary Table 6**). An examination of the item information curve
241 (**Supplementary Figure 3**) revealed five items (1, 25, 30, 38, & 41) provided very low
242 information regarding light exposure related behaviors with relatively flat curves ($I(\theta)$)

243 <0.20). We discarded those items, culminating in a short form of LEBA with five factors
244 and 18 items (**Supplementary File 2**).

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

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

259 Discussion

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

268 sample, which is crucial when relying on voluntary uncompensated participation.

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

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

295 exposure at night has been shown to influence sleep negatively (T. M. Brown et al.,
296 2022; Santhi & Ball, 2020), this overlap confirms our aim to measure the physiologically
297 relevant aspects of light-exposure-related behaviour. Nevertheless, the general
298 objectives of the complete questionnaires and the LEBA differ evidently.

299 Often psychological measurements require application of several questionnaires
300 simultaneously. Responding to several lengthy questionnaires increases the participants
301 losing focus and becoming tried. To avoid these situations we derived a short version of
302 the LEBA (18 items) using IRT analysis. We fitted a graded response model to the
303 combined EFA and CFA sample ($n=690$) and discarded five items (1, 25, 30, 38, & 41)
304 with relatively flat item information curve [$I(\theta) < .20$]. The resulting test information curves
305 suggest that the short-LEBA is a psychometrically sound measure with adequate
306 coverage of underlying traits and can be applied to capture the frequency of different
307 light exposure related behaviours reliably.

308 Findings from the Item and person fit index analysis demonstrate that all five fitted
309 models were acceptable and provide evidence of validity for the factors. In addition, the
310 diverse item discrimination parameters indicate an appropriate range of discrimination –
311 the ability to differentiate respondents with different levels of light exposure-related
312 behaviour.

313 Known limitations

314 We acknowledge that this work is limited concerning the following aspects:
315 The fifth factor, “using light in the morning and during daytime”, exhibited low
316 internal consistency both in the exploratory and confirmatory factor analysis (EFA: 0.62;
317 CFA: 0.52). Since, it was above .50, considering the developmental phase of this
318 inventory we accepted the fifth factor. This particular factor captures our behaviour
319 related to usages of light in the morning and daytime. Since, light exposure during

320 morning and daytime influences our alertness and cognition (Lok, Smolders, Beersma, &
321 de Kort, 2018; Siraji, Kalavally, Schaefer, & Haque, 2021), we deemed capturing these
322 behaviours is essential for the sake of completeness of our inventory. However, the
323 possibility of improving the reliability should be investigated further by adding more
324 appropriate and relevant items to this factor.

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

334 As with all studies relying on retrospective self-report data, individuals filling in the
335 LEBA may have difficulties precisely recalling the inquired light-related behaviours. In
336 the interest of bypassing a substantial memory component, we limited the recall period
337 to four weeks and chose response options that do not require exact memory recall. In
338 contrast to directly assessing light properties via self-report, we assume that reporting
339 behaviours might be more manageable for inexperienced laypeople, as the latter does
340 not rely on existing knowledge about light sources. The comprehensibility of the LEBA is
341 also reflected by the Flesch-Kincaid grade level identification method (Flesch, 1948) that
342 suggested a minimum age of 8.33 years and an educational grade of four or higher (US
343 grading system). We argue that measuring light-related behaviours via self-report is
344 crucial because these behaviours will hardly be as observable by anyone else or
345 measurable with other methods (like behavioural observations) with reasonable effort.

346 Future directions

347 To our knowledge, the LEBA is the first inventory characterising light
348 exposure-related behaviour in a scalable manner. Thus, estimating convergent validity
349 with similar subjective scales was impossible. Alternatively, the validity of the LEBA
350 could be evaluated by administering it conjointly with objective field measurements of
351 light exposure (e.g. with portable light loggers, see literature review). By this route, one
352 could study how the (subjectively measured) light exposure-related behavioural patterns
353 translate into (objectively measured) received light exposure.

354 Conclusion

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

362 Methods**363 Data collection**

364 A quantitative cross-sectional, fully anonymous, geographically unconstrained
365 online survey was conducted via REDCap (Harris et al., 2019, 2009) by way of the
366 University of Basel sciCORE. Participants were recruited via the website
367 (<https://enlightenyourclock.org/participate-in-research>) of the science-communication
368 comic book “Enlighten your clock”, co-released with the survey (Weinzaepflein &

369 Spitschan, 2021), social media (i.e., LinkedIn, Twitter, Facebook), mailing lists, word of
370 mouth, the investigators' personal contacts, and supported by the distribution of the
371 survey link via f.lux (F.lux Software LLC, 2021). The initial page of the online survey
372 provided information about the study, including that participation was voluntary and that
373 respondents could withdraw from participation at any time without being penalised.
374 Subsequently, consent was recorded digitally for the adult participants (>18 years), while
375 under-aged participants (<18 years) were prompted to obtain additional assent from their
376 parents/legal guardians. Filling in all questionnaires was estimated to take less than 30
377 minutes, and participation was not compensated.

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

388 **Analytic strategy**

389 Figure 6 summarises the steps we followed while developing the LEBA. We
390 conducted all analyses with the statistical software environment R. **Firstly**, we set an
391 item pool of 48 items with a six-point Likert-type response format (0-Does not apply/I
392 don’t know, 1-Never, 2-Rarely 3-Sometimes, 4-Often, 5-Always) for our initial inventory.
393 Our purpose was to capture light exposure-related behaviour. In that context, the first
394 two response options: “Does not apply/I don’t know” and “Never”, provided similar

395 information. As such, we collapsed them into one, making it a 5-point Likert-type
396 response format (1-Never, 2-Rarely, 3-Sometimes, 4-Often, 5-Always).

397 **Secondly**, the two rounds of data collection were administered. In the first round
398 (EFA sample; n=428) we collected data for the exploratory factor analysis (EFA). A
399 sample of at least 250-300 is recommended for EFA (Comrey & Lee, 2013; Schönbrodt
400 & Perugini, 2013). The EFA sample exceeded this recommendation. The second round
401 data (CFA sample; n=262) was subjected to confirmatory factor analysis (CFA). To
402 assess sampling adequacy for CFA, we followed the N:q rule (Bentler & Chou, 1987;
403 Jackson, 2003; Kline, 2016; Worthington & Whittaker, 2006), where at least ten
404 participants per item are required to earn trustworthiness of the result. Again, our CFA
405 sample exceeded this guidelines.

406 **Thirdly**, we conducted descriptive and item analyses and proceeded to EFA on the
407 EFA sample. Prior to the EFA, the necessary assumptions, including sample adequacy,
408 normality assumptions, and quality of correlation matrix, were assessed. As our data
409 violated both the univariate and multivariate normality assumption and yielded ordinal
410 response data, we used a polychoric correlation matrix in the EFA and employed
411 “principal axis” (PA) as the factor extraction method (Desjardins & Bulut, 2018; Watkins,
412 2020). We applied a combination of methods, including a Scree plot (Cattell, 1966),
413 minimum average partials method (Velicer, 1976), and Hull method (Lorenzo-Seva et al.,
414 2011) to identify factor numbers. To determine the latent structure, we followed the
415 common guidelines: (i) no factors with fewer than three items (ii) no factors with a factor
416 loading <0.3 (iii) no items with cross-loading > .3 across factors (Bandalos & Finney,
417 2018).

418 Though Cronbach’s internal consistency coefficient alpha is widely used for
419 estimating internal consistency, it tends to deflate the estimates for Likert-type data since
420 the calculation is based on the Pearson-correlation matrix, which requires response data

421 to be continuous in nature (Gadermann, Guhn, & Zumbo, 2012; Zumbo, Gadermann, &
422 Zeisser, 2007). Subsequently, we reported ordinal alpha for each factor obtained in the
423 EFA which was suggested as a better reliability estimates for ordinal data (Zumbo et al.,
424 2007). We also estimated the internal consistency reliability of the total inventory using
425 McDonald's ω_t coefficient, which was suggested as a better reliability estimate for
426 multidimensional constructs (Dunn, Baguley, & Brunsden, 2014; Sijtsma, 2009). Both
427 ordinal alpha and McDonald's ω_t coefficient values range between 0 to 1, where higher
428 values represent better reliability.

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

440 In order to evaluate whether the construct demonstrated psychometric equivalence
441 and the same meaning across native English speakers ($n=129$) and non-native English
442 speakers ($n=133$) in the CFA sample ($n=262$) (Kline, 2016; Putnick & Bornstein, 2016)
443 measurement invariance analysis was used. We used structural equation modelling
444 framework to assess the measurement invariance. We successively compared four
445 nested models: configural, metric, scalar, and residual models using the χ^2 difference
446 test ($\Delta\chi^2$). Among MI models, the configural model is the least restrictive, and the
447 residual model is the most restrictive. A non-significant $\Delta\chi^2$ test between two nested

448 measurement invariance models indicates mode fit does not significantly decrease for
449 the superior model, thus allowing the superior invariance model to be accepted
450 (Dimitrov, 2010; Widaman & Reise, 1997).

451 **Fourthly**, in a secondary analysis, we identified the educational grade level (US
452 education system) required to understand the items in our inventory with the
453 Flesch-Kincaid grade level identification method (Flesch, 1948). Correspondingly, we
454 analysed possible semantic overlap of our developed inventory using the “Semantic
455 Scale Network” (SSN) engine (Rosenbusch et al., 2020). The SSN detects semantically
456 related scales and provides a cosine similarity index ranging between -.66 to 1
457 (Rosenbusch et al., 2020). Pairs of scales with a cosine similarity index value of 1
458 indicate full semantical similarity, suggesting redundancy.

459 **Lastly**, we derived a short form of the LEBA employing an Item Response Theory
460 (IRT) based analysis. We fitted each factor of the LEBA to the combined EFA and CFA
461 sample ($n=690$) using the graded response model (Samejima et al., 1997). IRT assesses
462 the item quality by estimating the item discrimination, item difficulty, item information
463 curve, and test information curve (Baker & Kim, 2017). Item discrimination indicates how
464 well a particular item can differentiate between participants across the given latent trait
465 continuum (θ). Item difficulty corresponds to the latent trait level at which the probability
466 of endorsing a particular response option is 50%. The item information curve (IIC)
467 indicates the amount of information an item carries along the latent trait continuum.
468 Here, we reported the item difficulty and discrimination parameter and categorized the
469 items based on their item discrimination index: (i) none=0; (ii) very low=0.01 to 0.34; (iii)
470 low=0.35 to 0.64; (iv) moderate=0.65 to 1.34 ; (v) high=1.35 to 1.69; (vi) very high >1.70
471 (Baker & Kim, 2017). We discarded the items with a relatively flat item information curve
472 (information $<.2$) to derive the short form of LEBA. We also assessed the precision of the
473 short LEBA utilizing the test information curve (TIC). TIC indicates the amount of
474 information a particular scale carries along the latent trait continuum. Additionally, the

475 item and person fit of the fitted IRT models were analysed to gather more evidence on
476 the validity and meaningfulness of our scale (Desjardins & Bulut, 2018). The item fit was
477 evaluated using the RMSEA value obtained from Signed- χ^2 index implementation,
478 where an RMSEA value $\leq .06$ was considered an adequate item fit. The person fit was
479 estimated employing the standardized fit index Zh statistics (Drasgow, Levine, &
480 Williams, 1985). Here, $Zh < -2$ was considered as a misfit (Drasgow et al., 1985).

481 **Ethical approval**

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

488 **Code, materials and data availability**

489 The present article is a fully reproducible open access “R Markdown” document. All
490 code and data underlying this article is available on a public GitHub repository. The
491 English version of long and short form of LEBA inventory and online survey
492 implementation templates on common survey platforms(Qualtrics and REDCap) – is
493 available on another public GitHub repository as well as on the dedicated website of the
494 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	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. 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	Item Stem	Summary Statistics			Graphics		Response Pattern				
		Mean	SD	SW ¹	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)

¹ 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	Item 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.

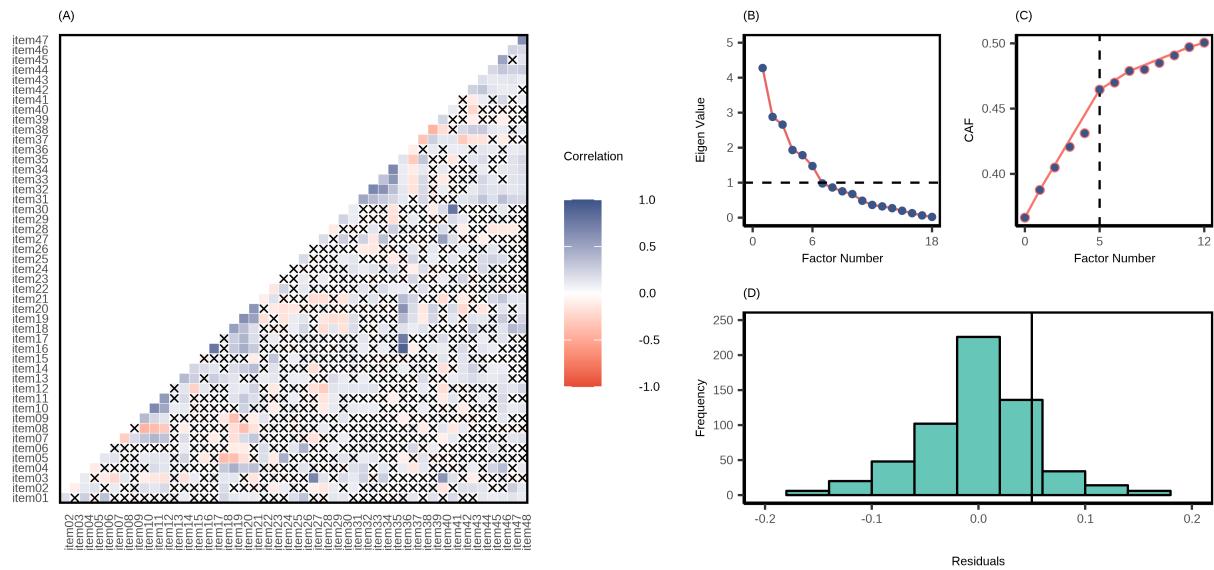


Figure 3. (A) Inter-item polychoric correlation coefficients for the 48 items. 4.9 % inter-item correlation coefficients were higher than $|.30|$. 'x' denotes non-significant correlation. (B) The Scree plot suggested six factors. (C) Hull method indicated that five factors were required to balance the 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.

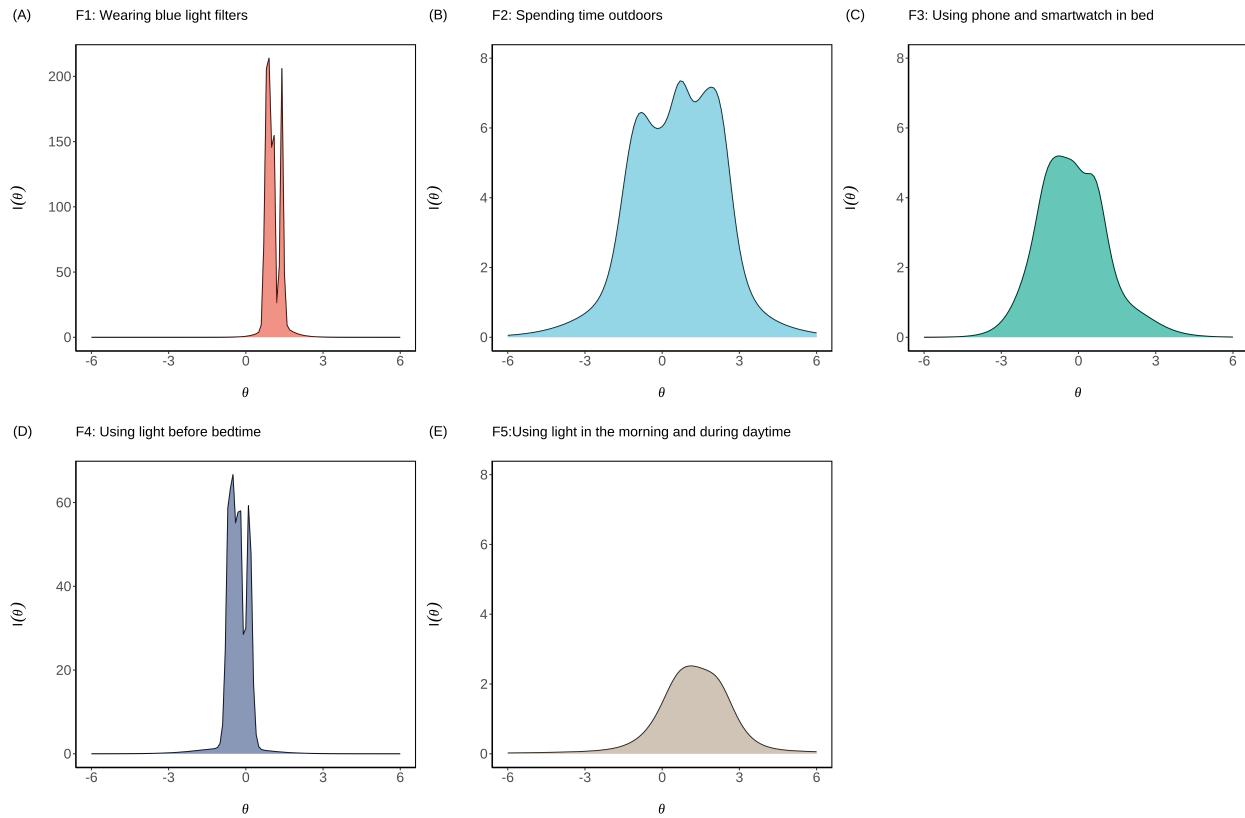


Figure 5. Test information curves for the five factors of LEBA: (A) wearing blue light filters (B) spending time outdoors (C) using a phone and smartwatch in bed (D) using light before bedtime (E) using light in the morning and during daytime. Along the x-axis, we plotted the underlying latent trait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

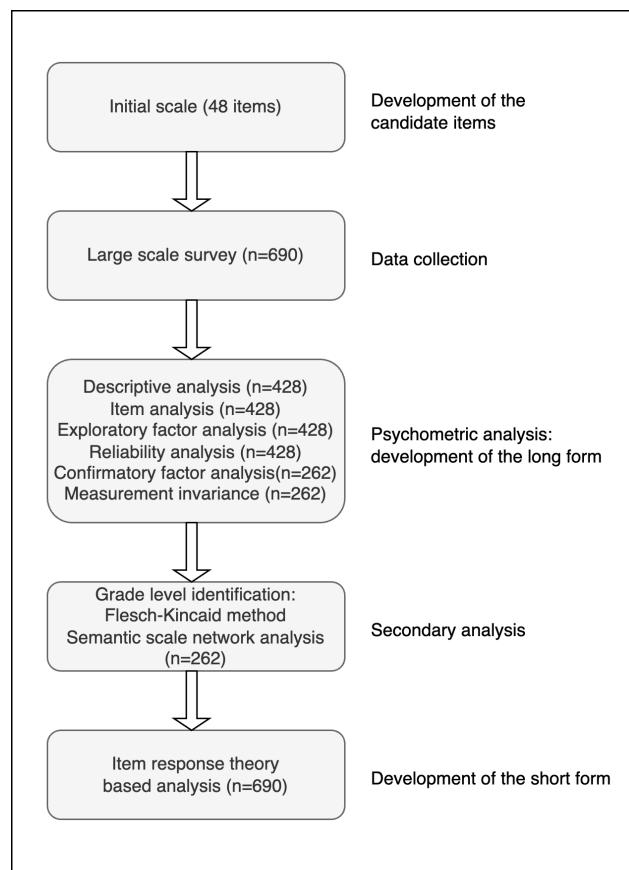


Figure 6. Flow chart of the LEBA (long and short form) development and evaluation.

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

LEBA: Supplementary Materials

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.

LEBA: Supplementary Materials

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.

LEBA: Supplementary Materials

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 (%).

LEBA: Supplementary Materials

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

LEBA: Supplementary Materials

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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LEBA: Supplementary Materials

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

LEBA: Supplementary Materials

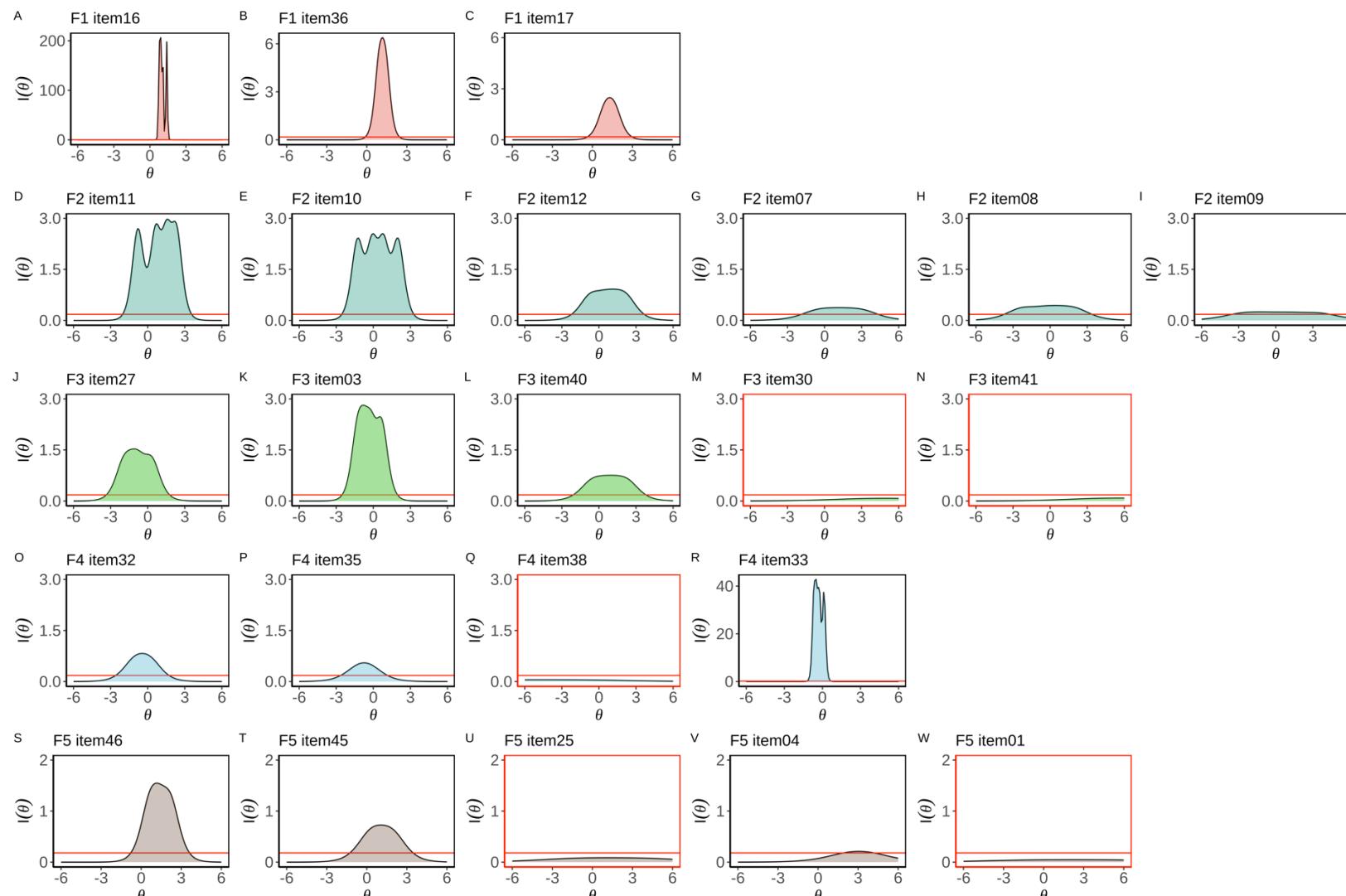
Light Exposure Behavior Assessment

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)

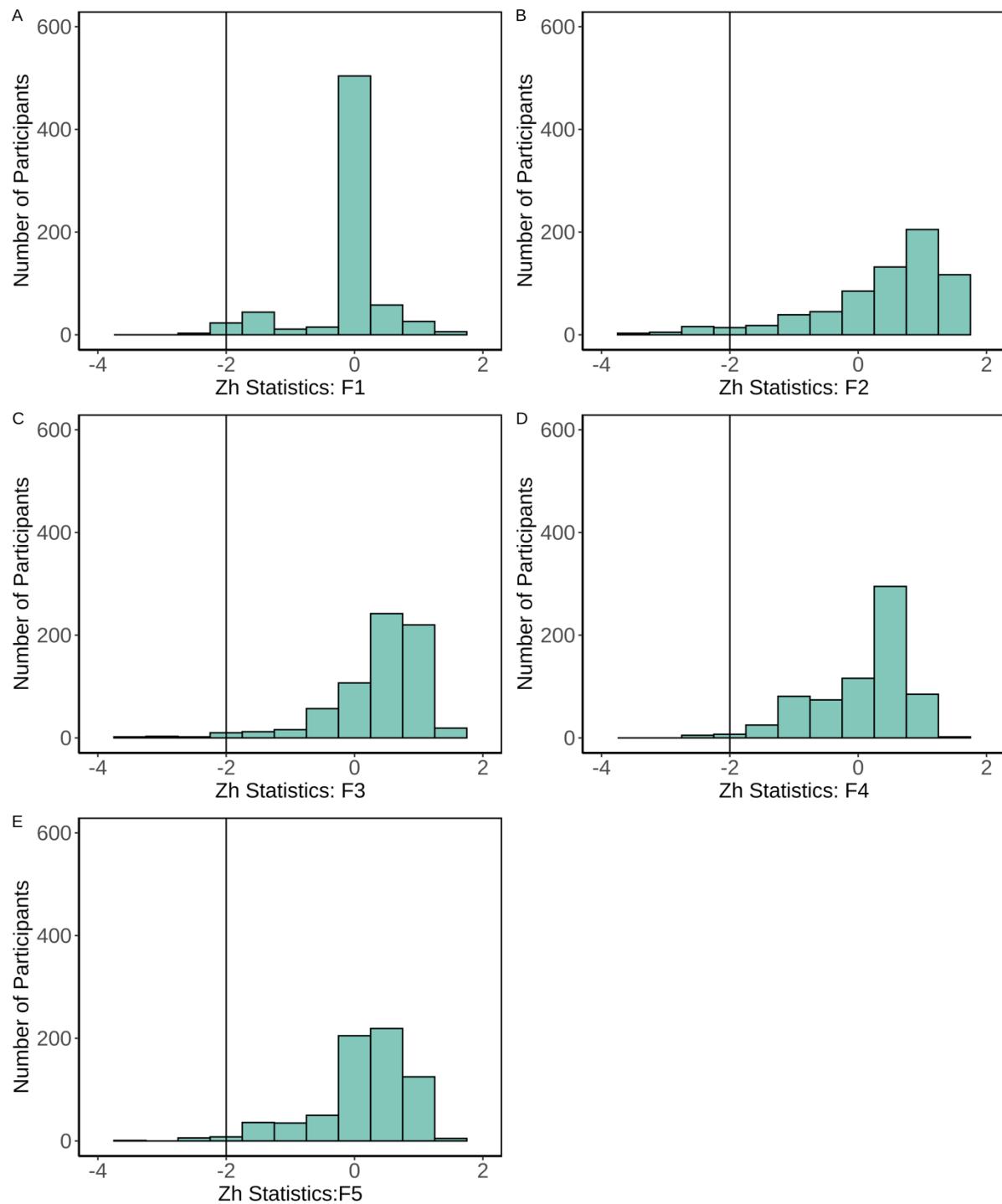
Sup.Fig.2. Summary descriptive statistics and response pattern of CFA sample (n = 262).

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.