

¹ *Light Exposure Behavior Assessment (LEBA): Development of a novel instrument to capture light exposure-related behaviours*

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50

Abstract

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

56 An expert panel prepared the initial 48 item pool spanning different light exposure
57 related behaviors. Responses, consisting rating the frequency of engaging in the
58 per-item behavior on a 5-point Likert type scale were collected in an online survey
59 yielding responses from a geographically unconstrained sample (690 completed
60 responses, 74 countries, 28 time zones). Exploratory factor analysis (EFA) on an initial
61 subset of our sample ($n=428$) rendered a five-factor solution with 25 items (Wearing blue
62 light filters, spending time outdoors, using phone and smart-watch in bed, using light
63 before bedtime, using light in the morning and during daytime). In a confirmatory factor
64 analysis (CFA) performed on an independent subset of participants ($n=262$), we
65 removed two further items to attain the best fit for the five-factor solution ($CFI=0.97$,
66 $TLI=0.96$, $RMSEA=0.05$, $SRMR=0.09$). The internal consistency reliability coefficient for
67 the total instrument was, McDonald's Omega(total)=0.73. Measurement model
68 invariance analysis between native and non-native English speakers showed our model
69 attained the highest level of invariance (residual invariance; $CFI=0.95$, $TLI =0.95$,
70 $RMSEA=0.05$). Lastly, a short form of LEBA ($n=18$) was developed using Item Response
71 Theory on the complete sample ($n=690$).

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

⁷⁶ *Keywords:* light exposure, light-related behaviours, non-visual effects of light,
⁷⁷ psychometrics

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

Introduction

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

Methods

89 Data Collection

A quantitative cross-sectional fully anonymous online survey was conducted via REDCap (Harris et al., 2019, 2009) by way of the University of Basel sciCORE. Participants were recruited via the website of a Comic co-released with the survey (Weinzaepflen & Spitschan, 2021), social media (i.e., LinkedIn, Twitter, Facebook), mailing lists, word of mouth, the investigators' personal contacts, and supported by distribution of the survey link via f.lux (F.lux Software LLC, 2021). The landing page of the online survey had the explanatory statements where we mentioned participation was voluntary and that respondents could withdraw from participation anytime without being penalized. At the beginning of the survey, for the adult participants (>18 years) consent was recorded digitally. Underaged participants (<18 years) were urged to obtain assent from their parents/legal guardians. The survey took around 15 to 20 minutes and

101 participants were not compensated. As a part of the demographic information
102 participants provided information regarding age, sex, gender identity, occupational
103 status, COVID-19 related occupational setting, time zone/country of residence and
104 native language. The demographic characteristics of our sample are given in Table
105 ???. To ensure high data quality, five attention check items were included in the survey
106 (e.g., “We want to make sure you are paying attention. What is 4+5?”). Participants
107 needed to confirm that they were participating the survey for the first time. Questions
108 incorporating retrospective recall were all aligned to the period of “past four weeks.” At
109 first we collected data for from 428 participants (EFA sample). Next, we collected data
110 from another 262 participants (CFA sample) making a total sample of 690. The data
111 analysed in this study was collected between 17 May 2021 and 3 September 2021.

112 Analytic Strategies

113 Figure 1 summarizes the steps of our psychometric analysis. In our analysis we
114 used R (version 4.1.0). In the item generation and selection phase we had developed a
115 item pool of 48 items with six-point Likert type response format (0:Does not apply/I don't
116 know; 1:Never, 2:Rarely; 3:Sometimes; 4:Often; 5:Always). Our purpose was to capture
117 light exposure related behaviour. In that context, the first two response options: “Does
118 not apply/I don't know” and “Never” were providing similar information. As such we
119 collapsed them into one, making it a 5 point Likert type response format. We conducted
120 an initial item analysis and proceed to the exploratory factor analysis (EFA) with all 48
121 items (EFA sample;n=428). Prior to the EFA, necessary assumptions, including sample
122 adequacy, normality assumptions, quality of correlation matrix were assessed. Our data
123 violated both the univariate and multivariate normality assumptions. Due to these
124 violations and the ordinal nature of our response data, in EFA we used polychoric
125 correlation matrix and employed principal axis (PA) as factor extraction method with
126 varimax rotation (Desjardins & Bulut, 2018; Watkins, 2020). We used a combination of

127 factor identification method including Scree plot (Cattell, 1966), minimum average
128 partials method (Velicer, 1976), and Hull method (Lorenzo-Seva, Timmerman, & Kiers,
129 2011) to identify factor numbers. To determine the latent structure, we followed the
130 common guidelines : (i) no factors with fewer than three items (ii) no factors with a factor
131 loading <0.3 (iii) no items with cross-loading > .3 across factors (Bandalos & Finney,
132 2018). We also conducted a EFA on non-merged response options data (Supp. Table
133 A9) and rejected the latent structure obtained as the factors were less interpretable.

134 For reliability estimation we used internal consistency reliability coefficient ordinal
135 alpha. Though Cronbach's alpha coefficient is widely used for estimating internal
136 consistency, it has a tendency to deflate the estimates for Likert type data since the
137 calculation is based on pearson-correlation matrix which requires response data to be
138 continuous of nature (Gadermann, Guhn, & Zumbo, 2012; Zumbo, Gadermann, &
139 Zeisser, 2007). Subsequently to get better estimates of reliability we reported ordinal
140 alpha for each factors using polychoric-correlation matrix (Zumbo et al., 2007). We also
141 estimated the internal consistency reliability of the total scale using McDonald's ω_t
142 coefficient which is a better reliability estimate for multidimensional constructs (Dunn,
143 Baguley, & Brunsden, 2014; Sijtsma, 2009). Both ordinal alpha and McDonald's ω_t
144 coefficient value range from 0 to 1 and higher value represents better reliability.

145 To validated the latent structure obtained in EFA, We conducted a categorical
146 confirmatory factor analysis (CFA) with weighted least square with mean and variance
147 adjusted (WLSMV) estimator estimator (Desjardins & Bulut, 2018) on a separate sample
148 (CFA sample;n=262). We assessed the model fit using common model fit guidelines: (i)
149 χ^2 test statistics: a non-significant test statistics is required to accept the model (ii)
150 comparative fit index (CFI) and Tucker Lewis index (TLI): close to .95 or above/ between
151 90-95 and above (iii) root mean square error of approximation (RMSEA): close to .06 or
152 below, (iv) Standardized root mean square (SRMR): close to .08 or below (Hu & Bentle,
153 1999; Schumacker & Lomax, 2004). However, the χ^2 test is sensitive to sample size

154 (Brown, 2015) and SRMR does not work well with ordinal data (Yu, 2002) As such, we
155 judged the model fit using CFI, TLI, SRMR and RMSEA.

156 We assessed the measurement invariance (MI) of our construct between native
157 English speakers (n=129) and non-native English speakers (n=133) among the CFA
158 sample (n=262). MI evaluates whether a construct has the psychometric equivalence
159 and same meaning across groups (Kline, 2015; Putnick & Bornstein, 2016). We used
160 structural equation modelling framework to assess the measurement invariance. We
161 successively compared four nested models: configural, metric, scalar, and residual
162 models using the χ^2 difference test ($\Delta\chi^2$). Among MI models, configural model is the
163 least restrictive model and residual model is the most restrictive model. A non-significant
164 $\Delta\chi^2$ test between two nested measurement invariance models indicates mode fit does
165 not significantly decrease for the superior model (Dimitrov, 2010) thus allowing the
166 superior invariance model to be accepted. (Widaman & Reise, 1997).

167 We also analysed possible semantic overlap of our developed tool using “Semantic
168 Scale Network” (SSN) engine (Rosenbusch, Wanders, & Pit, 2020). The SSN detects
169 semantically related scales and provides cosine similarity index ranging between -.66 to
170 1 (Rosenbusch et al., 2020). Pair of scales with a cosine similarity index value of 1
171 indicates they are perfectly semantically similar scales indicating redundancy.
172 Additionally, To identify the educational grade level required to understand the items in
173 our tool we subjected the tool to Flesch-Kincaid Grade Level (Flesch, 1948)

174 Lastly, we sought Item Response Theory (IRT) based analysis on developing a
175 short form of LEBA. We fitted each factor of LEBA using the graded response model
176 (Samejima, Liden, & Hambleton, 1997) to the combined EFA and CFA sample (n =690).
177 IRT assesses the item quality by estimating item discrimination, item difficulty, item
178 information, and test information (Baker, 2017). Item discrimination indicates the pattern
179 of variation in the categorical responses with the changes in latent trait level (θ). Item

180 information curve (IIC) indicates the amount of information an item carries along the
181 latent trait continuum. Here, we reported the item discrimination parameter and
182 categorize the items according to the suggestions of Baker (2017) : none = 0; very low
183 =0.01 to 0.34; low = 0.35 to 0.64; moderate = 0.65 to 1.34 ; high = 1.35 to 1.69; very high
184 >1.70. We discarded the items with relatively flat item information curve (information <.2)
185 to develop the short form of LEBA. We also assessed the precision of the short LEBA
186 using Test information curve (TIC). TIC indicates the amount of information an the
187 full-scale carry along the latent trait continuum. Item fit and person fit of the fitted IRT
188 models were also analyzed to gather more evidence on validity and meaningfulness of
189 our Tool (Desjardins & Bulut, 2018). Item fit was evaluated using the RMSEA value
190 obtained from Signed- χ^2 index implementation, RMSEA value $\leq .06$ was considered
191 adequate item fit. Person fit was estimated using standardized fit index Zh statistics
192 (Drasgow, Levine, & Williams, 1985). Zh < -2 was be considered as a misfit (Drasgow et
193 al., 1985).

194 **Ethical approval**

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

201 **Data Availability**

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

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

207 **Results**

208 **Initial development of items**

209 After reviewing the literature, we identified several light exposure related scale.
210 However, no scales specifically measuring the behavioural component of light exposure
211 were found (Table 1). As such, all authors in collaboration of an expert panel developed
212 a comprehensive item pool of 48 items. The expert panel composed of all authors and
213 researchers from the fields of chronobiology, light research, neuroscience and
214 psychology. The 48 items were then judged based on their relevance and
215 representativeness of the construct “Light Exposure Related Behaviour” by the expert
216 panel. The panel members independently judged each of the items in terms of their
217 relevance and representativeness and suggested required modification, if there is any.
218 The author team acknowledged the suggestions and amended the items as required
219 thus creating a 48-item scale.

220 **Large-scale survey of instruments**



221 **Participants.** Table ?? summarizes the survey participants' demographic
222 characteristics. Only participants completing the full LEBA questionnaire were included,
223 thus there are no missing values in the item analyses. (XX??) participants were
224 excluded from analysis due to not passing at least one of the “attention check” items. For
225 EFA, a sample of 250-300 is recommended (Comrey & Lee, 1992; Schönbrodt &
226 Perugini, 2013). To assess sampling adequacy for CFA, we followed the N:q rule
227 (Bentler & Chou, 1987; Jackson, 2003; Kline, 2015; Worthington & Whittaker, 2006),
228 where ten participants per item is required to earn trustworthiness of the result. Both our

229 EFA and CFA sample size exceeded these requirements. We collected data from 74
230 countries (28 time zones). Participants reported a diverse range of geographic location
231 Participants indicated filling out the online survey from a diverse range of geographic
232 locations. Figure 2 depicts the top ten countries with highest participation in our survey.
233 For a complete list of geographic locations, see Suppl. Table A11.

234 Participants in our survey aged between 11 to 84 years [EFA sample: *min* = 11,
235 *max* = 84; CFA sample: *min* = 12, *max* = 74], with an overall mean of ~ 32.95 years of
236 age [Overall: *M* = 32.95, *SD* = 14.57; EFA: *M* = 32.99, *SD* = 15.11; CFA: *M* = 32.89, *SD* =
237 13.66]. In total 325 (47%) of the participants indicated female sex [EFA: 189 (44%); CFA:
238 136 (52%)], 351 (51%) indicated male [EFA: 230 (54%); CFA: 121 (46%)] and 14 (2.0%)
239 indicated other sex [EFA: 9 (2.1%), CFA: 5 (1.9%)]. Overall, 49 (7.2%) [EFA: 33 (7.8%);
240 CFA: 16 (6.2%)] participants indicated a gender-variant identity. In a “Yes/No” question
241 regarding native language, 320 (46%) of respondents [EFA: 191 (45%); CFA: 129 (49%)]
242 indicated to be native English speakers. For their “Occupational Status,” more than half
243 of the overall sample reported that they currently work [Overall: 396 (57%); EFA: 235
244 (55%); CFA: 161 (61%)], whereas 174 (25%) [EFA: 122 (29%); CFA: 52 (20%)] reported
245 that they go to school and 120 (17%) [EFA: 71 (17%); CFA: 49 (19%)] responded that
246 they do “Neither.” With respect to the COVID-19 pandemic we asked participants to
247 indicate their occupational setting during the last four weeks: In the overall sample 303
248 (44%) [EFA: 194 (45%); CFA: 109 (42%)] of the participants indicated that they were in a
249 home office/ home schooling setting, while 109 (16%) overall [EFA: 68 (16%) ; CFA: 41
250 (16%)] reported face-to-face work/schooling. Lastly, 147 (21%) overall [EFA: 94 (22%) ;
251 CFA: 53 (20%)] reported a combination of home- and face-to-face work/schooling,
252 whereas 131 (19%) overall [EFA: 72 (17%); CFA: 59 (23%)] filled in the “Neither (no work
253 or school, or on vacation)” response option. We tested all demographic variables in
254 Table 1 for significant group differences between the EFA and CFA sample, applying
255 Wilcoxon rank sum test for the continuous variable “Age” and Pearson’s χ^2 test for all

256 other categorical variables via the gtsummary R package's "add_p" function (Sjoberg et
257 al., 2021a) . The p-values were corrected for multiple testing applying false discovery
258 rate (FDR) via the "add_q" function of the same package. After p-value (FDR) correction
259 for multiple testing, none of the demographic variables were significantly different
260 between the EFA sample and the CFA sample (all q-values $q \geq 0.2$).

261 **Item Analysis.** Table 3 summarizes the univariate descriptive statistics for the 48
262 items. Some of the items were skewed with high Kurtosis values. Our data violated both
263 univariate normality (Shapiro & Wilk, 1965) and multivariate normality assumptions
264 (Mardia, 1970). Multivariate skew was 583.80 ($p < 0.001$) and multivariate kurtosis was
265 2,749.15 ($p < 0.001$). Due to these violations and ordinal nature of the response data
266 polychoric correlations over Pearson's correlations was chosen (Desjardins & Bulut,
267 2018). The corrected item-total correlation ranges between .03 -.48. However, no item
268 was discarded based on descriptive statistics or item analysis.

269 **Exploratory Factor Analysis.** Sampling adequacy was checked using
270 Kaiser-Meyer-Olkin (KMO) measures of sampling adequacy (Kaiser, 1974) . The overall
271 KMO vale for 48 items was 0.63 which was above the cutoff value (.50) indicating
272 adequate sample size (Hutcheson, 1999). Bartlett's test of sphericity (Bartlett, 1954), χ^2
273 (1128) = 5042.86, $p < .001$ indicated the correlations between items are adequate for
274 conducting the EFA. However only 4.96% of the inter-item correlation coefficients were
275 greater than $|.30|$. The inter-item correlation coefficients ranged between -.44 to .91.
276 Figure 3 depicts the correlation matrix.

277 Scree plot (Figure 4) suggested a six-factor solution. However, the minimum
278 average partial (MAP) (Velicer, 1976) method (Table A5) and Hull method (Lorenzo-Seva
279 et al., 2011) (Figure 4) suggested a five-factor solution. As a result, we tested both
280 five-factor and six-factor solutions.

281 With the initial 48 items we conducted three rounds of EFA and gradually discarded

282 problematic items. (cross-loading items and poor factor loading (<.30) items). Finally, a
283 five-factor EFA solution with 25 items was accepted with all factor-loading higher than
284 .30 and no cross-loading greater than .30. We further confirmed this five-factor latent
285 structure by another EFA using varimax rotation with a minimum residual extraction
286 method (Sup.Table A7). Table 4 displays the factor-loading (structural coefficients) and
287 communality of the items. The absolute value of the factor-loading ranged from .49 to
288 .99 indicating strong coefficients. The commonalities ranged between .11 to .99. Figure
289 6 depicts the data distribution and endorsement pattern for the included 25 items. Figure
290 5(A) depicts the five factor structure obtained in EFA. However, the histogram of the
291 absolute values of non-redundant residual-correlations (Figure 5(B)) showed 26%
292 correlations were greater than the absolute value of .05, indicating a possible
293 under-factoring. (Desjardins & Bulut, 2018). Subsequently, we fitted a six-factor solution.
294 However, a factor emerged with only two salient variables, thus disqualifying the
295 six-factor solution (Sup.Table A8).

296 In the five-factor solution, the first factor contained three items and explained
297 10.25% of the total variance with an internal reliability coefficient ordinal $\alpha = .94$. All the
298 items in this factor stemmed from the individual's preference of using blue light filters in
299 different light environments. The second factor contained six items and explained 9.93%
300 of the total variance with an internal reliability coefficient ordinal $\alpha = .76$. Items under this
301 factor investigated individuals' hours spent outdoor. The third factor contained five items
302 and explained 8.83% of the total variance. Items under this factor dealt with the specific
303 behaviours pertaining to using phone and smart-watch in bed. The internal consistency
304 reliability coefficient was, ordinal $\alpha = .75$. The fourth factor contained five items and
305 explained 8.44% of the total variance with an internal consistency coefficient, ordinal $\alpha =$
306 .72. These five items investigated the behaviours related to individual's light exposure
307 before bedtime. Lastly, the fifth factor contained six items and explained 6.14% of the
308 total variance. This factor captured individual's morning and daytime light exposure

related behaviour. The internal consistency reliability was, ordinal $\alpha = .62$. It is essential to attain a balance between psychometric properties and interpretability of the common themes when exploring the latent structure. As all of the emerged factors are highly interpretable and relevant towards our aim to capture light exposure related behaviour, regardless of the apparent low reliability of the fifth factor, we retain all the five-factors with 23 items for our confirmatory factor analysis (CFA). Two items showed negative factor-loading (items 44 and 21). Upon inspection, it was understood that these items are negatively correlated to the respective common theme, and thus in the CFA analysis, we reverse coded these two items.

Confirmatory Factor Analysis. Table 5 summarizes the CFA fit indices of our fitted model. Our fitted model attained acceptable fit ($CFI = .94$; $TLI = .93$); $RMSEA = .06$, [.05-.07, 90% CI]) with two imposed equity constrain on item pairs 32-33 [I dim my mobile phone screen within 1 hour before attempting to fall asleep.; I dim my computer screen within 1 hour before attempting to fall asleep.] and 16-17 [I wear blue-filtering, orange-tinted, and/or red-tinted glasses indoors during the day.; I wear blue-filtering, orange-tinted, and/or red-tinted glasses outdoors during the day.]. Items pair 32-33 stemmed from the preference of dimming electric device's brightness before bed time and items pair 16 and 19 stemmed from the preference of using blue filtering or coloured glasses during the daytime. Nevertheless, SRMR value was higher than the guideline (SRMR = .12). Further by allowing one pair of items (30-41) [I look at my smartwatch within 1 hour before attempting to fall asleep.; I look at my smartwatch when I wake up at night.] to covary their error variance and discarding two item (item 37 & 26) for very low r-square value, our model attained the best fit ($CFI = .95$; $TLI = .95$); $RMSEA = .06$, [.05-.06, 90% CI]). Internal consistency ordinal α for the five factors of LEBA were .96, .83, .70, .69, .52 respectively. Internal consistency McDonald's ω_t coefficient for the total scale was .68. Figure 8 depicts the obtained CFA structure. Figure 7 depicts the data distribution and endorsement pattern of the retained 23 items in our CFA sample.

336 **Measurement Invariance.** In our CFA sample we had 129 native English speakers

337 and 133 non-native English speakers (For a detailed description these two groups see

338 Sup. Table ??). Table 6 indicates our fitted model had acceptable fit indices for all of the

339 fitted MI models. The model fit did not significantly decrease across the nested models

340 indicating the acceptability of the highest measurement invariance model : residual

341 model.

342 **Semantic Analysis.** “Semantic Scale Network”(SSN) analysis (Rosenbusch et al.,

343 2020) indicated that LEBA (23 items) appeared most strongly related to scales about

344 sleep: “Sleep Disturbance Scale For Children” (Bruni et al., 1996) and “WHO-Composite

345 International Diagnostic Interview (CIDI): Insomnia”(WHO, 1990).The cosine similarities

346 lie between .47 to .51. Flesch-Kincaid Grade Level (Flesch, 1948) analysis on the the 23

347 items of our scale indicated required educational grade level was 3.33 and with a age

348 above 8.33.

349 **Developing Short form of LEBA.** We fitted each factor of LEBA with the graded

350 response model (Samejima et al., 1997) to the combined EFA and CFA sample (n =690).

351 Item discrimination parameters of our tool fell in very high (10 items), high (4 items),

352 moderate (4 items), and low (5 items) categorizes indicating a good range of

353 discrimination along the latent trait level (θ). Examination of the item information curve

354 (Sup.fig A1) indicated five items (1, 25, 38, 30, & 41) had relatively flat information

355 curves ($I(\theta) < .20$). We discarded those items which yielded a short form of LEBA with 5

356 factors and 18 items.

357 We treated each factor of short-LEBA as an unidimensional construct and obtain 5

358 TICs (Figure 9). These information curves indicated except the first and fifth factors, the

359 other three factor’s TICs are roughly centred on the centre of the trait continuum (θ).The

360 first and fifth factor had a peak to the right side of the centre of latent trait.Thus we

361 conferred the LEBA tool estimated the light exposure related behaviour with precision

362 near the centre of trait continuum for 2nd, 3rd and 4th factors and near the right side of

363 the centre of trait continuum for 1st and 5th factors (Baker, 2017).

364 Table 8 summarizes the item fit indexes of the items. All of the items had RMSEA
365 value $\leq .06$ indicating adequate fit of the items. Sup.Figure A2 depicts the person fit Zh
366 statistics histogram of out fitted models. Zh statistics are larger than -2 for most
367 participants, suggesting a good person fit of the selected IRT models.

368 Discussion 

369 Though there are lots of validated tool to measure light exposure, they don't tell us
370 much about the behavioural aspects pertaining to the light exposure. At present there is
371 a dearth of validated tool to measure light exposure related behaviours. In that vein we
372 have developed a subjective self-reported tool that can capture light exposure related
373 behaviour in different dimensions.

374 Authors along with an expert panel generated 48 items and evaluated their quality
375 and relevance and made necessary amendments. A large scale geographically
376 unconstrained quantitative cross-sectional survey was conducted yielding responses
377 from large sample (n=428 to explore the latent structure. Exploratory factor analysis
378 revealed a five factor solution with 25 items. ("Wearing blue light filters," "Spending time
379 outdoors," "Using phone and smart-watch in bed," "Using light before bedtime," and
380 "Using light in the morning and during daytime"). The internal consistency reliability
381 coefficient ordinal alpha ranged between .62-.94. As all the retained factors were
382 meaningful and contributed essentially towards our aim we retained all five factors.

383 A CFA on a separate sample ((n=262 gave a five-factor solution (CFI =.95; TLI =
384 .95); RMSEA = .06[.05-.06, 90% CI]) and SRMR = .11) after discarding two item. The
385 internal consistency McDonald's ω_t of the five factors were satisfactory (.96, .83, .70,
386 .69, .52) Internal consistency reliability of the total scale (23 items) was also satisfactory,
387 McDonald's ω_t = .68.In the same sample, our measurement invariance analysis revealed

388 that the latent structure attained the residual measurement invariance across subgroups:
389 male and female (CFI: .98, TLI: .98, SRMR: .98).



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



399 We developed a short-LEBA (18 items) using IRT analysis. We fitted a graded
400 response model model to the combined EFA and CFA sample (n=690). We discarded
401 five items with relatively flat item information curve [$I(\theta) < .20$]. IRT analysis indicated
402 short form of LEBA is a psychometrically sound measure. Item fit indexes and person fit
403 index for all five fitted model were acceptable. Items had diverse slope parameters
404 indicating a good range of discrimination- the ability to differentiate respondents with
405 different levels of the light exposure related behaviour. Test information curve also
406 indicated a good coverage of underlying trait continuum with precision.



407 LEBA can be used to profile individuals based on their light exposure related
408 behaviours, which can facilitate the development process of individual interventions to
409 promote health. All the five factors of LEBA can identify ‘problematic’ behaviours that are
410 opposed to good light hygiene.

411 Conclusion

412 We developed a novel self-reported subjective tool- “Light exposure behaviour
413 assessment”(LEBA) to capture light exposure related behaviour. We developed 48
414 items, judged the relevance and content of the items and conducted a large scale
415 geographically unrestricted cross-sectional survey. Our EFA gave a five solution with 25
416 items. A CFA with this 25-item scale again offered a five-factor solution, but this time two
417 more item was discarded. The 23-item “LEBA” was found reliable (internal consistency)
418 and valid (structural validity). A short-form of LEBA was developed using IRT analysis.
419 IRT analysis gave a 18-item scale with a good coverage across the underlying trait
420 continuum. Hence, we could recommend that LEBA can be used to measure different
421 aspects of light exposure related behaviour.

422 Future Direction 

423 Since, LEBA is the first of its kind, estimating convergent validity with other
424 subjective tool was not possible. One way to establish the convergent validity of LEBA is
425 to administer this subjective tool along which some objective measurement tools
426 (e.g. personalised light dosimeter). Though such objective tools do not directly capture
427 light exposure related behaviour, potential insight can be drawn by understanding the
428 behaviour pattern and light exposure. Also, light exposure related behaviours can be
429 dependent upon the socio-economic status as behaviours can be modulated by
430 available tools individual have on their disposal. Our analysis did not consider
431 socio-economic status, as we didn't measure it. Investigating the properties of LEBA
432 while considering different socio-economic status would be a valuable addition.

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Table 1

List of instruments measuring related constructs to LEBA

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

Table 1 continued

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

Table 2

Demographic Characteristics

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

¹ Mean (SD); n (%)² False discovery rate correction for multiple testing³ Wilcoxon rank sum test ⁴ Pearson's Chi-squared test

Table 3

Descriptive Statistics

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

Table 3 continued

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

Table 3 continued

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

Table 3 continued

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

Note. * $p < .001$

Table 4

Factor loadings and communality of the retained items

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

Note. Only loading higher than .30 is reported

Table 5

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

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

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

Table 6

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

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

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

Table 7

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

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

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

= response category difficulty parameter

Table 8

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

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

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

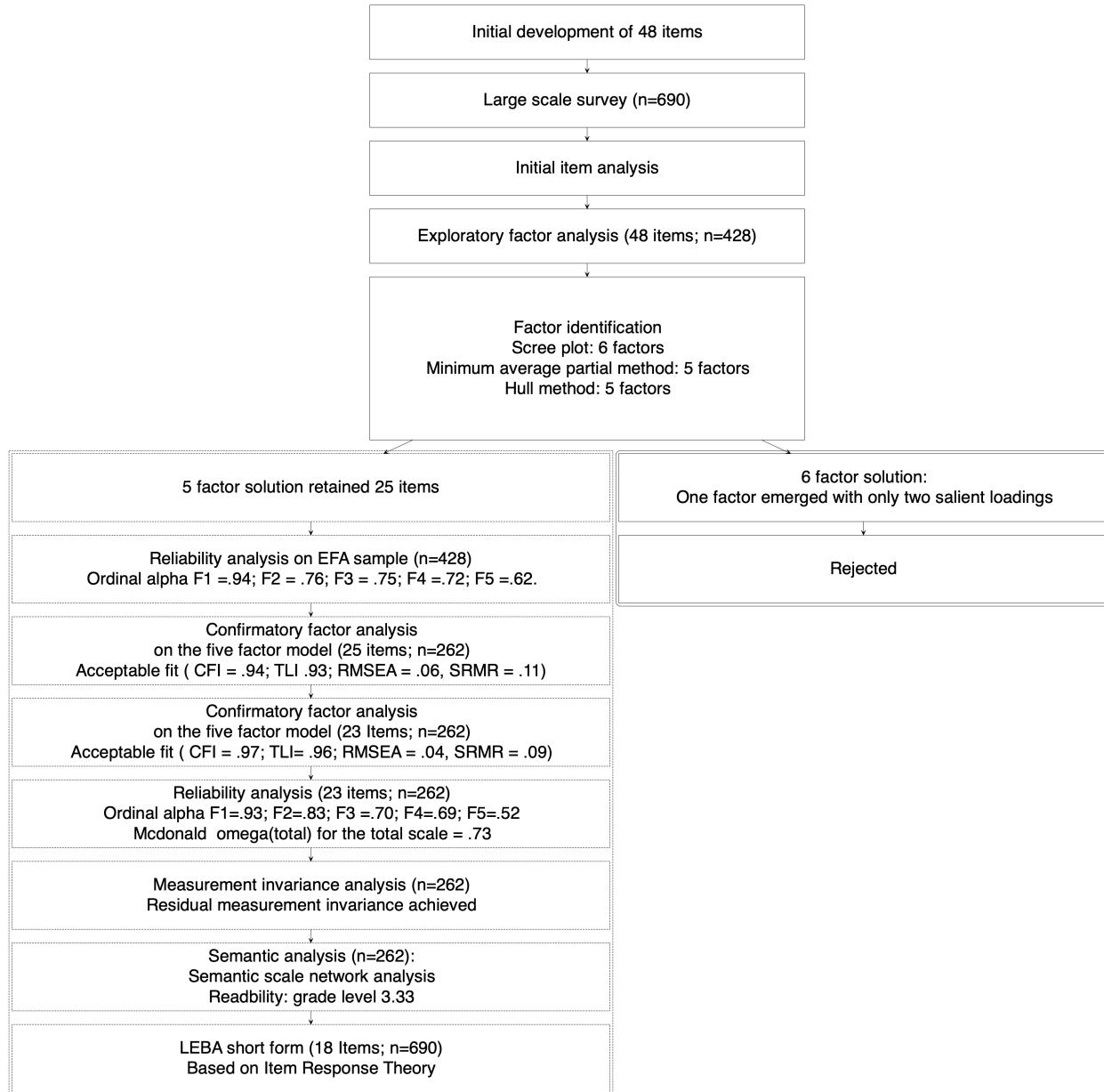


Figure 1. Development of long and short form of LEBA

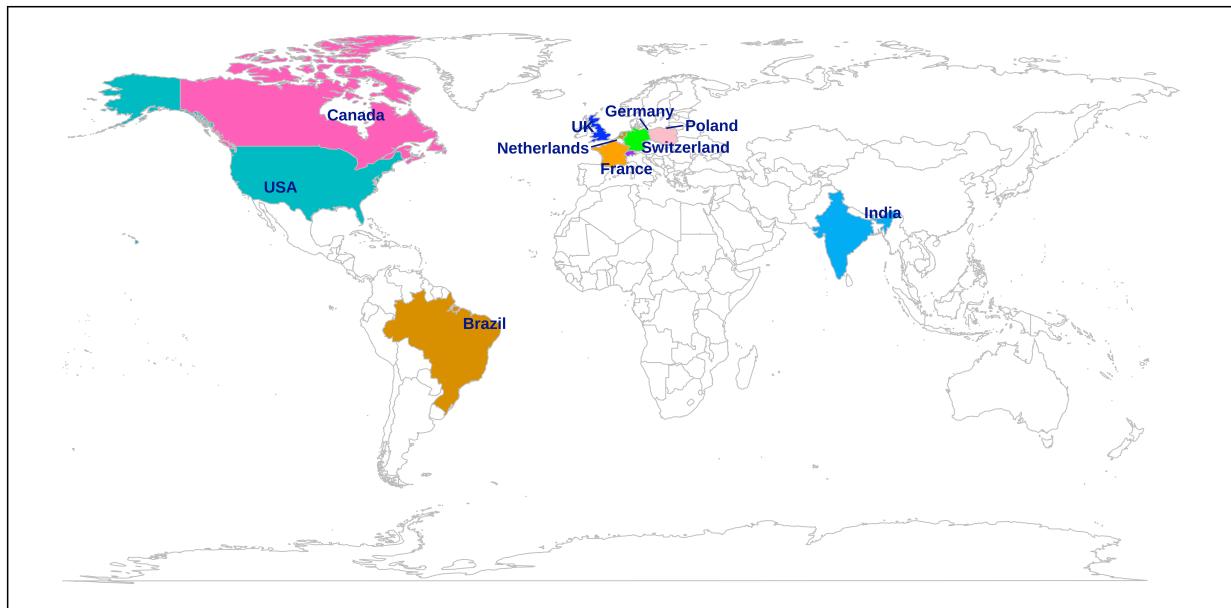


Figure 2. Top ten countries with highest responses in our survey

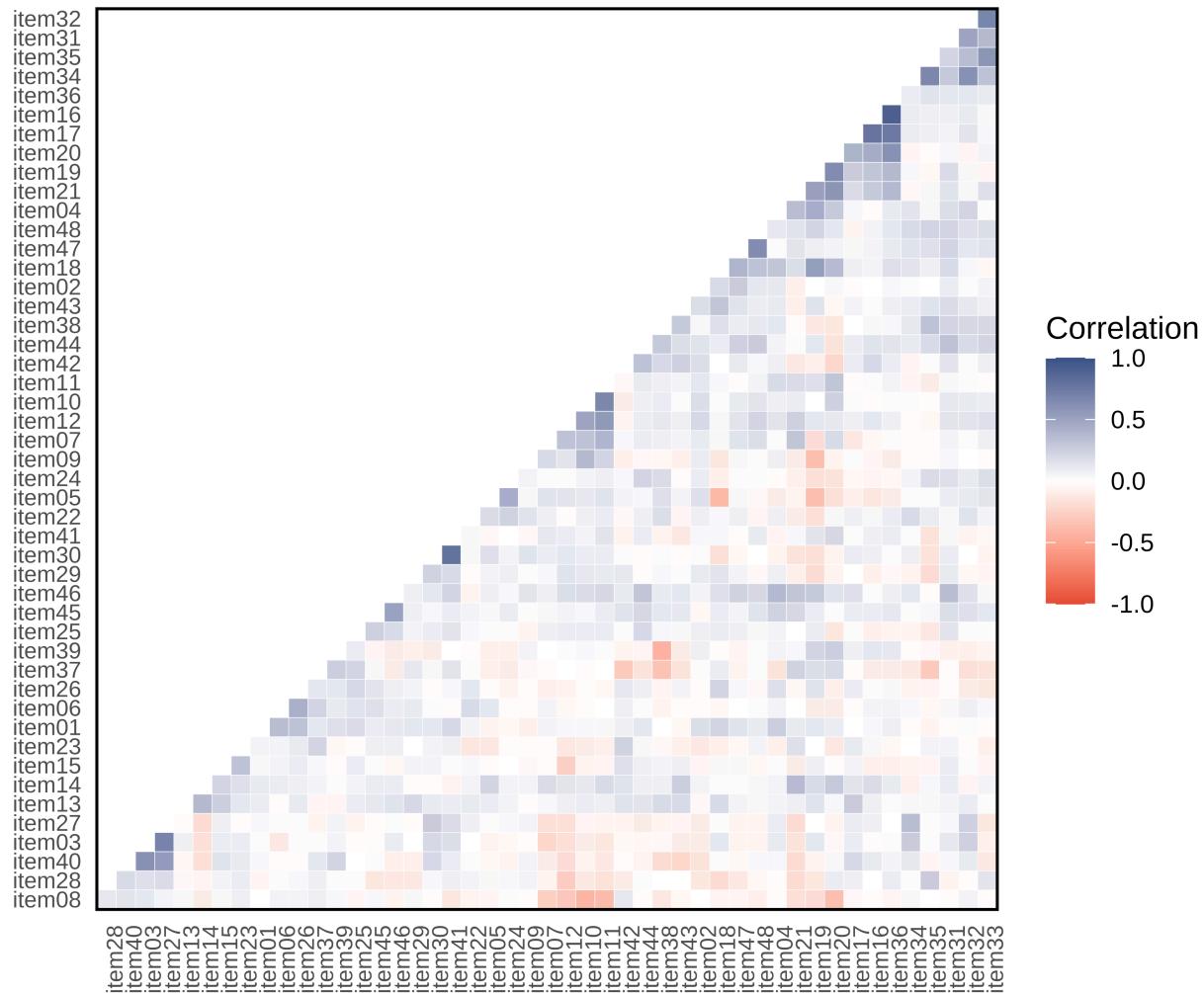


Figure 3. Inter-item polychoric correlation coefficients for the 48 items. 4.9 % inter-item correlation coefficients were higher than |.30|

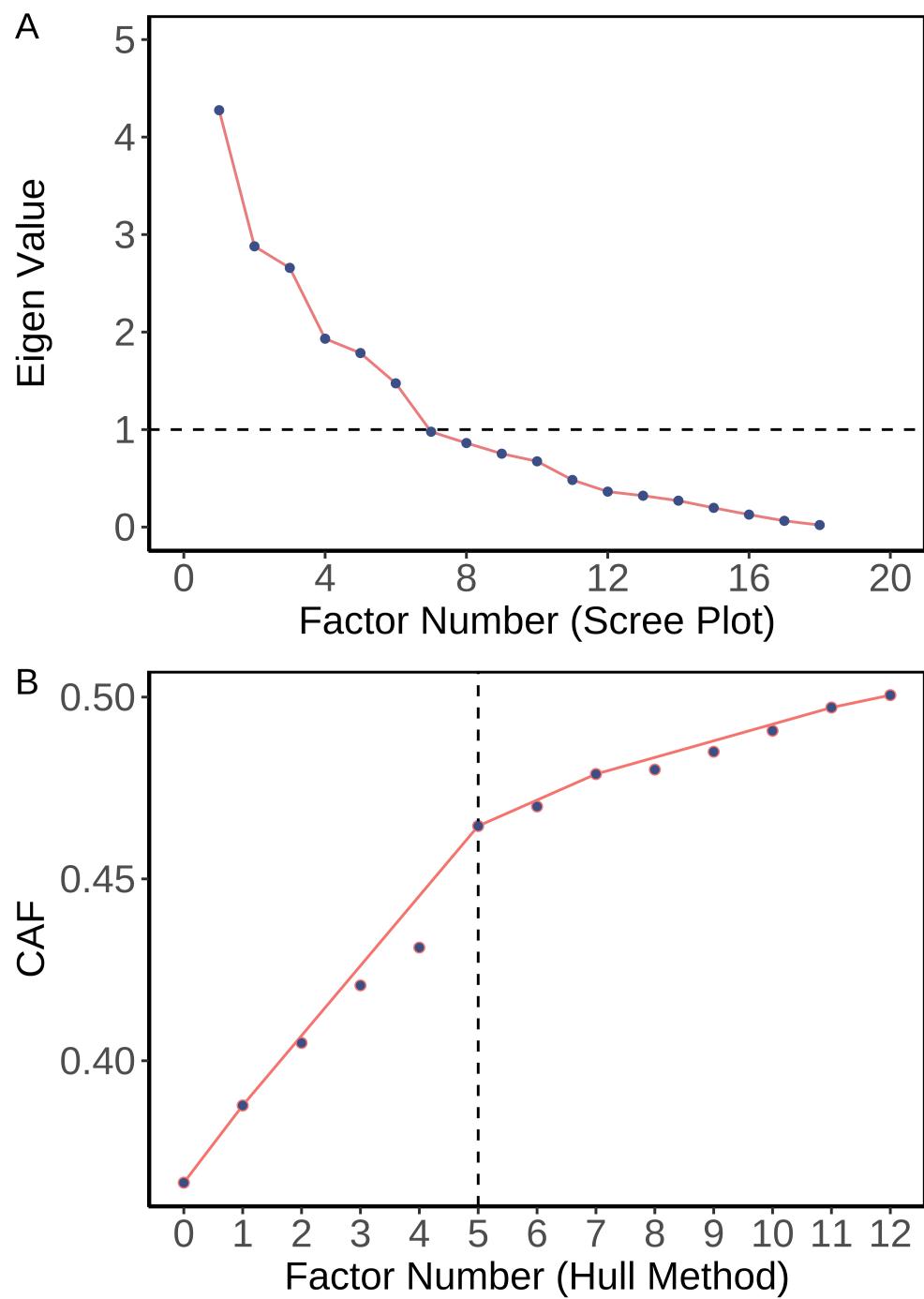


Figure 4. Factor Identification Methods (A) Scree plot suggested six factors. (B) Hull method indicated 5 factors were required to balance the model fit and number of parameters.

A

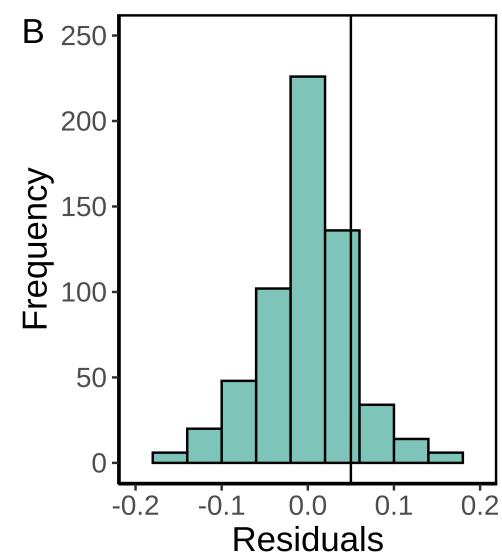
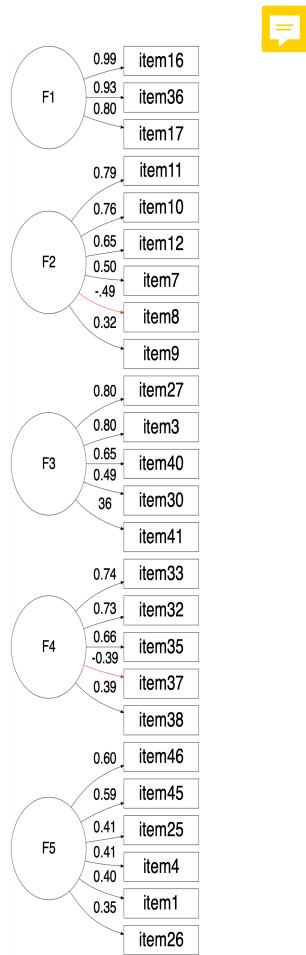


Figure 5. (A) Five factor solution obtained in exploratory factor analysis (B) Histogram of nonredundant residual correlations



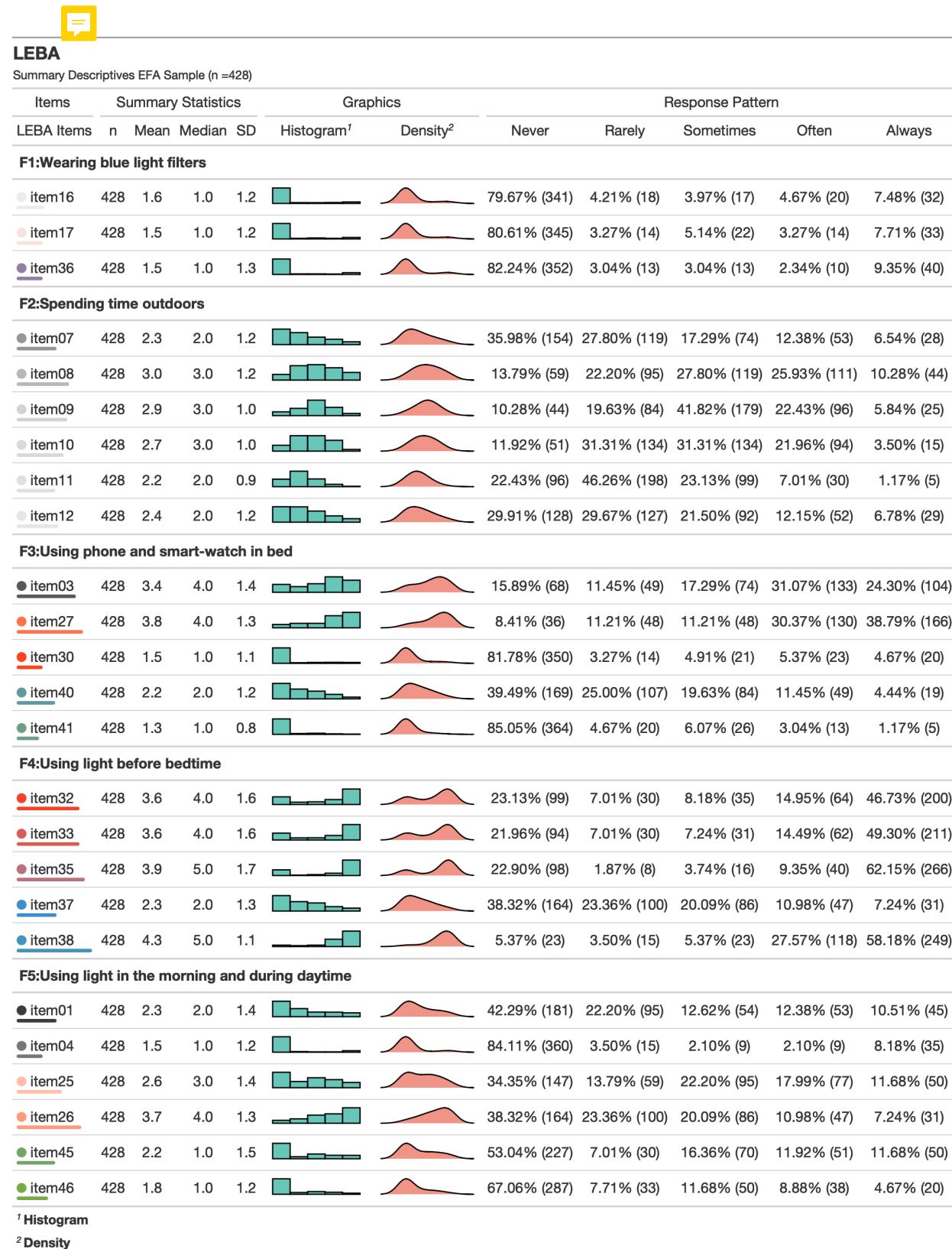


Figure 6. Summary descriptives and response pattern of EFA sample

LEBA

Summary Descriptives CFA Sample (Nn=262)

Items	Summary Statistics				Graphics		Response Pattern					
	LEBA Items	n	Mean	Median	SD	Histogram ¹	Density ²	Never	Rarely	Sometimes	Often	Always
F1:Wearing blue light filters												
item16	262	1.6	1.0	1.3	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	1.2			75.57% (198)	2.67% (7)	8.02% (21)	9.54% (25)	4.20% (11)

¹ Histogram² Density

Figure 7. Summary descriptives and response pattern of CFA sample

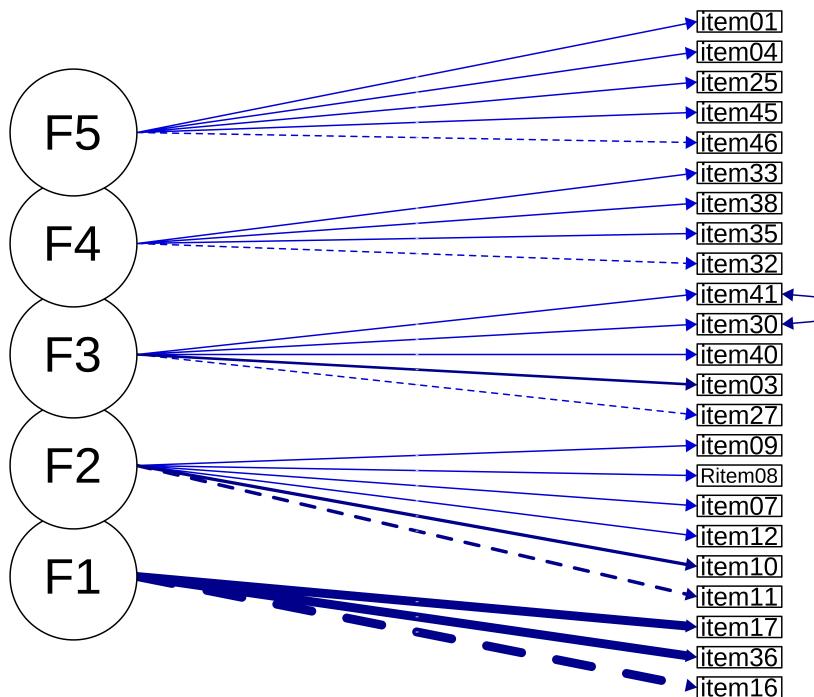


Figure 8. Five factor model of LEBA obtained by confirmatory factor analysis. By allowing item pair 41 and 30 to covary their error variance our model attained the best fit.

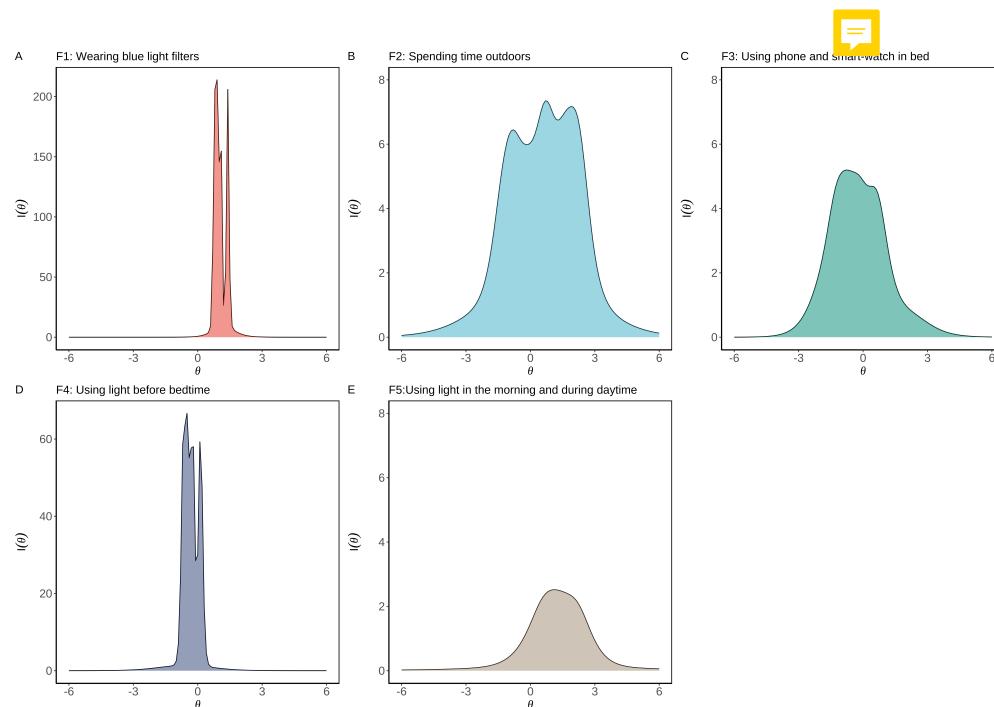


Figure 9. Test information curves (a) wearing blue light filters (b) spending time outdoors (c) using phone and smartwatch in bed (d) using light before bedtime (e) using light in the morning and during daytime

Appendix

⁷⁷⁶ **Disclaimer:** This is a non-public version of LEBA (dated February 16, 2022) and still a
⁷⁷⁷ work in progress. Please do not distribute!

⁷⁷⁸ LEBA captures light exposure-related behaviours on a 5 point Likert type scale
⁷⁷⁹ ranging from 1 to 5 (Never = 1; Rarely = 2; Sometimes = 3; Often = 4; Always = 5). The
⁷⁸⁰ score of each factor is calculated by the summation of scores of items belonging to the
⁷⁸¹ corresponding factor.

⁷⁸² **Instruction:**

⁷⁸³ “Please indicate how often you performed the following behaviours in the **past 4**
⁷⁸⁴ **weeks.**”

Table A1

LEBA Long Form (23 Items)

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

Table A1 continued

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

Table A2

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

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

Table A3

LEBA Short Form (18 Items)

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

Table A4

LEBA Short Form (18 Items): Latent Structure

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

Table A5

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

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

Table A6

Demographic characteristics: measurement invariance

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

¹ Mean (SD); n (%)² False discovery rate correction for multiple testing³ Wilcoxon rank sum test⁴ Fisher's exact test⁵ Pearson's Chi-squared test

Table A7

Factor loadings and communality of the retained items (minimum residual)

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

Note. Only loading higher than .30 is reported

Table A8

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

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

Table A8 continued

item	PA1	PA2	PA3	PA4	PA5	PA6	Communality	Uniqueness
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Note. Only loading higher than .30 is reported; Sixth factor has only two salient loadings

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Table A9

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

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

Table A9 continued

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

Note. Only loading higher than .30 is reported

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Table A10

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

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

Table A10 continued

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

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

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Table A11

Geographical location of the participants (n =690)

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

Table A11 continued

Timezone	Number of Participants
America/Anchorage (UTC -08:00)	3.00
America/Araguaina (UTC -03:00)	2.00
America/Argentina/Buenos_Aires (UTC -03:00)	5.00
America/Argentina/Cordoba (UTC -03:00)	2.00
America/Argentina/Jujuy (UTC -03:00)	1.00
America/Bahia (UTC -03:00)	2.00
America/Blanc-Sablon (UTC -04:00)	1.00
America/Bogota (UTC -05:00)	2.00
America/Boise (UTC -06:00)	4.00
America/Cayman (UTC -05:00)	1.00
America/Chicago (UTC -05:00)	30.00
America/Costa_Rica (UTC -06:00)	2.00
America/Cuiaba (UTC -04:00)	1.00
America/Denver (UTC -06:00)	6.00
America/Detroit (UTC -04:00)	6.00
America/Edmonton (UTC -06:00)	14.00
America/Fortaleza (UTC -03:00)	1.00
America/Guatemala (UTC -06:00)	1.00
America/Guayaquil (UTC -05:00)	2.00
America/Halifax (UTC -03:00)	1.00
America/Indiana/Indianapolis (UTC -04:00)	3.00
America/Indiana/Tell_City (UTC -05:00)	1.00
America/Kentucky/Louisville (UTC -04:00)	3.00
America/Los_Angeles (UTC -07:00)	37.00
America/Martinique (UTC -04:00)	1.00
America/Mexico_City (UTC -06:00)	2.00
America/Moncton (UTC -03:00)	2.00
America/Monterrey (UTC -06:00)	1.00
America/New_York (UTC -04:00)	63.00

Table A11 continued

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

Table A11 continued

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

Table A11 continued

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

Table A12

Five factor obtained from the unmerged data.

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

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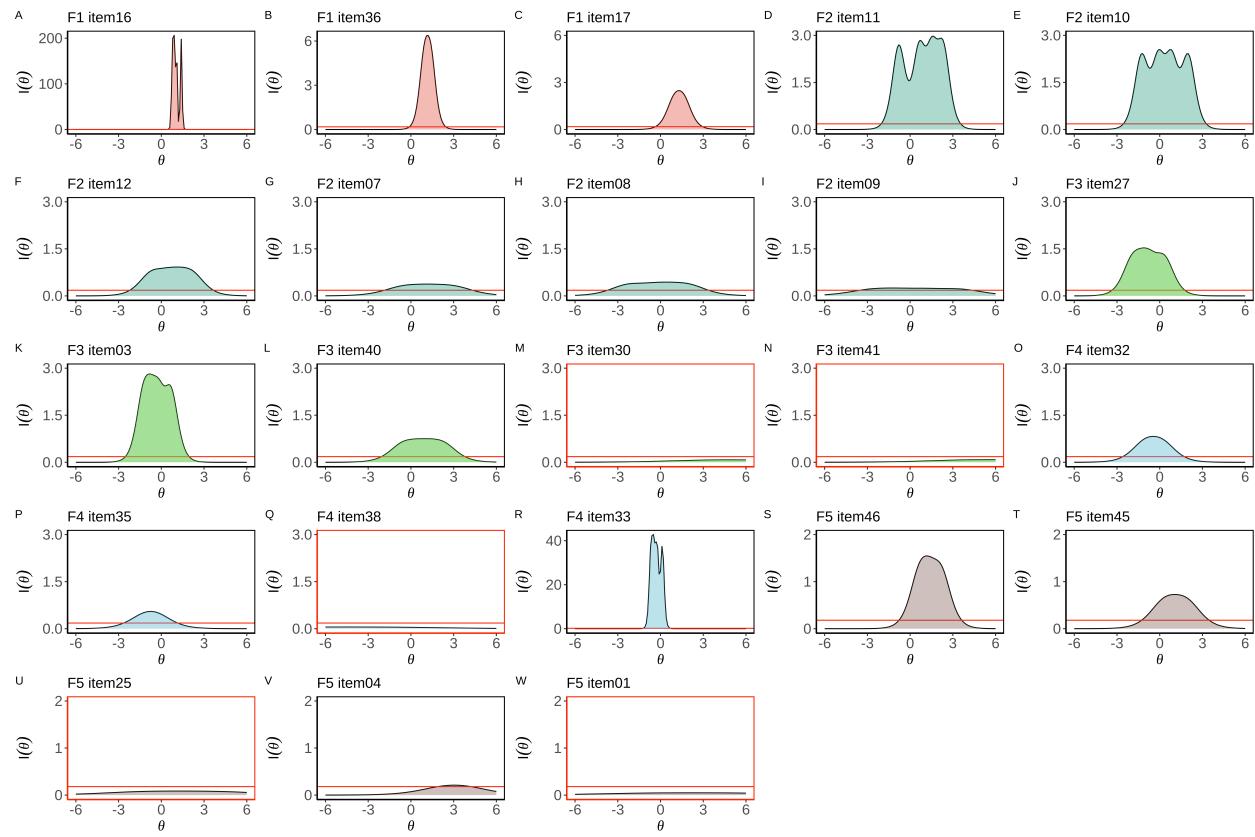


Figure A1. Item information curve. Five items (1, 25, 38, 30, 41) had relatively flat information curves

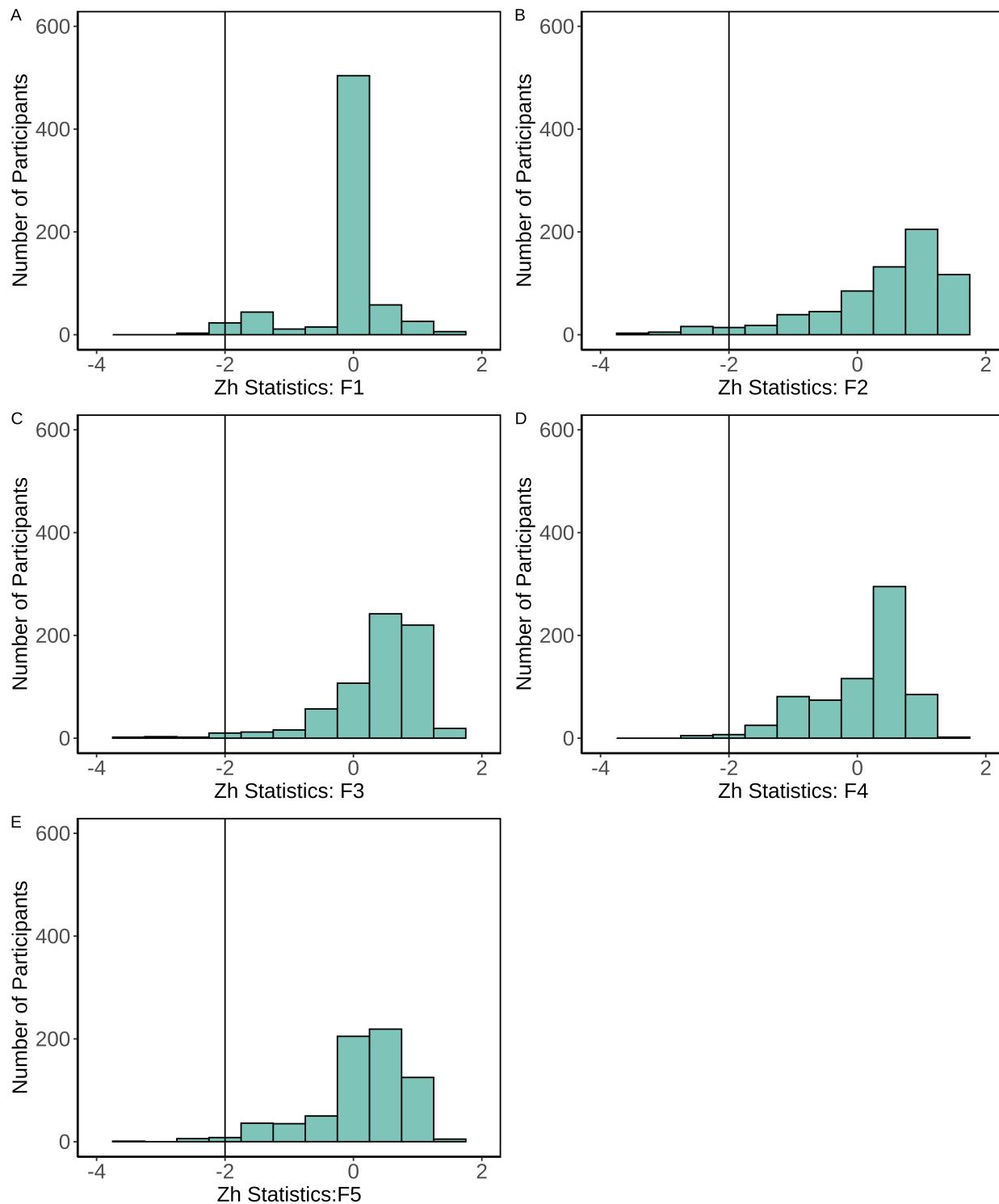


Figure A2. Person fit of the five fitted IRT models (a) Wearing blue light filters (b) Spending time outdoors (c) Using phone and smartwatchin bed (d) Using light before bedtime (e) Using light in the morning and during daytime