

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

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51

Abstract

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

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

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

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

⁷⁸ psychometrics

⁷⁹ Word count: X

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

Introduction

- Light exposure is important
 - Light exposure Behaviour is important
 - Supplementary Table S1 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

90 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 (<https://enlightenyourclock.org/participate-in-research>) of the science-communication comic-book “Enlighten your clock” co-released with the survey (Weinzaepflein & 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

103 parents/legal guardians. The entire survey was estimated to take <30 minutes.
104 Participants were not compensated. As a part of the demographic information
105 participants provided information regarding age, sex, gender identity, occupational
106 status, COVID-19 related occupational setting, time zone/country of residence and
107 native language. The demographic characteristics of our sample are given in Table
108 ???. To ensure high data quality, five attention check items were included in the survey
109 (e.g., “We want to make sure you are paying attention. What is 4+5?”). Participants were
110 asked to confirm that they were participating the survey for the first time. Questions
111 incorporating retrospective recall were all aligned to the period of “past four weeks.”

112 We conducted two rounds of data collections. At first we collected data from
113 428 participants In the second round we collected data from another 262 participants
114 making a total sample of 690.

115 The data analysed in this study was collected between 17 May 2021 and 3
116 September 2021.

117 Analytic Strategy

118 Figure 1 summarizes the steps of our psychometric analysis. In our analysis we
119 used R (version 4.1.0) (R Core Team, 2021). In the item generation and selection phase
120 we had developed a item pool of 48 items with six-point Likert type response format
121 (0-Does not apply/I don't know, 1-Never, 2-Rarely 3-Sometimes, 4-Often, 5-Always). Our
122 purpose was to capture light exposure related behaviour. In that context, the first two
123 response options: “Does not apply/I don't know” and “Never” were providing similar
124 information. As such we collapsed them into one, making it a 5 point Likert type
125 response format.

126 We conducted an initial item analysis and proceed to the exploratory factor analysis
127 (EFA) with all 48 items using the data collected in our first round. (EFA sample;n=428).

Prior to the EFA, necessary assumptions, including sample adequacy, normality assumptions, quality of correlation matrix were assessed. Our data violated both the univariate and multivariate normality assumptions. Due to these violations and the ordinal nature of our response data, in EFA we used polychoric correlation matrix and employed principal axis (PA) as factor extraction method with varimax rotation (Desjardins & Bulut, 2018; Watkins, 2020). We used a combination of factor identification method including Scree plot (Cattell, 1966), minimum average partials method (Velicer, 1976), and Hull method (Lorenzo-Seva, Timmerman, & Kiers, 2011) to identify factor numbers. To determine the latent structure, we followed the common guidelines : (i) no factors with fewer than three items (ii) no factors with a factor loading <0.3 (iii) no items with cross-loading $> .3$ across factors (Bandalos & Finney, 2018). We also conducted a EFA on non-merged response options data (Supp. Table A9).

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

To validate the latent structure obtained in EFA, We conducted a categorical confirmatory factor analysis (CFA) with weighted least square with mean and variance adjusted (WLSMV) estimator (Desjardins & Bulut, 2018) on the data collected in our second round of data collection (CFA sample; n=262). We assessed the model fit using

common model fit guidelines: (i) χ^2 test statistics: a non-significant test statistics is required to accept the model (ii) comparative fit index (CFI) and Tucker Lewis index (TLI): close to .95 or above/ between 90-95 and above (iii) root mean square error of approximation (RMSEA): close to .06 or below, (iv) Standardized root mean square (SRMR): close to .08 or below (Hu & Bentle, 1999; Schumacker & Lomax, 2004). However, the χ^2 test is sensitive to sample size (Brown, 2015) and SRMR does not work well with ordinal data (Yu, 2002) As such, we judged the model fit using CFI, TLI, SRMR and RMSEA.

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

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

181 Lastly, we sought Item Response Theory (IRT) based analysis on developing a
182 short form of LEBA. We fitted each factor of LEBA using the graded response model
183 (Samejima, Liden, & Hambleton, 1997) to the combined EFA and CFA sample (n =690).
184 IRT assesses the item quality by estimating item discrimination, item difficulty, item
185 information, and test information (Baker, 2017). Item discrimination indicates the pattern
186 of variation in the categorical responses with the changes in latent trait level (θ). Item
187 information curve (IIC) indicates the amount of information an item carries along the
188 latent trait continuum. Here, we reported the item discrimination parameter and
189 categorize the items according to the suggestions of Baker (2017) : none = 0; very low
190 =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
191 >1.70. We discarded the items with relatively flat item information curve (information <.2)
192 to develop the short form of LEBA. We also assessed the precision of the short LEBA
193 using Test information curve (TIC). TIC indicates the amount of information an the
194 full-scale carry along the latent trait continuum. Item fit and person fit of the fitted IRT
195 models were also analyzed to gather more evidence on validity and meaningfulness of
196 our Tool (Desjardins & Bulut, 2018). Item fit was evaluated using the RMSEA value
197 obtained from Signed- χ^2 index implementation, RMSEA value $\leq .06$ was considered
198 adequate item fit. Person fit was estimated using standardized fit index Zh statistics
199 (Drasgow, Levine, & Williams, 1985). Zh < -2 was be considered as a misfit (Drasgow et
200 al., 1985).

201 **Ethical approval**

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

207 responsibility.

208 **Data Availability**

209 The present article is a fully reproducible open-access “R Markdown” document. All
210 code and data underlying this article – along with two versions of the LEBA questionnaire
211 (full and short) and online survey implementation templates on common survey platforms
212 – will be available under open-access licence (CC-BY-NC-ND) on a public GitHub
213 repository.

214 **Results**

215 **Initial development of items**

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

227 **Large-scale survey of instruments**

228 **Participants.** Table ?? summarizes the survey participants’ demographic
229 characteristics. Only participants completing the full LEBA questionnaire were included,

thus there are no missing values in the item analyses. (XX??) participants were excluded from analysis due to not passing at least one of the “attention check” items. For EFA, a sample of 250-300 is recommended (Comrey & Lee, 1992; Schönbrodt & Perugini, 2013). To assess sampling adequacy for CFA, we followed the N:q rule (Bentler & Chou, 1987; Jackson, 2003; Kline, 2015; Worthington & Whittaker, 2006), where ten participants per item is required to earn trustworthiness of the result. Both our EFA and CFA sample size exceeded these requirements. We collected data from 74 countries (28 time zones). Participants reported a diverse range of geographic location. Participants indicated filling out the online survey from a diverse range of geographic locations. For a complete list of geographic locations, see Suppl. Table A11.

Participants in our survey aged between 11 to 84 years [EFA sample: *min* = 11, *max* = 84; CFA sample: *min* = 12, *max* = 74], with an overall mean of ~ 32.95 years of age [Overall: *M* = 32.95, *SD* = 14.57; EFA: *M* = 32.99, *SD* = 15.11; CFA: *M* = 32.89, *SD* = 13.66]. In total 325 (47%) of the participants indicated female sex [EFA: 189 (44%); CFA: 136 (52%)], 351 (51%) indicated male [EFA: 230 (54%); CFA: 121 (46%)] and 14 (2.0%) indicated other sex [EFA: 9 (2.1%), CFA: 5 (1.9%)]. Overall, 49 (7.2%) [EFA: 33 (7.8%); CFA: 16 (6.2%)] participants indicated a gender-variant identity. In a “Yes/No” question regarding native language, 320 (46%) of respondents [EFA: 191 (45%); CFA: 129 (49%)] indicated to be native English speakers. For their “Occupational Status,” more than half of the overall sample reported that they currently work [Overall: 396 (57%); EFA: 235 (55%); CFA: 161 (61%)], whereas 174 (25%) [EFA: 122 (29%); CFA: 52 (20%)] reported that they go to school and 120 (17%) [EFA: 71 (17%); CFA: 49 (19%)] responded that they do “Neither.” With respect to the COVID-19 pandemic we asked participants to indicate their occupational setting during the last four weeks: In the overall sample 303 (44%) [EFA: 194 (45%); CFA: 109 (42%)] of the participants indicated that they were in a home office/ home schooling setting, while 109 (16%) overall [EFA: 68 (16%); CFA: 41 (16%)] reported face-to-face work/schooling. Lastly, 147 (21%) overall [EFA: 94 (22%);

257 CFA: 53 (20%)] reported a combination of home- and face-to-face work/schooling,
258 whereas 131 (19%) overall [EFA: 72 (17%); CFA: 59 (23%)] filled in the “Neither (no work
259 or school, or on vacation)” response option. We tested all demographic variables in
260 Table 1 for significant group differences between the EFA and CFA sample, applying
261 Wilcoxon rank sum test for the continuous variable “Age” and Pearson’s χ^2 test for all
262 other categorical variables via the gtsummary R package’s “add_p” function (Sjoberg et
263 al., 2021a). The p-values were corrected for multiple testing applying false discovery
264 rate (FDR) via the “add_q” function of the same package. After p-value (FDR) correction
265 for multiple testing, none of the demographic variables were significantly different
266 between the EFA sample and the CFA sample (all q-values $q \geq \text{Inf}$).

267 **Descriptive Statistics.** Figure 2 and Figure 3 summarize the response pattern of
268 our total sample ($n = 690$) for all 48 items. Most of the items were skewed and violated
269 normality assumption.

270 **Item Analysis.** S1 Fig summarizes the univariate descriptive statistics for the 48
271 items among EFA sample ($n = 428$). Our data violated both univariate normality (Shapiro
272 & Wilk, 1965) and multivariate normality assumptions (Mardia, 1970). Multivariate skew
273 was 583.80 ($p < 0.001$) and multivariate kurtosis was 2,749.15 ($p < 0.001$). Due to these
274 violations and ordinal nature of the response data polychoric correlations over Pearson’s
275 correlations was chosen (Desjardins & Bulut, 2018). The corrected item-total correlation
276 ranges between .03 - .48. However, no item was discarded based on descriptive
277 statistics or item analysis.

278 **Exploratory Factor Analysis.** Sampling adequacy was checked using
279 Kaiser-Meyer-Olkin (KMO) measures of sampling adequacy using the EFA sample (n
280 = 428) (Kaiser, 1974). The overall KMO vale for 48 items was 0.63 which was above the
281 cutoff value (.50) indicating adequate sample size (Hutcheson, 1999). Bartlett’s test of
282 sphericity (Bartlett, 1954), χ^2 (1128) = 5042.86, $p < .001$ indicated the correlations
283 between items are adequate for conducting the EFA. However only 4.96% of the

284 inter-item correlation coefficients were greater than |.30|. The inter-item correlation
285 coefficients ranged between -.44 to .91. Figure ?? depicts the correlation matrix.

286 Scree plot (Figure ??) suggested a six-factor solution. However, the minimum
287 average partial (MAP) (Velicer, 1976) method (Table A5) and Hull method (Lorenzo-Seva
288 et al., 2011) (Figure ??) suggested a five-factor solution. As a result, we tested both
289 five-factor and six-factor solutions.

290 With the initial 48 items we conducted three rounds of EFA and gradually discarded
291 problematic items. (cross-loading items and poor factor loading (<.30) items). Finally, a
292 five-factor EFA solution with 25 items was accepted with all factor-loading higher than
293 .30 and no cross-loading greater than .30. We further confirmed this five-factor latent
294 structure by another EFA using varimax rotation with a minimum residual extraction
295 method (Sup.Table A7). Table 2 displays the factor-loading (structural coefficients) and
296 communality of the items. The absolute value of the factor-loading ranged from .49 to
297 .99 indicating strong coefficients. The commonalities ranged between .11 to .99. Figure
298 ?? depicts the data distribution and endorsement pattern for the included 25 items.
299 Figure ??(A) depicts the five factor structure obtained in EFA. However, the histogram of
300 the absolute values of non-redundant residual-correlations (Figure ??(B)) showed 26%
301 correlations were greater than the absolute value of .05, indicating a possible
302 under-factoring. (Desjardins & Bulut, 2018). Subsequently, we fitted a six-factor solution.
303 However, a factor emerged with only two salient variables, thus disqualifying the
304 six-factor solution (Sup.Table A8).

305 In the five-factor solution, the first factor contained three items and explained
306 10.25% of the total variance with an internal reliability coefficient ordinal $\alpha = .94$. All the
307 items in this factor stemmed from the individual's preference of using blue light filters in
308 different light environments. The second factor contained six items and explained 9.93%
309 of the total variance with an internal reliability coefficient ordinal $\alpha = .76$. Items under this

factor investigated individuals' hours spent outdoor. The third factor contained five items and explained 8.83% of the total variance. Items under this factor dealt with the specific behaviours pertaining to using phone and smart-watch in bed. The internal consistency reliability coefficient was, ordinal $\alpha = .75$. The fourth factor contained five items and explained 8.44% of the total variance with an internal consistency coefficient, ordinal $\alpha = .72$. These five items investigated the behaviours related to individual's light exposure before bedtime. Lastly, the fifth factor contained six items and explained 6.14% of the total variance. This factor captured individual's morning and daytime light exposure related 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 3 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

337 (SRMR = .12). Further by allowing one pair of items (30-41) [I look at my smartwatch
338 within 1 hour before attempting to fall asleep.; I look at my smartwatch when I wake up at
339 night.] to covary their error variance and discarding two item (item 37 & 26) for very low
340 r-square value, our model attained the best fit (CFI = .95; TLI = .95); RMSEA =
341 .06[.05-.06, 90% CI]). Internal consistency ordinal α for the five factors of LEBA were
342 .96, .83, .70, .69, .52 respectively. Internal consistency McDonald's ω_t coefficient for the
343 total scale was .68. Figure 5 depicts the obtained CFA structure. Figure ?? depicts the
344 data distribution and endorsement pattern of the retained 23 items in our CFA sample.

345 **Measurement Invariance.** In our CFA sample we had 129 native English speakers
346 and 133 non-native English speakers (For a detailed description these two groups see
347 Sup. Table ??). Table 4 indicates our fitted model had acceptable fit indices for all of the
348 fitted MI models. The model fit did not significantly decrease across the nested models
349 indicating the acceptability of the highest measurement invariance model : residual
350 model.

351 **Semantic Analysis.** “Semantic Scale Network”(SSN) analysis (Rosenbusch et al.,
352 2020) indicated that LEBA (23 items) appeared most strongly related to scales about
353 sleep: “Sleep Disturbance Scale For Children” (Bruni et al., 1996) and “WHO-Composite
354 International Diagnostic Interview (CIDI): Insomnia”(WHO, 1990). The cosine similarities
355 lie between .47 to .51. Flesch-Kincaid Grade Level (Flesch, 1948) analysis on the the 23
356 items of our scale indicated required educational grade level was 3.33 and with a age
357 above 8.33.

358 **Developing Short form of LEBA.** We fitted each factor of LEBA with the graded
359 response model (Samejima et al., 1997) to the combined EFA and CFA sample (n =690).
360 Item discrimination parameters of our tool fell in very high (10 items), high (4 items),
361 moderate (4 items), and low (5 items) categorizes indicating a good range of
362 discrimination along the latent trait level (θ) (Supplementary Table 2). Examination of the
363 item information curve (Sup.fig A1) indicated five items (1, 25, 38, 30, & 41) had

364 relatively flat information curves ($I(\theta) < .20$). We discarded those items which yielded a
365 short form of LEBA with 5 factors and 18 items.

366 We treated each factor of short-LEBA as an unidimensional construct and obtain 5
367 TICs (Figure 6). These information curves indicated except the first and fifth factors, the
368 other three factor's TICs are roughly centred on the centre of the trait continuum (θ). The
369 first and fifth factor had a peak to the right side of the centre of latent trait. Thus we
370 conferred the LEBA tool estimated the light exposure related behaviour with precision
371 near the centre of trait continuum for 2nd, 3rd and 4th factors and near the right side of
372 the centre of trait continuum for 1st and 5th factors (Baker, 2017).

373 Supplementary Table S3 summarizes the item fit indexes of the 18 items. All of the
374 items had RMSEA value $\leq .06$ indicating adequate fit of the items to the fitted IRT model.
375 Sup. Figure A2 depicts the person fit Zh statistics histogram of out fitted models. Zh
376 statistics are larger than -2 for most participants, suggesting a good person fit of the
377 selected IRT models.

378 Discussion

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

384 Authors along with an expert panel generated 48 items and evaluated their quality
385 and relevance and made necessary amendments. A large scale geographically
386 unconstrained quantitative cross-sectional survey was conducted yielding responses
387 from large sample ($n=428$) to explore the latent structure. Exploratory factor analysis
388 revealed a five factor solution with 25 items. ("Wearing blue light filters," "Spending time

389 outdoors," "Using phone and smart-watch in bed," "Using light before bedtime," and
390 "Using light in the morning and during daytime"). The internal consistency reliability
391 coefficient ordinal alpha ranged between .62.94. As all the retained factors were
392 meaningful and contributed essentially towards our aim we retained all five factors.

393 LEBA can be used to profile individuals based on their light exposure related
394 behaviours, which can facilitate the development process of individual interventions to
395 promote health. All the five factors of LEBA may identify 'problematic' behaviours that
396 are opposed to good light hygiene.

397 Conclusion

398 We developed a novel self-reported subjective tool—"Light exposure behaviour
399 assessment"(LEBA) to capture light exposure related behaviour. We developed 48
400 items, judged the relevance and content of the items and conducted a large scale
401 geographically unrestricted cross-sectional survey. Our EFA gave a five solution with 25
402 items. A CFA with this 25-item scale again offered a five-factor solution, but this time two
403 more item was discarded. The 23-item "LEBA" was found reliable (internal consistency)
404 and valid (structural validity). A short-form of LEBA was developed using IRT analysis.
405 IRT analysis gave a 18-item scale with a good coverage across the underlying trait
406 continuum. Hence, we could recommend that LEBA can be used to measure different
407 aspects of light exposure related behaviour.

408 Future Direction

409 Since, LEBA is the first of its kind, estimating convergent validity with other
410 subjective tool was not possible. One way to establish the convergent validity of LEBA is
411 to administer this subjective tool along which some objective measurement tools
412 (e.g. personalised light dosimeter). Though such objective tools do not directly capture

413 light exposure related behaviour, potential insight can be drawn by understanding the
414 behaviour pattern and light exposure. Also, light exposure related behaviours can be
415 dependent upon the socio-economic status as behaviours can be modulated by
416 available tools individual have on their disposal. Our analysis did not consider
417 socio-economic status, as we didn't measure it. Investigating the properties of LEBA
418 while considering different socio-economic status would be a valuable addition.

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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

item	Stem	PA1	PA2	PA3	PA4	PA5	Communality	Uniqueness
item16	I wear blue-filtering, orange-tinted, and/or red-tinted glasses indoors during the day.	0.99					0.993	0.007
item36	I wear blue-filtering, orange-tinted, and/or red-tinted glasses within 1 hour before attempting to fall asleep.	0.94					0.899	0.101
item17	I wear blue-filtering, orange-tinted, and/or red-tinted glasses outdoors during the day.	0.8					0.658	0.342
item11	I spend more than 3 hours per day (in total) outside.		0.79				0.642	0.358
item10	I spend between 1 and 3 hours per day (in total) outside.		0.76				0.592	0.408
item12	I spend as much time outside as possible.		0.65				0.465	0.535
item07	I go for a walk or exercise outside within 2 hours after waking up.		0.5				0.267	0.733
item08	I spend 30 minutes or less per day (in total) outside.		-0.49				0.252	0.748
item09	I spend between 30 minutes and 1 hour per day (in total) outside.		0.32				0.113	0.887
item27	I use my mobile phone within 1 hour before attempting to fall asleep.			0.8			0.658	0.342
item03	I look at my mobile phone screen immediately after waking up.			0.8			0.682	0.318
item40	I check my phone when I wake up at night.			0.65			0.464	0.536
item30	I look at my smartwatch within 1 hour before attempting to fall asleep.			0.45			0.353	0.647
item41	I look at my smartwatch when I wake up at night.			0.36			0.329	0.671

Table 2 continued

item	Stem	PA1	PA2	PA3	PA4	PA5	Communality	Uniqueness
item33	I dim my computer screen within 1 hour before attempting to fall asleep.			0.74		0.555	0.445	
item32	I dim my mobile phone screen within 1 hour before attempting to fall asleep.			0.73		0.624	0.376	
item35	I use a blue-filter app on my computer screen within 1 hour before attempting to fall asleep.			0.66		0.454	0.546	
item37	I purposely leave a light on in my sleep environment while sleeping.			-0.39		0.174	0.826	
item38	I use as little light as possible when I get up during the night.		0.38		0.178		0.822	
item46	I use tunable lights to create a healthy light environment.			0.6	0.422		0.578	
item45	I use LEDs to create a healthy light environment.			0.59	0.374		0.626	
item25	I use a desk lamp when I do focused work.		0.41		0.193		0.807	
item04	I use an alarm with a dawn simulation light.		0.41		0.219		0.781	
item01	I turn on the lights immediately after waking up.		0.4		0.17		0.83	
item26	I turn on my ceiling room light when it is light outside.		0.35		0.165		0.835	

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
Model 1	448.51	222.00	.94	0.93	0.06	0.05	0.07	0.12
Model 2	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 4

Measurment 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; d = Structural vs Residual; * = df of model comparison

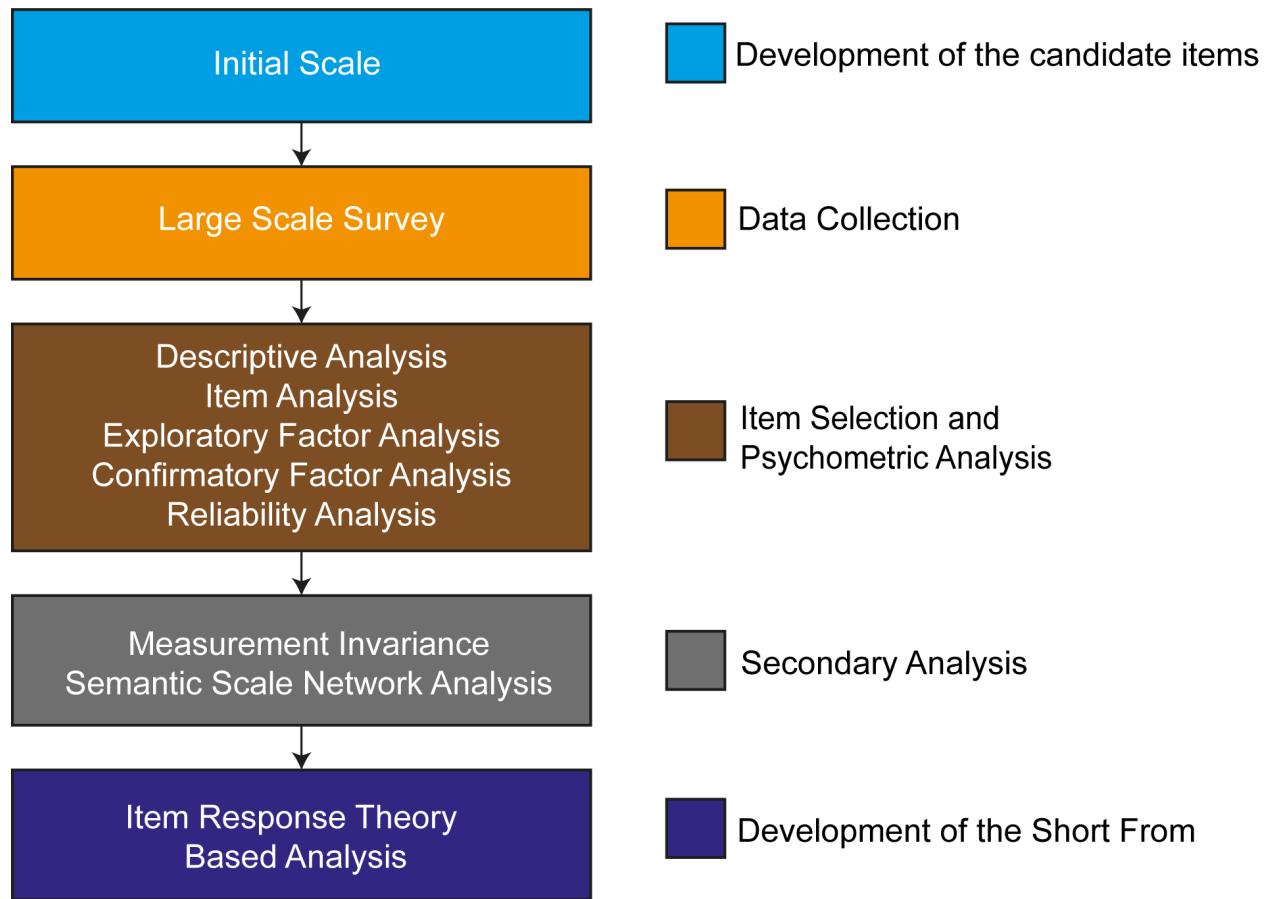


Figure 1. Development of long form (23-item) and short form (18-item) of LEBA.

Summary Descriptives (n =690)											
Items 01-24											
Items	Item	Summary Statistics			Graphics		Response Pattern				
		Mean	Median	SD	Histogram	Density	Never	Rarely	Sometimes	Often	Always
●item01	I turn on the lights immediately after waking up.	2.3	2.0	1.4			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	3.0	1.6			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	4.0	1.4			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	1.0	1.1			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	5.0	1.4			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	3.0	1.5			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	2.0	1.2			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	3.0	1.2			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	3.0	1.0			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	3.0	1.1			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	2.0	0.9			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	2.0	1.2			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	3.0	1.5			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	2.0	1.3			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	3.0	1.1			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	1.0	1.3			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	1.0	1.2			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	1.0	0.5			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	1.0	0.3			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	1.0	0.3			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	1.0	0.6			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	4.0	1.1			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	2.0	1.3			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	4.0	1.0			2.90% (20)	5.65% (39)	11.45% (79)	37.83% (261)	42.17% (291)

Figure 2. Summary descriptives and response pattern

Summary Descriptives (n = 690)											
Item		Summary Statistics			Graphics		Response Pattern				
LEBA Items	Item Stem	Mean	Median	SD	Histogram	Density	Never	Rarely	Sometimes	Often	Always
●item24	I spend most of my indoor time within 3 meters from a window.	4.1	4.0	1.0			2.90% (20)	5.65% (39)	11.45% (79)	37.83% (261)	42.17% (291)
●item25	I use a desk lamp when I do focused work.	2.6	3.0	1.4			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	4.0	1.3			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	4.0	1.3			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	4.0	1.2			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	2.0	1.3			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	1.0	1.1			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	3.0	1.6			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	4.0	1.6			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	4.0	1.7			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	5.0	1.8			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	5.0	1.7			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	1.0	1.3			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	2.0	1.3			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	5.0	1.1			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	2.0	1.1			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	2.0	1.3			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	1.0	0.8			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	5.0	1.4			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	1.0	1.2			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	4.0	1.3			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	1.0	1.5			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	1.0	1.2			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	2.0	1.2			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	2.0	1.3			26.81% (185)	23.33% (161)	28.12% (194)	12.46% (86)	9.28% (64)

Figure 3. Summary descriptives and response pattern

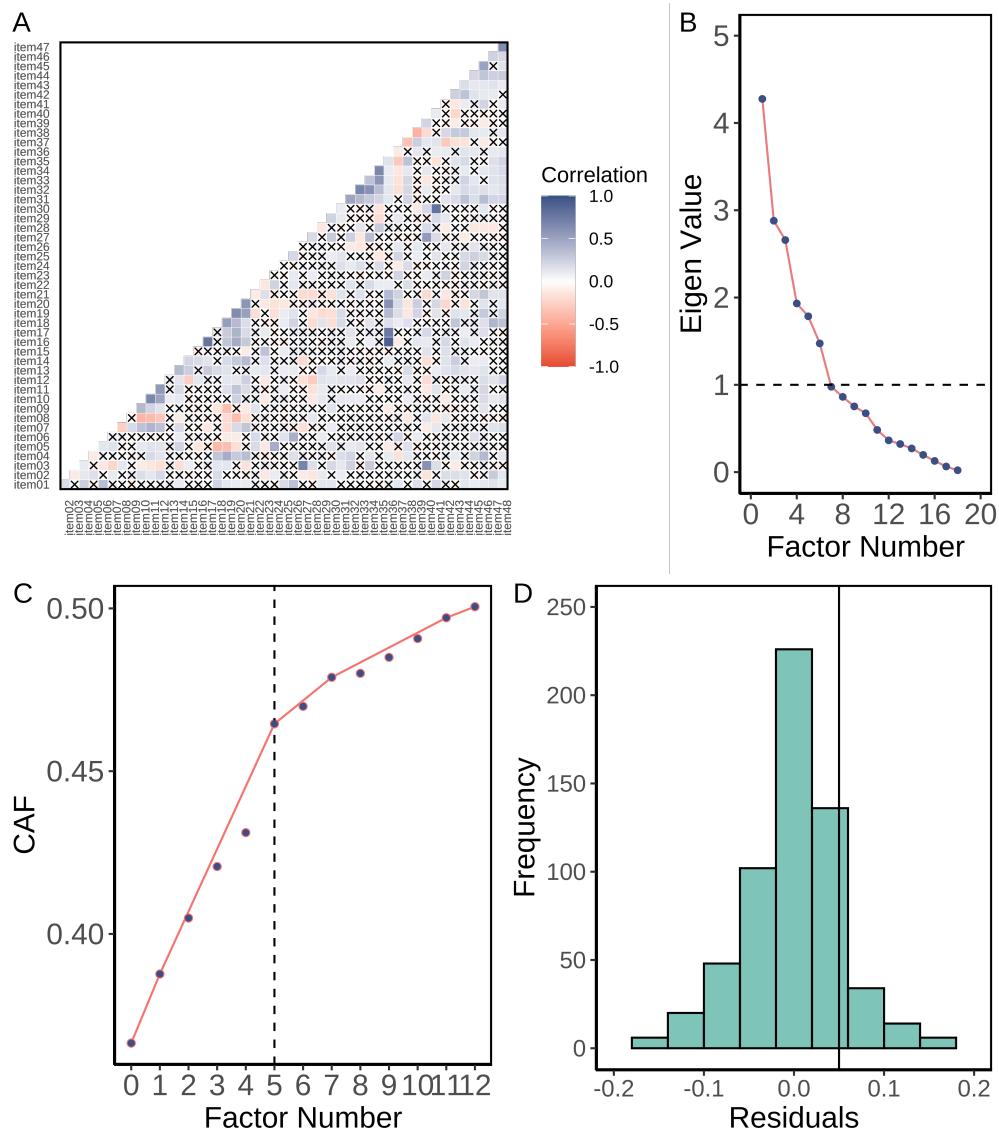


Figure 4. (A) Inter-item polychoric correlation coefficients for the 48 items. 4.9 % inter-item correlation coefficients were higher than $|.30|$. (B) Scree plot suggested six factors. (C) Hull method indicated 5 factors were required to balance the model fit and number of parameters. (D) Histogram of nonredundant residual correlations indicated possible under factoring.

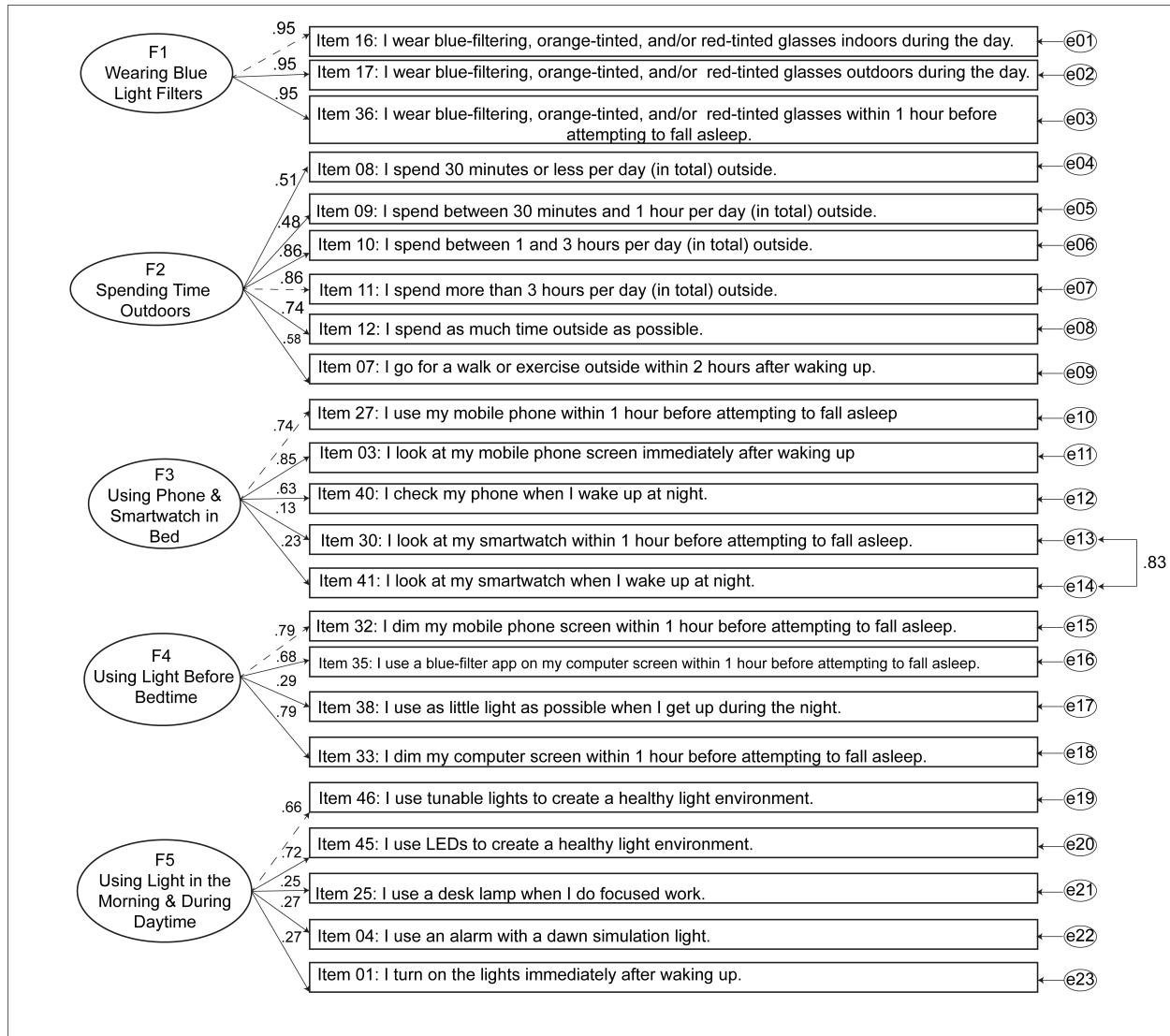


Figure 5. Five factor model of LEBA obtained by confirmatory factor analysis. By allowing item pair 41 and 30 to covary their error variance our model attained the best fit.

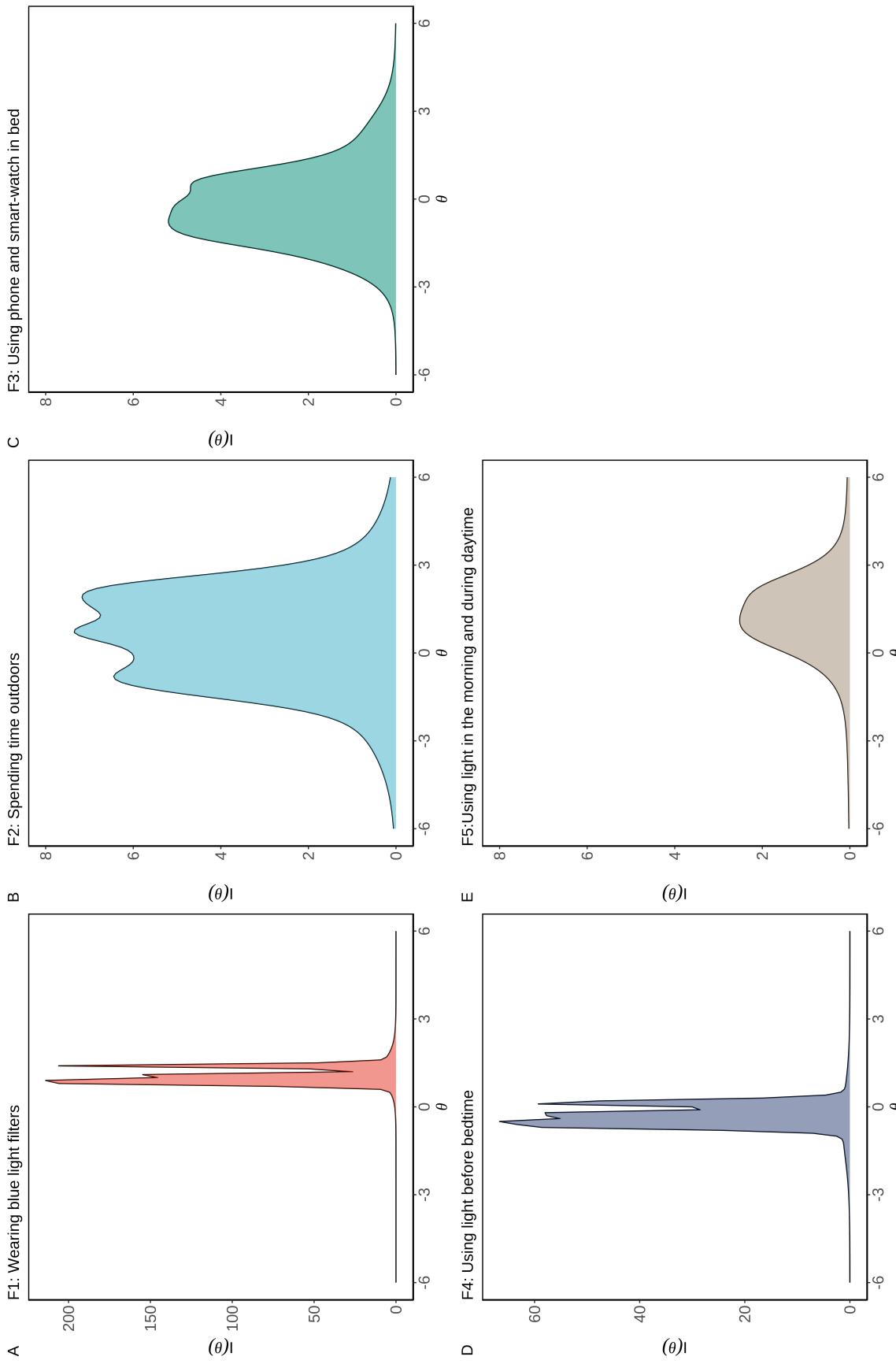


Figure 6. Test information curves for the five factors of LEBA: (a) wearing blue light filters (b) spending time outdoors (c) using phone and smartwatch in bed (d) using light before bedtime (e) using light in the morning and during daytime. Along x-axis we plotted the underlying latent trait continuum for each factor. Along y-axis we plotted how much information a particular factor is carrying across its latent trait continuum

Appendix

⁷⁶⁴ **Disclaimer:** This is a non-public version of LEBA (dated March 24, 2022) and still a work
⁷⁶⁵ in progress. Please do not distribute!

⁷⁶⁶ LEBA captures light exposure-related behaviours on a 5 point Likert type scale
⁷⁶⁷ ranging from 1 to 5 (Never = 1; Rarely = 2; Sometimes = 3; Often = 4; Always = 5). The
⁷⁶⁸ score of each factor is calculated by the summation of scores of items belonging to the
⁷⁶⁹ corresponding factor.

⁷⁷⁰ **Instruction:**

⁷⁷¹ “Please indicate how often you performed the following behaviours in the **past 4**
⁷⁷² **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 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.					

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 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 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
F1: Wearing blue light filters	01-03
F2: Spending time outdoors	4-8(Item 4 is reversed)
F3: Using phone and smartwatch in bed	9-11
F4: Using light before bedtime	12-14
F5: Using light in the morning and during daytime	15-18

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.
-

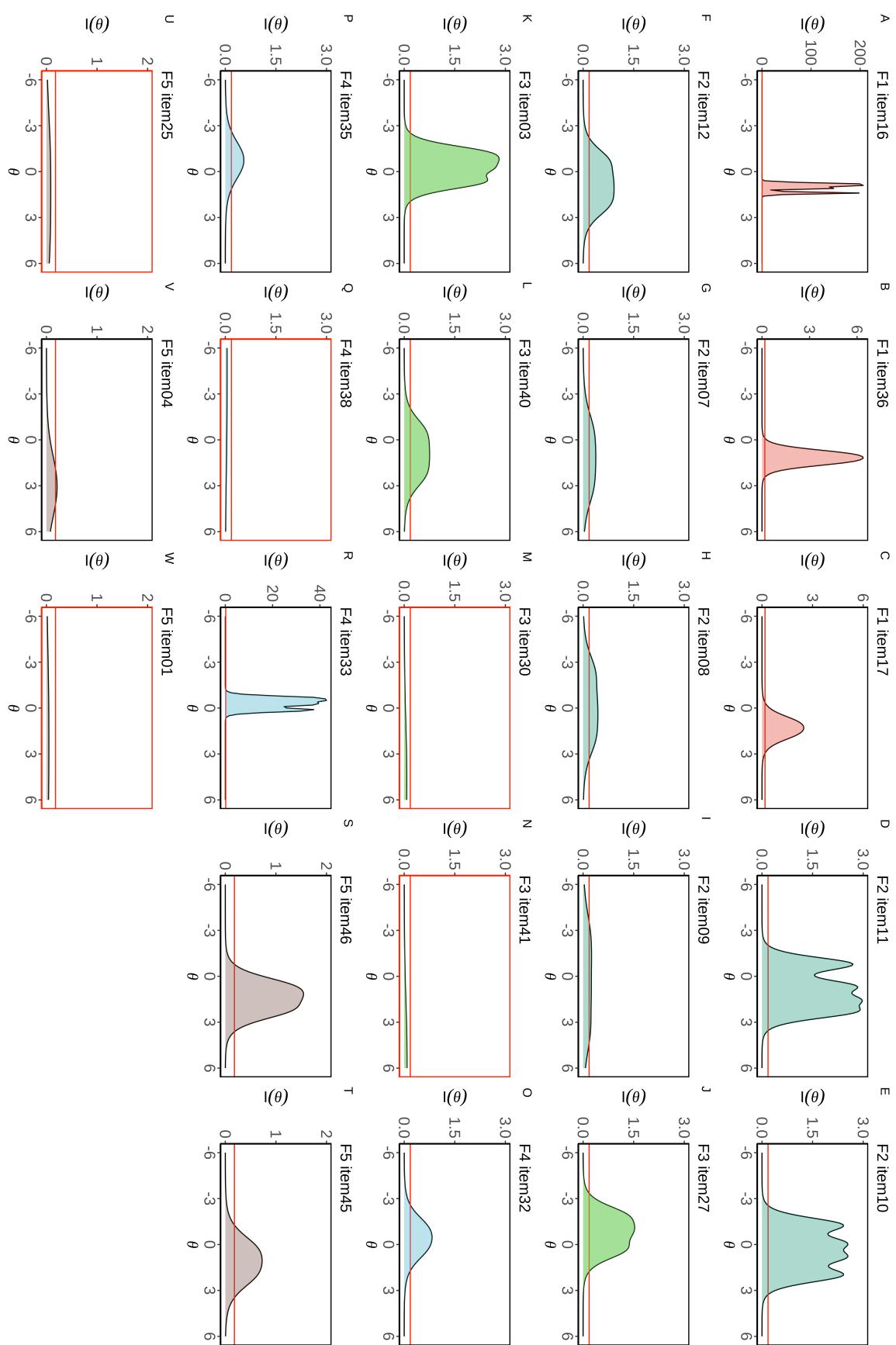


Figure A1. Item information curve. Five items (1, 25, 38, 30, 41) had relatively flat information curves

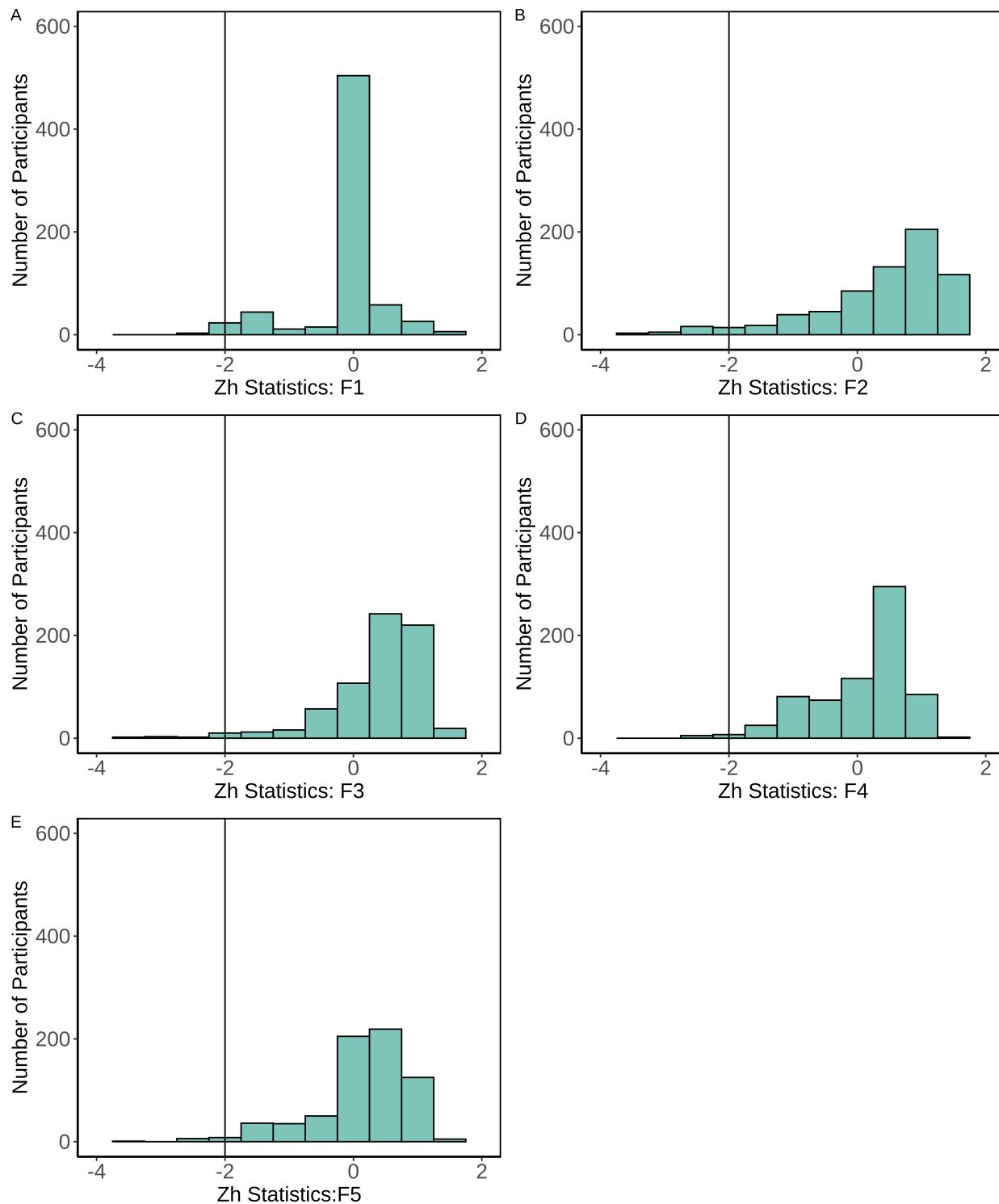


Figure A2. Person fit of the five fitted IRT models (a) Wearing blue light filters (b) Spending time outdoors (c) Using phone and smartwatchin bed (d) Using light before bedtime (e) Using light in the morning and during daytime