

<sup>1</sup> *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. Responses to these items were  
57 then collected in an online survey producing responses from an international sample  
58 (690 completed responses, 74 countries, 28 time zones). Exploratory factor analysis  
59 (EFA) on an initial subset of our sample ( $n=428$ ) rendered a five-factor solution with 25  
60 items (Wearing blue light filters, spending time outdoors, using phone and smart-watch  
61 in bed, using light before bedtime, using light in the morning and during daytime). In a  
62 confirmatory factor analysis (CFA) performed on an independent subset of participants  
63 ( $n=262$ ), we removed two further items to attain the best fit for the five-factor solution  
64 ( $CFI=0.97$ ,  $TLI=0.96$ ,  $RMSEA=0.05$ ,  $SRMR=0.09$ ). The internal consistency reliability  
65 coefficient for the total instrument was McDonald's  $\omega_{total}=0.73$ . Measurement  
66 model invariance analysis between native and non-native English speakers showed our  
67 model attained the highest level of invariance (residual invariance;  $CFI=0.95$ ,  $TLI =0.95$ ,  
68  $RMSEA=0.05$ ). Lastly, a short form of LEBA ( $n=18$ ) was developed using Item Response  
69 Theory on the complete sample ( $n=690$ ).

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

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

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Word count: X

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## Introduction

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

## Methods

## 87 Ethical approval

88 The cantonal ethics commission (Ethikkommission Nordwest- und Zentralschweiz,  
89 project ID Req-2021-00488) reviewed this project and issued an official clarification of  
90 responsibility (full document see Suppl. Fig X in appendix) stating: "The research project  
91 does not fall under the scope of the Human Research Act, because your project is using  
92 only anonymised data. An authorisation from the ethics committee is therefore not  
93 required and the EKNZ is not responsible for its review."

94 Data Availability

All code and data underlying this article is available on a public GitHub repository (<https://github.com/leba-instrument/leba-manuscript>).

97 Survey characteristics

98 Data was collected in a quantitative cross-sectional approach via a fully anonymous  
99 online survey hosted on REDCap (Harris et al., 2019, 2009) by way of the University of  
100 Basel sciCORE. Participants were recruited via the website of a Comic co-released with  
101 the survey(Weinzaepflen & Spitschan, 2021) , social media (i.e., LinkedIn, Twitter,  
102 Facebook), mailing lists, word of mouth, the investigators' personal contacts, and  
103 supported by distribution of the survey link via f.lux software (F.lux Software LLC, 2021).

104 Completing the online survey took approx. 15 to 20 minutes and was not  
105 compensated. The first page of the survey comprised a participant information sheet,  
106 where participants' informed consent to participate was obtained before any of the  
107 questions were displayed. Underaged participants (<18 years) were urged to obtain  
108 assent from their parents/legal guardians, before filling in the survey. Information on the  
109 first page included the objectives of the study, inclusion criteria, estimated duration, the  
110 use, storage and sharing of the data, compensation (none), and information about the  
111 type of questions in the survey. Moreover, participants needed to confirm that they were  
112 participating the survey for the first time. To ensure high data quality, five attention check  
113 items were included in the survey (e.g., "We want to make sure you are paying attention.  
114 What is 4+5?"). The data analysed in this study was collected between 17.05.2021 and  
115 03.09.2021. Questions incorporating retrospective recall were all aligned to the period of  
116 "past four weeks," matching the presented LEBA instrument.

117 In addition to the LEBA questionnaire, which is subject of the current study, the  
118 following variables and items were assessed but not included in the analysis:

- 119 • Sleep disturbance and sleep-related impairment (adult and pediatric versions)  
120 (Bevans et al., 2019; Daniel J. Buysse et al., 2010; Forrest et al., 2018; Harb,  
121 Hidalgo, & Martau, 2015; L. Yu et al., 2011)

- 122 • Sleep duration, timing, and latency, chronotype, social jetlag, time in bed,
- 123 work/sleep schedule and outdoor light exposure duration (version for adults and
- 124 adolescents) (Roenneberg, Wirz-Justice, & Merrow, 2003)
- 125 • Sleep environment (Olivier et al., 2016)
- 126 • Meal timing & caffeine consumption [custom items]
- 127 • Light sensitivity (photophobia vs. photophilia) (Wu & Hallett, 2017)
- 128 • Self-reported pubertal stage (only if younger than 18 years old) (Petersen,
- 129 Crockett, Richards, & Boxer, 1988)

130 Furthermore, the following 1-item demographic variables were assessed:

- 131 • Age
- 132 • Sex
- 133 • Gender identity
- 134 • Occupational Status
- 135 • COVID-19 related Occupational setting during the past four weeks
- 136 • Time zone & country of residence
- 137 • English as native language

## 138 Participants

139 Table 2 summarizes the survey participants' demographic characteristics. Only  
140 participants completing the full LEBA questionnaire were included, thus there are no  
141 missing values in the item analyses. XX participants were excluded from analysis due to  
142 not passing at least one of the "attention check" items. For exploring initial factor  
143 structure (EFA), a sample of 250-300 is recommended (Comrey & Lee, 1992;  
144 Schönbrodt & Perugini, 2013). For estimating the sample size for the confirmatory factor  
145 analysis (CFA) we followed the N:q rule (Bentler & Chou, 1987; Jackson, 2003; Kline,  
146 2015; Worthington & Whittaker, 2006), where ten participants per parameter is required

147 to earn trustworthiness of the result. Our sample size exceeds these requirements:  
148 Anonymous responses from a total of  $n = 690$  participants were included in the analysis  
149 of the current study, split into samples for Exploratory Factor Analysis (EFA:  $n = 428$ ) and  
150 Confirmatory Factor Analysis (CFA:  $n = 262$ ). The EFA sample included participants  
151 filling out the questionnaire from 17.05.2021 to XX.XX.XXXX, whereas participants who  
152 filled out the questionnaire from YY.YY.YYYY to 03.09.2021 were included in the CFA  
153 analysis. Participants indicated filling out the online survey from a diverse range of  
154 geographic locations. The ten most common country + timezone combinations included:

- 155 • United States - America/New\_York (UTC -04:00): 63 (9.1%)
- 156 • United Kingdom - Europe/London (UTC): 57 (8.3%)
- 157 • Germany - Europe/Berlin (UTC +01:00): 53 (7.7%)
- 158 • India - Asia/Kolkata (UTC +05:30): 38 (5.5%)
- 159 • United States - America/Los\_Angeles (UTC -07:00): 37 (5.4%)
- 160 • United States - America/Chicago (UTC -05:00): 30 (4.3%)
- 161 • France - Europe/Paris (UTC +01:00): 22 (3.2%)
- 162 • Switzerland - Europe/Zurich (UTC +01:00): 21 (3.0%)
- 163 • Brazil - America/Sao\_Paulo (UTC -03:00): 19 (2.8%)
- 164 • Netherlands - Europe/Amsterdam (UTC +01:00): 19 (2.8%)

165 For a complete list of geographic locations, see Suppl. Table X in the appendix.

166 Age among all participants ranged from 11 years to 84 years [EFA:  $\min = 11$ ,  $\max =$   
167 84; CFA:  $\min = 12$ ,  $\max = 74$ ], with an overall mean of ~ 33 years of age [Overall:  $M =$   
168 32.95,  $SD = 14.57$ ; EFA:  $M = 32.99$ ,  $SD = 15.11$ ; CFA:  $M = 32.89$ ,  $SD = 13.66$ ]. In total  
169 325 (47%) of the participants indicated female sex [EFA: 189 (44%); CFA: 136 (52%)],  
170 351 (51%) indicated male [EFA: 230 (54%); CFA: 121 (46%)] and 14 (2.0%) indicated  
171 other sex [EFA: 9 (2.1%), CFA: 5 (1.9%)]. Overall, 49 (7.2%) [EFA: 33 (7.8%); CFA: 16  
172 (6.2%)] participants indicated a gender-variant identity. In a “Yes/No” question regarding

native language, 320 (46%) of respondents [EFA: 191 (45%); CFA: 129 (49%)] indicated to be native English speakers. For their “Occupational Status,” more than half of the overall sample reported that they currently work [Overall: 396 (57%); EFA: 235 (55%); CFA: 161 (61%)], whereas 174 (25%) [EFA: 122 (29%); CFA: 52 (20%)] reported that they go to school and 120 (17%) [EFA: 71 (17%); CFA: 49 (19%)] responded that they do “Neither.” With respect to the COVID-19 pandemic we asked participants to indicate their occupational setting during the last four weeks: In the overall sample 303 (44%) [EFA: 194 (45%); CFA: 109 (42%)] of the participants indicated that they were in a home office/home schooling setting, while 109 (16%) overall [EFA: 68 (16%); CFA: 41 (16%)] reported face-to-face work/schooling. Lastly, 147 (21%) overall [EFA: 94 (22%); CFA: 53 (20%)] reported a combination of home- and face-to-face work/schooling, whereas 131 (19%) overall [EFA: 72 (17%); CFA: 59 (23%)] filled in the “Neither (no work or school, or on vacation)” response option. We tested all demographic variables in Table 1 for significant group differences between the EFA and CFA sample, applying Wilcoxon rank sum test for the continuous variable “Age” and Pearson’s  $\chi^2$  test for all other categorical variables via the gtsummary R package’s “add\_p” function (Sjoberg et al., 2021a). The p-values were corrected for multiple testing applying false discovery rate (FDR) via the “add\_q” function of the same package. After p-value (FDR) correction for multiple testing, none of the demographic variables were significantly different between the EFA sample and the CFA sample (all q-values  $q \geq 0.2$ ).

### Item Generation

To ensure construct adequacy we thoroughly assessed the current status of literature and identified a variety of light exposure related scales. However, no scales specifically measuring the behavioral component of light exposure were found (Table ??). Consequentially we pursued to introduce a new openly available scale to address this research gap. For this purpose an expert researcher panel from the fields of

199 chronobiology, light research, neuroscience and psychology (including seven of the  
200 authors, see authors roles) generated and collected preliminary item ideas. Special  
201 attention was paid to design items circumscribed to assess light exposure *behavior* as  
202 opposed to subjective measurements of the light environment (cf.(Eklund & Boyce,  
203 1996) & (Dianat, Sedghi, Bagherzade, Jafarabadi, & Stedmon, 2013)) and  
204 semi-quantitative assesments of light sources' illuminance (cf. (Bajaj, Rosner, Lockley, &  
205 Schernhammer, 2011)) in order to maintain content validity. In a collective effort the  
206 generated items were then peer-reviewed, amended, unified, and complemented with a  
207 suitable response scale (5 point Likert-scale ranging from 1 "Never/Does not apply/  
208 don't know" to 5 "Always"). This process was finalized when all experts were in  
209 agreement, resulting in 48 items to implement in the data collection.

## 210 Analytic Strategies

211 Figure 1 summarizes the steps of our psychometric analysis. In our analysis we  
212 used R (version 4.1.0), with several R packages. Initially, our tool had six point Likert  
213 type response format (0:Does not apply/I don't know; 1:Never, 2:Rarely; 3:Sometimes;  
214 4:Often; 5:Always). Our purpose was to capture light exposure related behavior and  
215 these two response options: "Does not apply/I don't know" and "Never" were providing  
216 similar information. As such we decided to collapse them into one, making it a 5 point  
217 Likert type response format. Necessary assumptions of EFA, including sample  
218 adequacy, normality assumptions, quality of correlation matrix, were assessed. Our data  
219 violated both the univariate and multivariate normality assumptions. Due to these  
220 violations and the ordinal nature of our response data, we used polychoric correlation  
221 matrix (Desjardins & Bulut, 2018) for the EFA. We employed principal axis (PA) as factor  
222 extraction method with varimax rotation. PA is robust to the normality assumption  
223 violations (Watkins, 2020). The obtained latent structure was confirmed by another factor  
224 extraction method: "the minimum residuals extraction" as well. We used a combination

of factor identification method including scree plot (Cattell, 1966), Horn's parallel analysis (Horn, 1965), minimum average partials method (Velicer, 1976), and hull method (Lorenzo-Seva, Timmerman, & Kiers, 2011) to identify factor numbers. Additionally, to determine the simple structure, we followed the guidelines recommended by psychometricians: (i) no factors with fewer than three items (ii) no factors with a factor loading <0.3 (iii) no items with cross-loading greater than .3 across factors (Bandalos & Finney, 2018). We confirmed the latent structure obtained in the EFA by conducting a categorical "Confirmatory Factor Analysis" (CFA) using "robust weighted least square estimator" (WLSMV). We established the measurement invariance of our tool across the native and non-native English speakers using structural equation model framework. To assess the possible semantic overlap of our tool with the existing tools, we sought to "Semantic Scale Network" (Rosenbusch, Wanders, & Pit, 2020). To assess the possible semantic overlap of our tool with the existing tools, we sought to "Semantic Scale Network" (Rosenbusch et al., 2020). Lastly, we sought "Item Response Theory" (IRT) based analysis on developing a short form of LEBA. We also conducted psychometric analysis on non-merged response options data (Supp. Table A9) and rejected the latent structure obtained as the factors were less interpretable.

## Results

### Item Analysis

Table 3 summarizes the univariate descriptive statistics for the 48 items. Some of the items were skewed with high Kurtosis values. Our data violated both univariate normality (Shapiro-Wilk statistics; (Shapiro & Wilk, 1965)) and multivariate normality assumptions [Marida's test;(Mardia, 1970)]. Multivariate skew was = 583.80 ( $p < 0.001$ ) and multivariate kurtosis was = 2,749.15 ( $p < 0.001$ ). Due to these violations and ordinal nature of the response data polychoric correlations over Pearson's correlations was

250 chosen (Desjardins & Bulut, 2018). The corrected item-total correlation ranges between  
251 .03 -.48. However, no item was discarded based on descriptive statistics or item analysis.

252 **Exploratory Factor Analysis**

253 Sampling adequacy was checked using Kaiser-Meyer-Olkin (KMO) measures of  
254 sampling adequacy (Kaiser, 1974) . The overall KMO vale for 48 items was 0.63 which  
255 was above the cutoff value (.50) indicating a mediocre sample (Hutcheson, 1999).  
256 Bartlett's test of sphericity (Bartlett, 1954),  $\chi^2$  (1128) = 5042.86, p < .001 indicated the  
257 correlations between items are adequate for the EFA. However only 4.96% of the  
258 inter-item correlation coefficients were greater than .30. The absolute value of inter-item  
259 correlation ranged between .00 to .91. Figure 2 depicts the correlation matrix.

260

261 Scree plot ( Figure 3) suggested a six-factor solution. Horn's parallel analysis  
262 (Horn, 1965) with 500 iterations also indicated a six-factor solution. However, the  
263 minimum average partial (MAP) method (Table ??) (Velicer, 1976) and Hull method  
264 (Lorenzo-Seva et al., 2011) ( Figure 3) suggested a five-factor solution. As a result, we  
265 tested both five-factor and six-factor solutions.

266 With the initial 48 items we conducted three rounds of EFA and gradually discarded  
267 problematic items. (cross-loading items and poor factor loading (<.30) items). Finally, a  
268 five-factor EFA solution with 25 items was accepted with low RMSR = 0.08 (Brown,  
269 2015), all factor-loading higher than .30 and no cross-loading greater than .30. We  
270 further confirmed this five-factor latent structure by another EFA using varimax rotation  
271 with a minimum residual extraction method (Sup.Table A7). Table 4 displays the  
272 factor-loading (structural coefficients) and communality of the items. The absolute value  
273 of the factor-loading ranged from .49 to .99 indicating strong coefficients. The

274 commonalities ranged between .11 to .99. Figure 4(A) depicts the obtained five factor  
275 structure. However, the histogram of the absolute values of non-redundant  
276 residual-correlations (Figure 4(B)) showed 26% correlations were greater than the  
277 absolute value of .05, indicating a possible under-factoring. (Desjardins & Bulut, 2018).  
278 Subsequently, we fitted a six-factor solution. However, a factor emerged with only two  
279 salient variables, thus disqualifying the six-factor solution (Sup.Table A8). Internal  
280 consistency reliability coefficient Cronbach's alpha assumes all the factor-loadings of the  
281 items under a factor are equal (Graham, 2006; Novick & Lewis, 1967) which is not the  
282 case in our sample. Additionally Cronbach's alpha coefficient has a tendency to deflate  
283 the estimates for Likert type data as the calculation is based on pearson-correlation  
284 matrix which requires that response data should be in continuous of nature (Gadermann,  
285 Guhn, & Zumbo, 2012; Zumbo, Gadermann, & Zeisser, 2007). Subsequently to get  
286 better estimates of reliability we reported ordinal alpha which used polychoric-correlation  
287 matrix and assumed that the responses data were ordered in nature instead of  
288 continuous (Zumbo et al., 2007). Ordinal alpha coefficient value ranges from 0 to 1 and  
289 higher value represents better reliability. In the five-factor solution, the first factor  
290 contained three items and explained 10.25% of the total variance with a internal reliability  
291 coefficient ordinal  $\alpha = .94$ . All the items in this factor stemmed from the individual's  
292 preference to use blue light filters in different light environments. The second factor  
293 contained six items and explained 9.93% of the total variance with a internal reliability  
294 coefficient ordinal  $\alpha = .76$ . Items under this factor commonly investigated an individual's  
295 hours spent outdoor. The third factor contained five items and explained 8.83% of the  
296 total variance. Items under this factor dealt with the specific behaviors pertaining to using  
297 phone and smart-watch in bed. The internal consistency reliability coefficient was,  
298 ordinal  $\alpha = .75$ . The fourth factor contained five items and explained 8.44% of the total  
299 variance with an internal consistency coefficient, ordinal  $\alpha = .72$ . These five items  
300 investigated the behaviors related to individual's light exposure before bedtime. Lastly,

301 the fifth factor contained six items and explained 6.14% of the total variance. This factor  
302 captured individual's morning and daytime light exposure related behavior. The internal  
303 consistency reliability was, ordinal  $\alpha = .62$ . It is essential to attain a balance between  
304 psychometric properties and interpretability of the common themes when exploring the  
305 latent structure. As all of the emerged factors are highly interpretable and relevant  
306 towards our aim to capture light exposure related behavior, regardless of the apparent  
307 low reliability of the fifth factor, we retain all the five-factors with 23 items for our  
308 confirmatory factor analysis (CFA). Two items showed negative factor-loading (items 44  
309 and 21). Upon inspection, it was understood that these items are negatively correlated to  
310 the common theme, and thus in the CFA analysis, we reversed the response code for  
311 these two items. Figure ?? depicts the data distribution and endorsement pattern for the  
312 included items in our LEBA tool for both the EFA and CFA sample.

### 313 Confirmatory Factor Analysis

314 We conducted categorical confirmatory factor analysis with robust weighted least  
315 square (WLSMV) estimator since our response data was of ordinary nature (Desjardins  
316 & Bulut, 2018). Several indices are suggested to measure model fit which can be  
317 categorized as absolute, comparative and parsimony fit indices (Brown, 2015). Absolute  
318 fit assess the model fit at an absolute level using indices including  $\chi^2$  test statistics and  
319 the standardized root mean square (SRMR). Parsimony fit indices including the root  
320 mean square error of approximation (RMSEA) considers the number of free parameters  
321 in the model to assesses the parsimony of the model. Comparative fit indices evaluate  
322 the fit of the specified model solution in relation to a more restricted baseline model  
323 restricting all covariances among the indicators as zero. Comparative fit index (CFI) and  
324 the Tucker Lewis index (TLI) are such two comparative fit indices. Commonly used  
325 Model fit guidelines (Hu & Bentle, 1999; Schumacker & Lomax, 2004) includes (i)  
326 Reporting of  $\chi^2$  test statistics (A non-significant test statistics is required to reflect model

327 fit) (ii) CFI and TLI (CFI/TLI close to .95 or above/ranging between 90-95 and above) (iii)  
328 RMSEA (close to .06 or below), (iv) SRMR (close to .08 or below) to estimate the model  
329 fit. Table 5 summarizes the fit indices of our fitted model. Our fitted model failed to attain  
330 an absolute fit estimated by the  $\chi^2$  test. However, the  $\chi^2$  test is sensitive to sample size  
331 and not recommended to be used as the sole index of absolute model fit (Brown, 2015).  
332 Another absolute fit index we obtained in our analysis was SRMR which does not work  
333 well with categorical data (C. Yu, 2002). We judged the model fit based on the  
334 comparative fit indices: CFI, TLI and parsimony fit index:RMSEA. Our fitted model  
335 attained acceptable fit (CFI = .94; TLI = .93); RMSEA = .06,[.05-.07, 90% CI]) with two  
336 imposed equity constrain on item pairs 32-33 [I dim my mobile phone screen within 1  
337 hour before attempting to fall asleep.;I dim my computer screen within 1 hour before  
338 attempting to fall asleep.] and 16-17 [I wear blue-filtering, orange-tinted, and/or  
339 red-tinted glasses indoors during the day.;I wear blue-filtering, orange-tinted, and/or  
340 red-tinted glasses outdoors during the day]. Items pair 32-33 stemmed from the  
341 preference of dimming electric device's brightness before bed time and items pair 16 and  
342 19 stemmed from the preference of using blue filtering or colored glasses during the  
343 daytime. Nevertheless, SRMR value was higher than the guideline (SRMR = .12).  
344 Further by allowing one pair of items (30-41) [I look at my smartwatch within 1 hour  
345 before attempting to fall asleep.;I look at my smartwatch when I wake up at night.] to  
346 covary their error variance and discarding two item (item 37 & 26) for very low r-square  
347 value, our model attained best fit (CFI = .95; TLI = .95); RMSEA = .06[.05-.06, 90% CI])  
348 and SRMR value (SRMR = .11) was also close to the suggestions of Hu and Bentle  
349 (1999). Internal consistency ordinal  $\alpha$  for the five factors of LEBA were .96, .83, .70, .69,  
350 .52 respectively. We also estimated the internal consistency reliability of the total scale  
351 using McDonald's  $\omega_t$  coefficient which is a better reliability estimate for multidimensional  
352 constructs (Dunn, Baguley, & Brunsden, 2014; Sijtsma, 2009). McDonald's  $\omega_t$  coefficient  
353 for the total scale was .68. Figure 7 depicts the obtained CFA structure.

354 **Measurement Invariance**

355 Measurement invariance (MI) evaluates whether a construct has the psychometric  
356 equivalence and same meaning across groups or measurement occasions (Kline, 2015;  
357 Putnick & Bornstein, 2016). We used structural equation modeling framework to assess  
358 the measurement invariance of our developed tool across two groups: native English  
359 speakers(n= 129) and non-native English speakers (n = 133). For a detailed description  
360 these two groups please see Sup. Table ???. Our measurement invariance testing  
361 involved successively comparing the nested models: configural, metric, scalar, and  
362 residual invariance models with each others (Widaman & Reise, 1997). Among these  
363 nested models configural model is the first and least restrictive model. The configural  
364 model assumes that the number of factors and item number under each factor will be  
365 equal across two groups. The metric invariance model assumes configural invariance of  
366 the fitted model and requires the factor-loadings of the items across the two groups to be  
367 equal. Having the factor-loadings equal across groups indicates each item contributes to  
368 the measured construct equivalently. Scalar invariance assumes the metric invariance of  
369 the fitted model demands the item intercepts to be equivalent across groups. This equity  
370 of item intercepts indicates the equivalence of response scale across the groups, i.e.,  
371 persons with the same level of the underlying construct will score the same across the  
372 groups. The residual invariance model assumes metric invariance for the fitted model  
373 and adds the assumption of equality in error variances and covariances across the  
374 groups. This model is the highest level of MI and assures the equivalence of precision of  
375 items across the groups in measuring the underlying constructs. The invariance model fit  
376 of our tool was assessed using the fit indices including  $\chi^2$  test, CFI and TLI (close to .95  
377 or above), RMSEA (close to .06 or below) (Hu & Bentle, 1999). We excluded SRMR  
378 from our consideration as it does not behave optimally for categorical variables (C. Yu,  
379 2002). Table 6 summarized the fit indices. The comparison among different  
380 measurement invariance models was made using the  $\chi^2$  difference test ( $\Delta\chi^2$ ) to

381 assess whether our obtained latent structure of “LEBA” attained the highest level of the  
382 MI. A non-significant  $\Delta\chi^2$  test between two MI models fit indicates mode fit does not  
383 significantly decrease for the superior model (Dimitrov, 2010) thus allowing the superior  
384 level of invariance model to be accepted. We started our analysis by comparing the  
385 model fit of the least restrictive model:configural model to metric MI model and continued  
386 successive comparisons. Table 6 indicates that our fitted model had acceptable fit  
387 indices for all of the fitted MI models. The model fit did not significantly decrease across  
388 the nested models up to the scalar MI model. The chi-square value difference between  
389 the scalar and residual model is zero, indicating model fit remained the same for both:  
390 scalar and residual MI model, indicating the acceptability of the residual MI model.

391 **Semantic Analysis**

392 To find out if our developed tool (23 items) is overlapping with existing instruments,  
393 we subjected the items of LEBA to the “Semantic Scale Network”(SSN) analysis  
394 (Rosenbusch et al., 2020). The SSN detects semantically related scales and provides  
395 cosine similarity index ranging between -.66 to 1 (Rosenbusch et al., 2020). Pair of  
396 scales with a cosine similarity index value of 1 indicates they are perfectly semantically  
397 similar scales indicating redundancy. LEBA appeared most strongly related to scales  
398 about sleep: “Sleep Disturbance Scale For Children” (Bruni et al., 1996) and  
399 “WHO-Composite International Diagnostic Interview (CIDI): Insomnia”(WHO, 1990).The  
400 cosine similarities lie between .47 to .51. Flesch-Kincaid Grade Level (Flesch, 1948)  
401 analysis on the the 23 items of our scale indicated required educational grade level was  
402 3.33 and with a age above 8.33.

404 **Developing Short form of LEBA**

405 We sought the Item Response Theory (IRT) to develop the short form of LEBA. IRT  
406 the conventional classical test theory-based analysis by gathering information on item  
407 quality by indices like item difficulty, item discrimination, and item information (Baker,  
408 2017). Item is judged based on item information in relation to participants' latent trait  
409 level ( $\theta$ ). We fitted each factor of LEBA with the graded response model (Samejima,  
410 Liden, & Hambleton, 1997) to the combined EFA and CFA sample (n =690). Item  
411 discrimination indicates the pattern of variation in the categorical responses with the  
412 changes in latent trait level ( $\theta$ ), and item information curve (IIC) indicates the amount of  
413 information an item carries along the latent trait continuum. Here, we reported the item  
414 discrimination parameter and only discarded the items with relatively flat item information  
415 curve (information <.2) to develop the short form of LEBA. Baker (2017) categorized the  
416 item discrimination in as none = 0; very low =0.01 to 0.34; low = 0.35 to 0.64; moderate =  
417 0.65 to 1.34 ; high = 1.35 to 1.69; very high >1.70. Table 7 summarizes the IRT  
418 parameters of our tool. Item discrimination parameters of our tool fell in very high (10  
419 items), high (4 items), moderate (4 items), and low ( 5 items) categorizes indicating a  
420 good range of discrimination along the latent trait level ( $\theta$ ). Examination of the item  
421 information curve (Sup.fig A2-A5) indicated 5 items (1, 25, 38, 30, & 41) had relatively  
422 flat information curves ( $I(\theta) < .20$ ) thus discarded creating a short form of LEBA with 5  
423 factors and 18 items.

424 Test information curve (TIC) (Figure 8) indicate the amount of information an the  
425 full-scale carry along the latent trait continuum. As we treated each factor of short-LEBA  
426 as an unidimensional construct we obtain 5 TICs (Figure 8). These information curves  
427 indicated except the first and fifth factors, the other three factor's TICs are roughly  
428 centered on the center of the trait continuum ( $\theta$ ).The first and fifth factor had a peak to  
429 the right side of the center of latent trait.Thus we conferred the LEBA tool estimated the

430 light exposure related behavior with precision near the center of trait continuum for 2nd,  
431 3rd and 4th factors and near the right side of the center of trait continuum for 1st and 5th  
432 factors (Baker, 2017).

433 Table 8 summarizes the item fit indexes of the items. All the items fitted well to the  
434 respective models as assessed by RMSEA value obtained from Signed- $\chi^2$  index  
435 implementation. All of the items had RMSEA value  $\leq .06$  indicating adequate fit.  
436 Sup. Figure A6 depicts the person fit of out fitted models. Person fit indicates the validity  
437 and meaningfulness of the fitted model at the participants latent trait level (Desjardins &  
438 Bulut, 2018). We estimated the person fit statistics using standardized fit index Zh  
439 statistics (Drasgow, Levine, & Williams, 1985). Zh  $< -2$  should be considered as a misfit.  
440 Fig indicates that Zh is larger than -2 for most participants, suggesting a good fit of the  
441 selected IRT models.

## 442 Discussion

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

446 48 items were generated by an expert panel and administered to a large sample ( $n$   
447 = 428 to explore the latent structure. Exploratory Factor Analysis revealed a five factor  
448 solution with 25 items. ("Wearing blue light filters," "Spending time outdoors," "Using  
449 phone and smart-watch in bed," "Using light before bedtime," and "Using light in the  
450 morning and during daytime"). The internal consistency reliability coefficient ordinal  
451 alpha ranged between .62-.94. As all the retained factors were meaningful and  
452 contributed essentially towards our aim we retained all five factors.

453 A CFA on a separate sample (( $n = 262$  gave a five-factor solution (CFI = .95; TLI =  
454 .95); RMSEA = .06[.05-.06, 90% CI]) and SRMR = .11) after discarding two item. The

455 internal consistency McDonald's  $\omega_t$  of the five factors were satisfactory (.96, .83, .70,  
456 .69, .52) Internal consistency reliability of the total scale (23 items) was also satisfactory,  
457 McDonald's  $\omega_t = .68$ . In the same sample, our measurement invariance analysis  
458 revealed that the latent structure attained the residual measurement invariance across  
459 subgroups: male and female (CFI: .98, TLI: .98, SRMR: .98).

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

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

## 477 Conclusion

478 "The Light exposure behavior assessment"(LEBA) gave a five solution with 25  
479 items in an EFA. A CFA with this 25-item scale again offered a five-factor solution, but

480 this time two more item was discarded. The 23-item “LEBA” was found reliable and valid.  
481 A short-form of LEBA was developed using IRT analysis. IRT analysis gave a 18-item  
482 scale with a good range of coverage across the underlying trait continuum. All-in-all, we  
483 can recommend both forms to be used to capture individual’s light exposure related  
484 behavior

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**Table 1**  
**Related Scales**

Name	Author	Description	Relevant Items	Scale type	Validity evidences
Visual Sensitivity Questionnaire-8	Light 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	Light Bajaj et al., 2011	1 item quantitative questionnaire	semi-light	Semi-quantitative	Correlation with physical measurement
Hospital Survey	Lighting Dianat et el., 2013	23 items questionnaire to assess light environment in a hospital	Item 16,17	5-point Likert scale	Face and Content validity
Morningness-Eveningness Questionnaire	Horne et al., 1976	19 items questionnaire to understand your body clock	item 1,2,8,13,14	Mixed response format	Correlation with oral temperature

Table 1 continued

Name	Author	Description	Relevant Items	Scale type	Validity evidences
Munich Chronotype Questionnaire (MCTQ)	Roenneberg et al., 2003	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	Factor measuring practice, behavior and attitude related sleep	Subscale 8&9	5-point Likert scale	Face and Construct validity
The Sleep Quality Index (PSQI)	Pittsburgh 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%)		

<sup>1</sup> Mean (SD); n (%)

<sup>2</sup> False discovery rate correction for multiple testing

<sup>3</sup> Wilcoxon rank sum test

<sup>4</sup> Pearson's Chi-squared test

Table 3

*Descriptive Statistics*

	Mean	SD	Skew	Kurtosis	Shapiro-Wilk Statistics	Item-Total Correlation
Item01	2.27	1.39	0.74	-0.81	0.81*	0.19
Item02	2.87	1.59	0.08	-1.60	0.83*	0.28
Item03	3.36	1.38	-0.48	-1.03	0.87*	0.23
Item04	1.47	1.18	2.38	4.00	0.43*	0.24
Item05	4.01	1.40	-1.22	0.07	0.70*	0.17
Item06	2.79	1.55	0.19	-1.48	0.85*	0.13
Item07	2.26	1.25	0.70	-0.60	0.85*	0.32
Item08	2.97	1.20	-0.06	-0.94	0.91*	0.25
Item09	2.94	1.03	-0.12	-0.40	0.91*	0.08
Item10	2.74	1.04	0.09	-0.74	0.91*	0.42
Item11	2.18	0.90	0.60	0.12	0.86*	0.41
Item12	2.36	1.22	0.59	-0.62	0.87*	0.48
Item13	2.73	1.46	0.20	-1.36	0.87*	0.25
Item14	2.14	1.31	0.77	-0.78	0.80*	0.28
Item15	3.26	1.09	-0.26	-0.45	0.91*	0.03
Item16	1.56	1.23	2.00	2.45	0.50*	0.28
Item17	1.54	1.21	2.07	2.75	0.49*	0.21
Item18	1.12	0.49	5.02	27.80	0.25*	0.18
Item19	1.05	0.36	7.23	52.98	0.13*	0.17
Item20	1.04	0.33	8.99	85.28	0.10*	0.16
Item21	1.14	0.59	4.79	24.05	0.25*	0.21
Item22	3.57	1.07	-0.65	-0.17	0.88*	0.20
Item23	2.56	1.27	0.33	-1.00	0.89*	0.08

Table 3 continued

	Mean	SD	Skew	Kurtosis	Shapiro-Wilk Statistics	Item-Total Correlation
Item24	4.14	0.99	-1.23	1.14	0.79*	0.22
Item25	2.59	1.41	0.27	-1.27	0.86*	0.15
Item26	2.25	1.27	0.69	-0.64	0.84*	0.08
Item27	3.80	1.29	-0.87	-0.42	0.82*	0.17
Item28	3.76	1.14	-0.68	-0.45	0.86*	0.18
Item29	2.44	1.31	0.38	-1.14	0.86*	0.13
Item30	1.48	1.11	2.18	3.35	0.48*	0.13
Item31	3.00	1.62	-0.08	-1.61	0.83*	0.39
Item32	3.55	1.65	-0.60	-1.34	0.76*	0.33
Item33	3.62	1.64	-0.68	-1.25	0.74*	0.37
Item34	3.42	1.83	-0.45	-1.69	0.69*	0.20
Item35	3.86	1.67	-0.99	-0.85	0.65*	0.20
Item36	1.54	1.25	2.13	2.86	0.46*	0.35
Item37	1.33	0.91	3.03	8.43	0.41*	0.09
Item38	4.30	1.08	-1.79	2.53	0.67*	0.32
Item39	1.96	0.98	1.02	0.69	0.82*	0.07
Item40	2.16	1.19	0.71	-0.54	0.84*	0.25
Item41	1.31	0.81	2.75	6.92	0.43*	0.14
Item42	3.93	1.48	-1.06	-0.44	0.71*	0.15
Item43	1.64	1.18	1.79	2.02	0.60*	0.22
Item44	3.51	1.30	-0.70	-0.59	0.85*	0.40
Item45	2.22	1.48	0.71	-1.02	0.76*	0.29
Item46	1.76	1.23	1.35	0.44	0.66*	0.39
Item47	2.11	1.17	0.77	-0.39	0.83*	0.37

Table 3 continued

	Mean	SD	Skew	Kurtosis	Shapiro-Wilk Statistics	Item-Total Correlation
Item48	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 tesponse category**thresholds of LEBA with 23 items (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

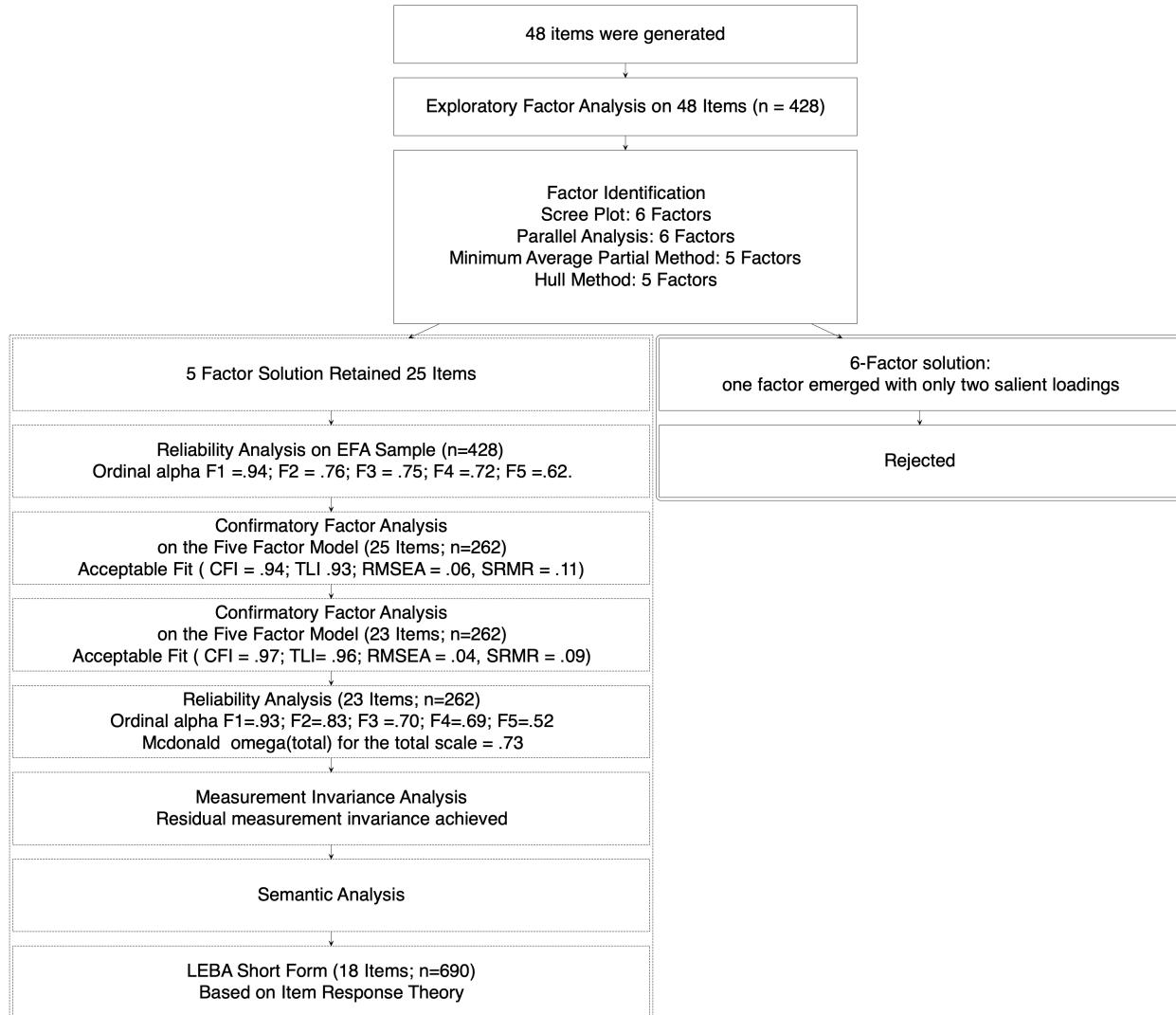
*Note.* a = item discrimination parameter; b(1-4)

= response category difficulty parameter

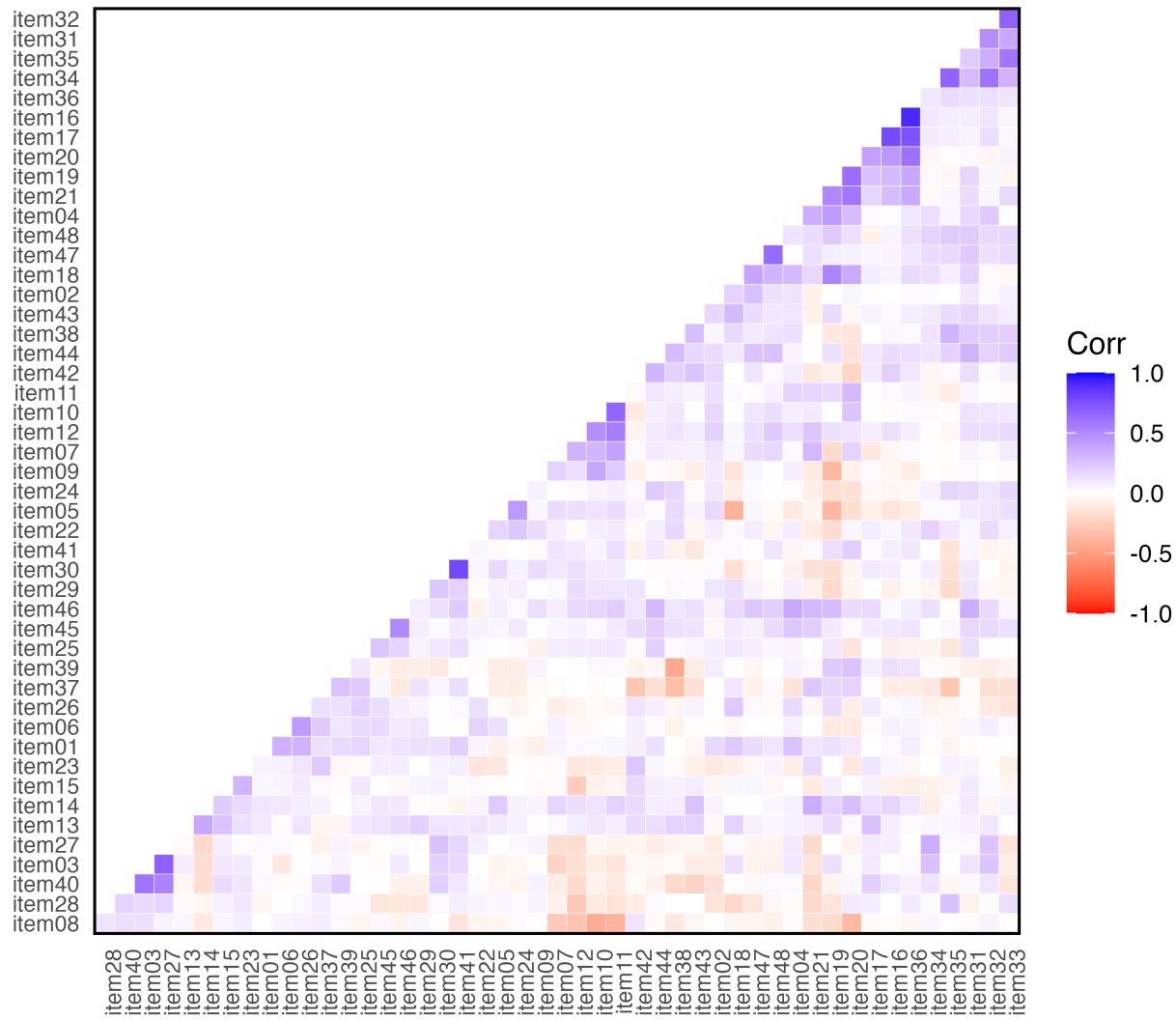
Table 8

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

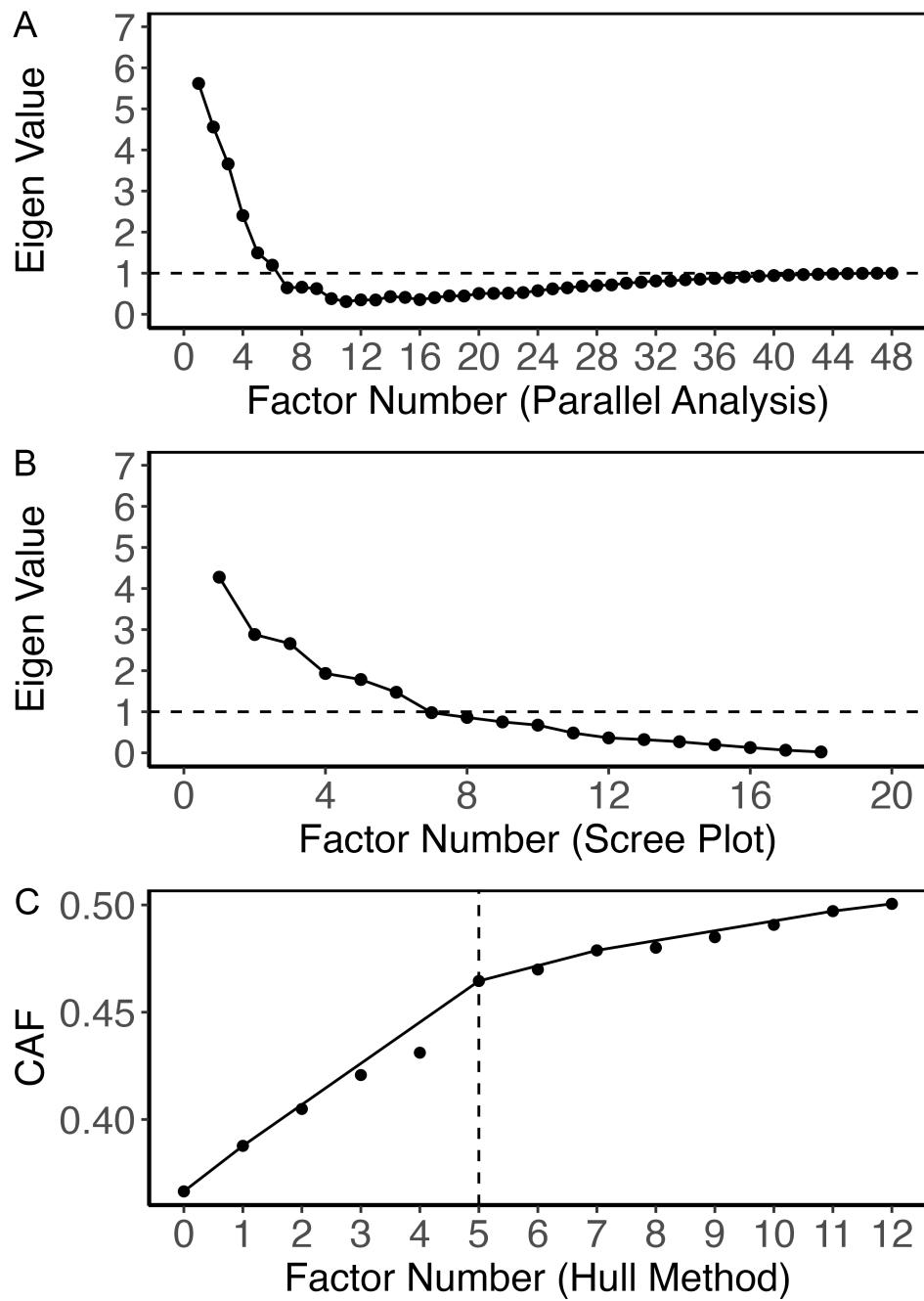
Items	a	b1	b2	b3	b4	Signed Chi-square	df	RMSEA	p
item16	28.13	0.78	0.90	1.06	1.40	2.02	6.00	0.00	0.92
item36	4.49	0.94	1.08	1.23	1.40	39.07	13.00	0.05	0.00
item17	2.81	0.97	1.11	1.38	1.62	25.58	13.00	0.04	0.02
item11	3.27	-0.79	0.65	1.54	2.31	55.03	27.00	0.04	0.00
item10	3.07	-1.27	-0.09	0.82	2.00	53.19	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



*Figure 1. Development of long and short form of LEBA*



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



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

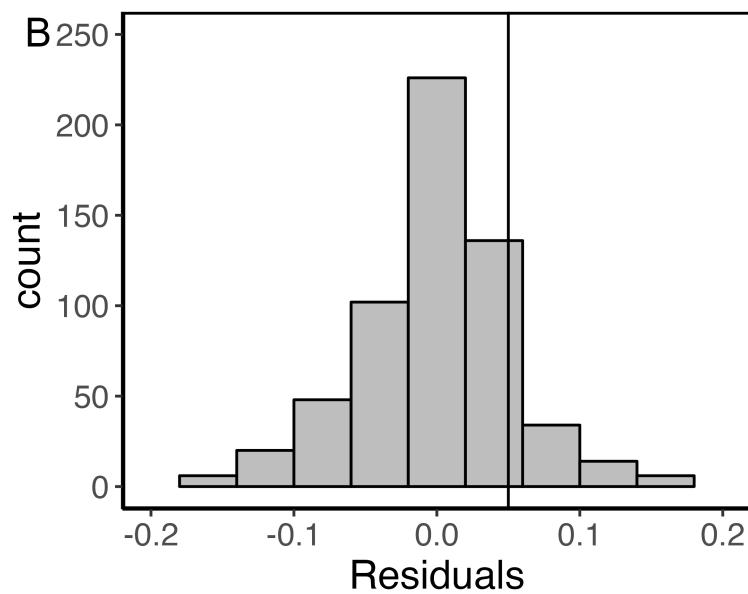
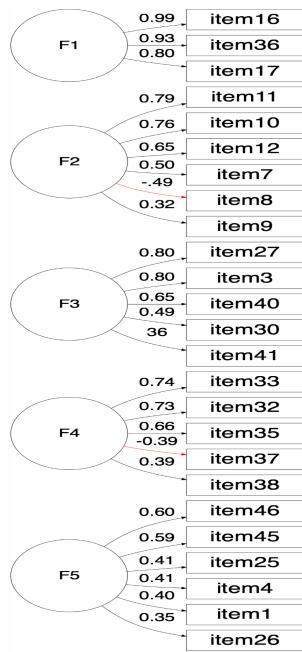
**A**

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

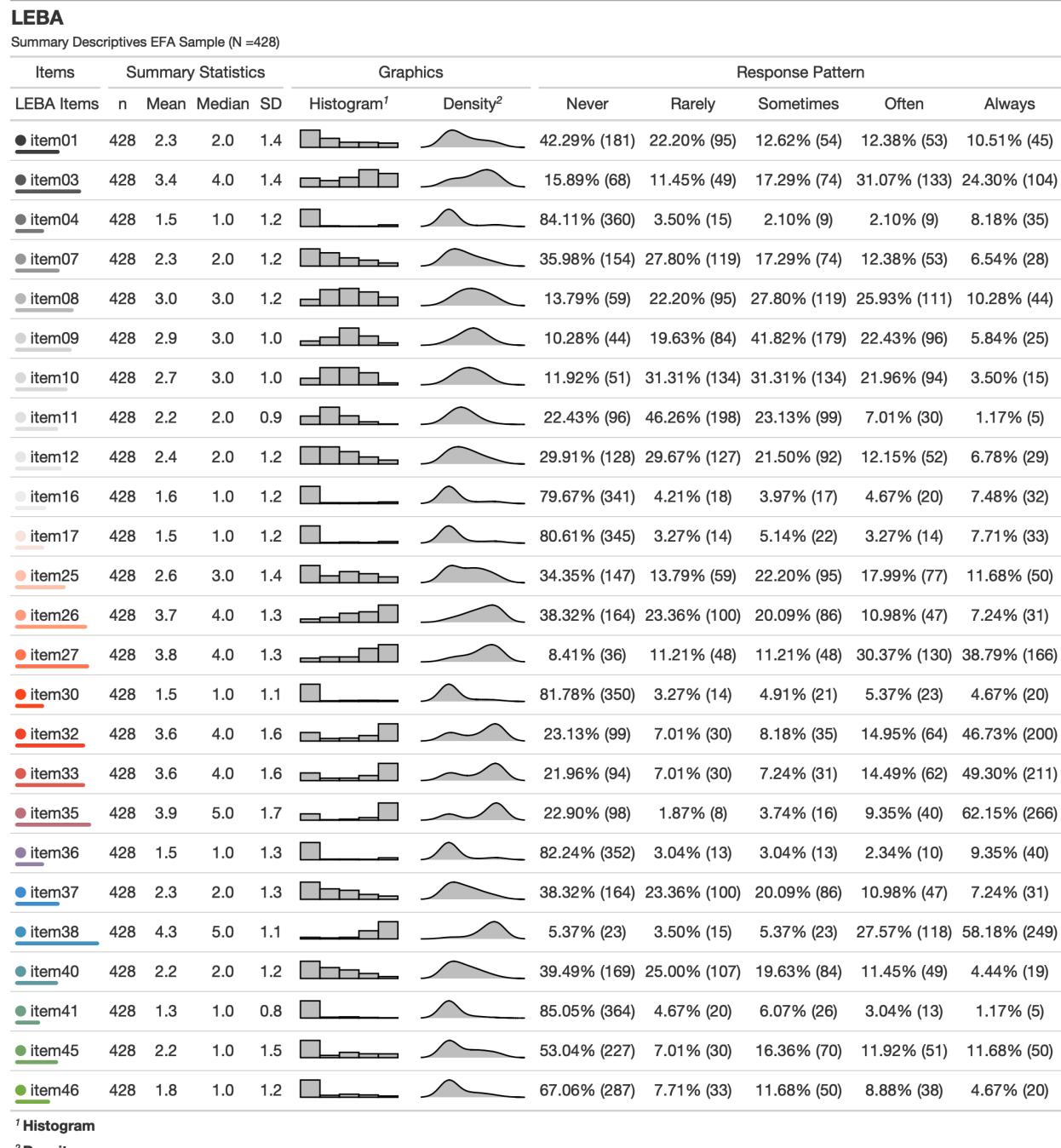


Figure 5. Summary Descriptives EFA Sample

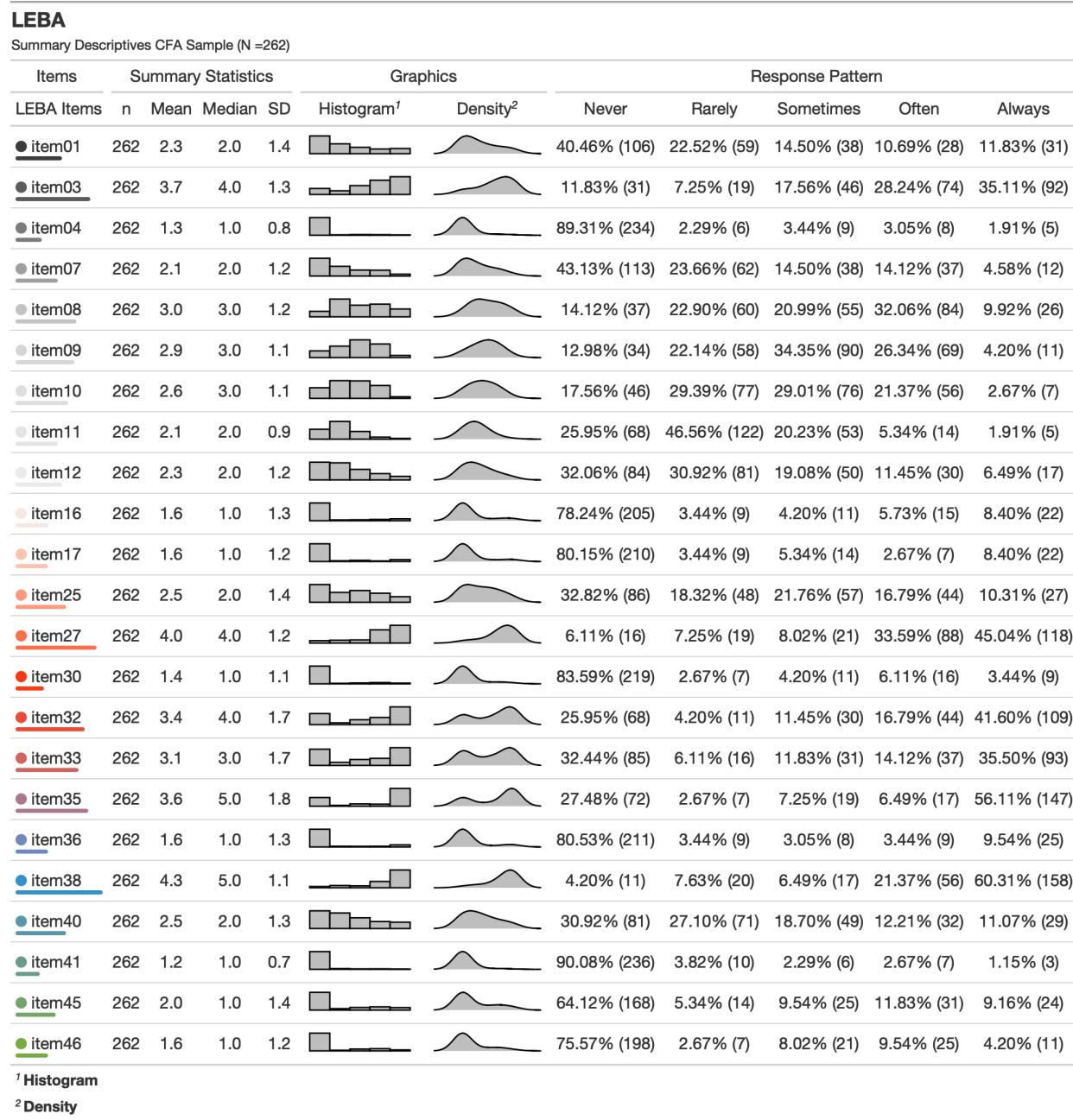
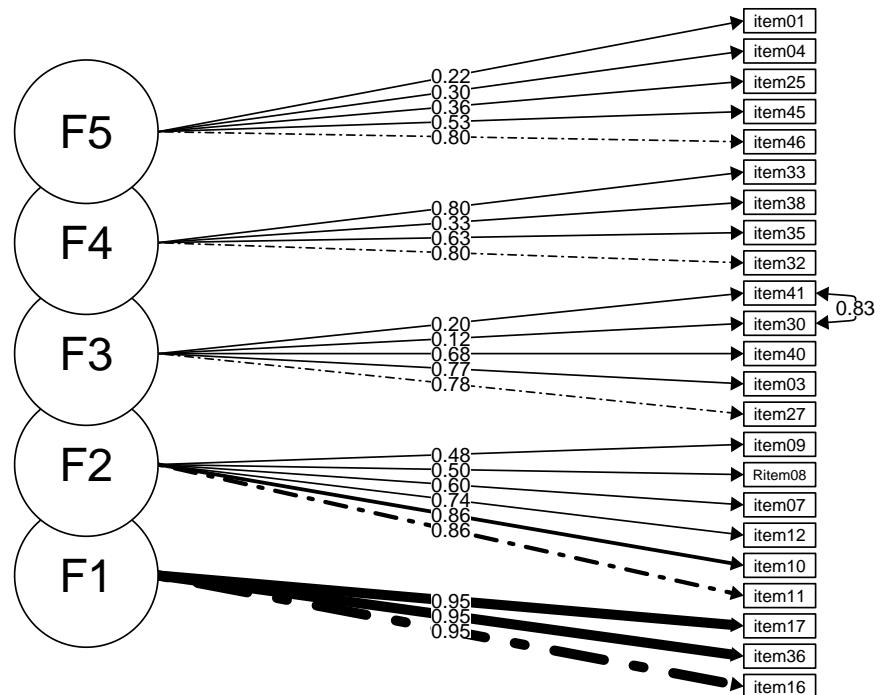
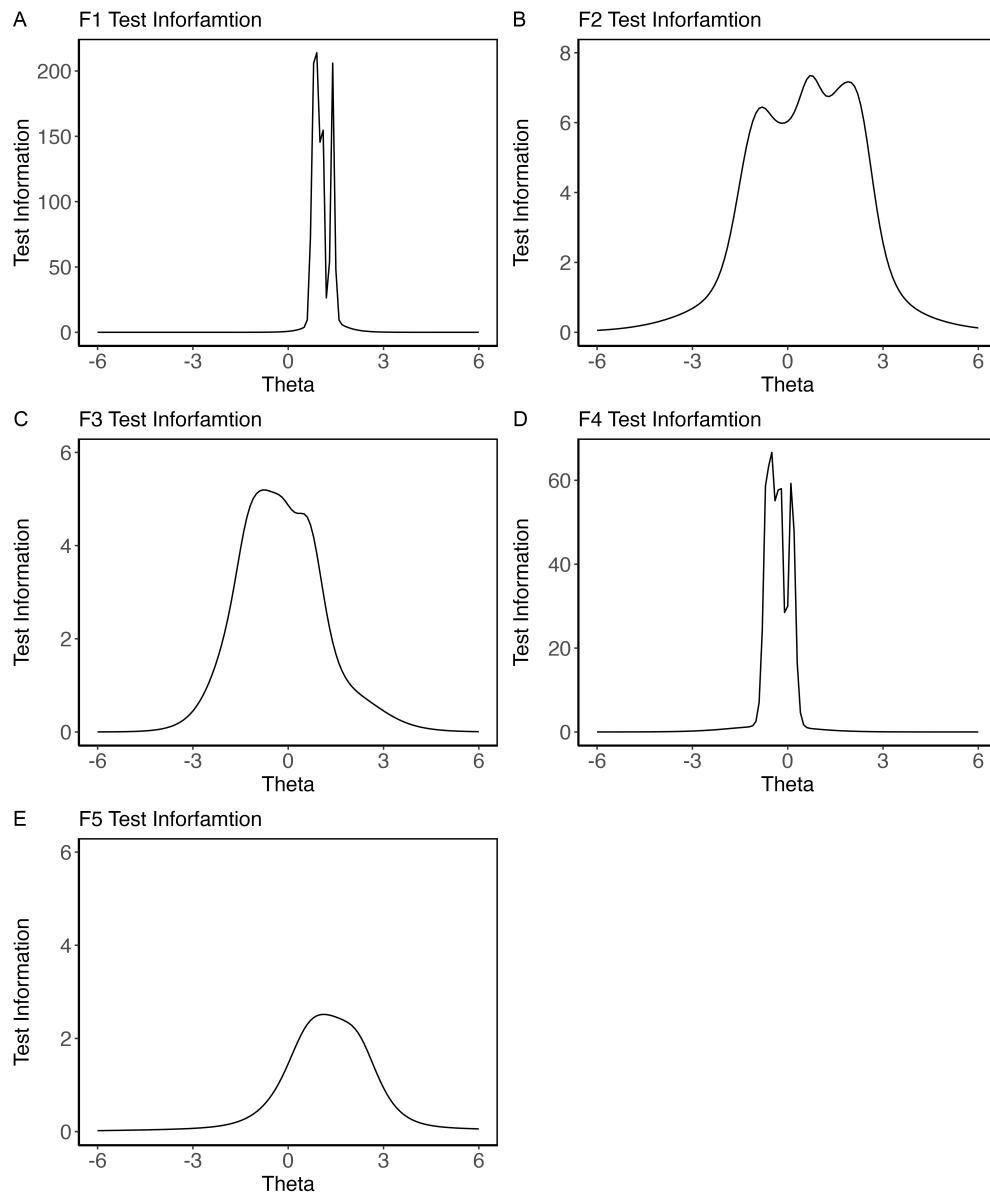


Figure 6. Summary Descriptives of CFA Sample



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



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

## Appendix

840 **Disclaimer:** This is a non-public version of LEBA (dated January 10, 2022) and still a  
841 work in progress. Please do not distribute!

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

846 **Instruction:**

847 "Please indicate how often you performed the following behaviours in the **past 4**  
848 **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

*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 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

Table A7 continued

item	MR1	MR2	MR3	MR4	MR5	Communality	Uniqueness
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

849

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

Table A8 continued

item	PA1	PA2	PA3	PA4	PA5	PA6	Communality	Uniqueness
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		

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

850

Table A9

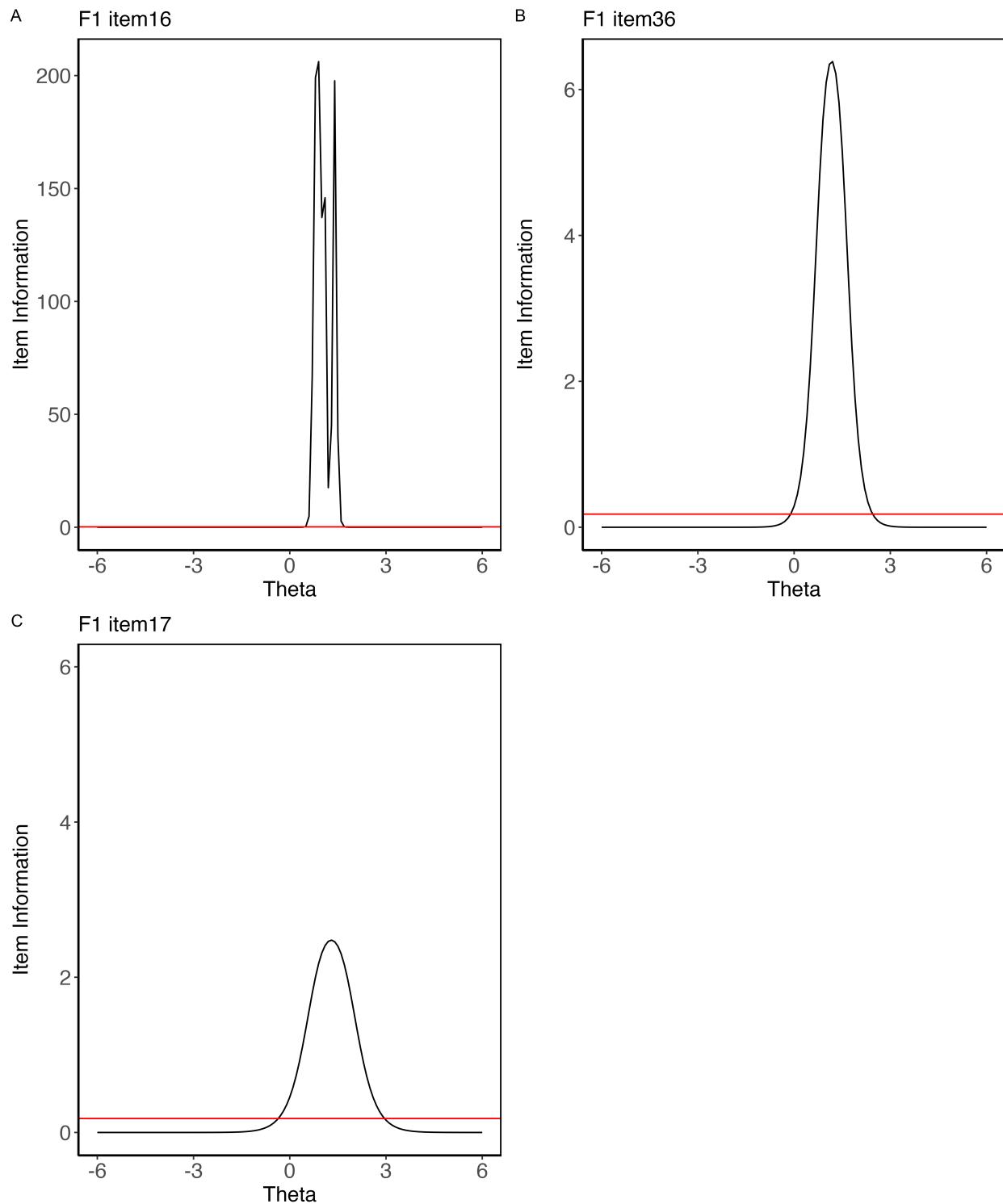
*Factor loadings and communality of the retained items in five factor solution [Unmerged Responses]*

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

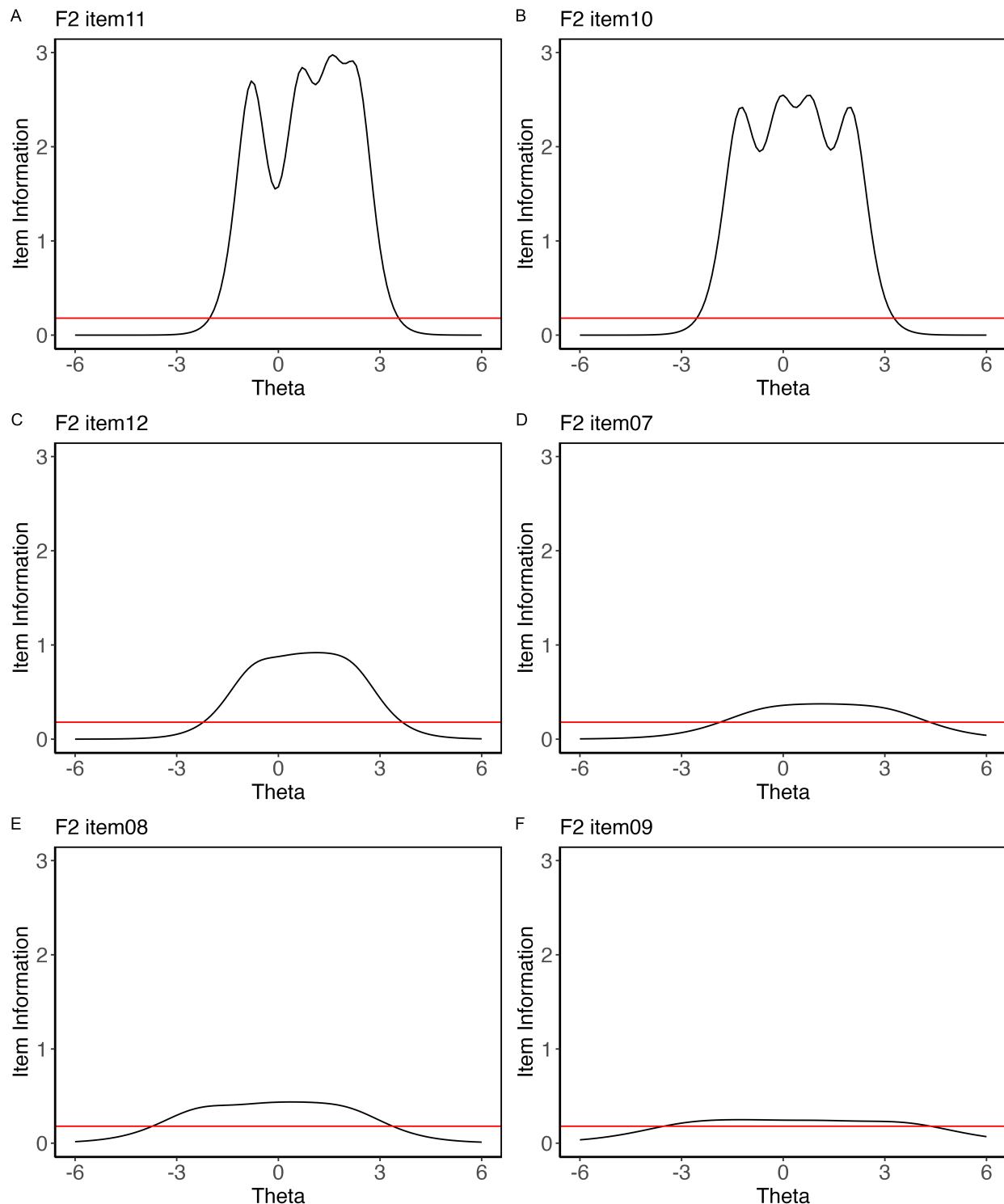
Table A9 continued

item	PA1	PA2	PA5	PA3	PA4	Communality	Uniqueness
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
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		

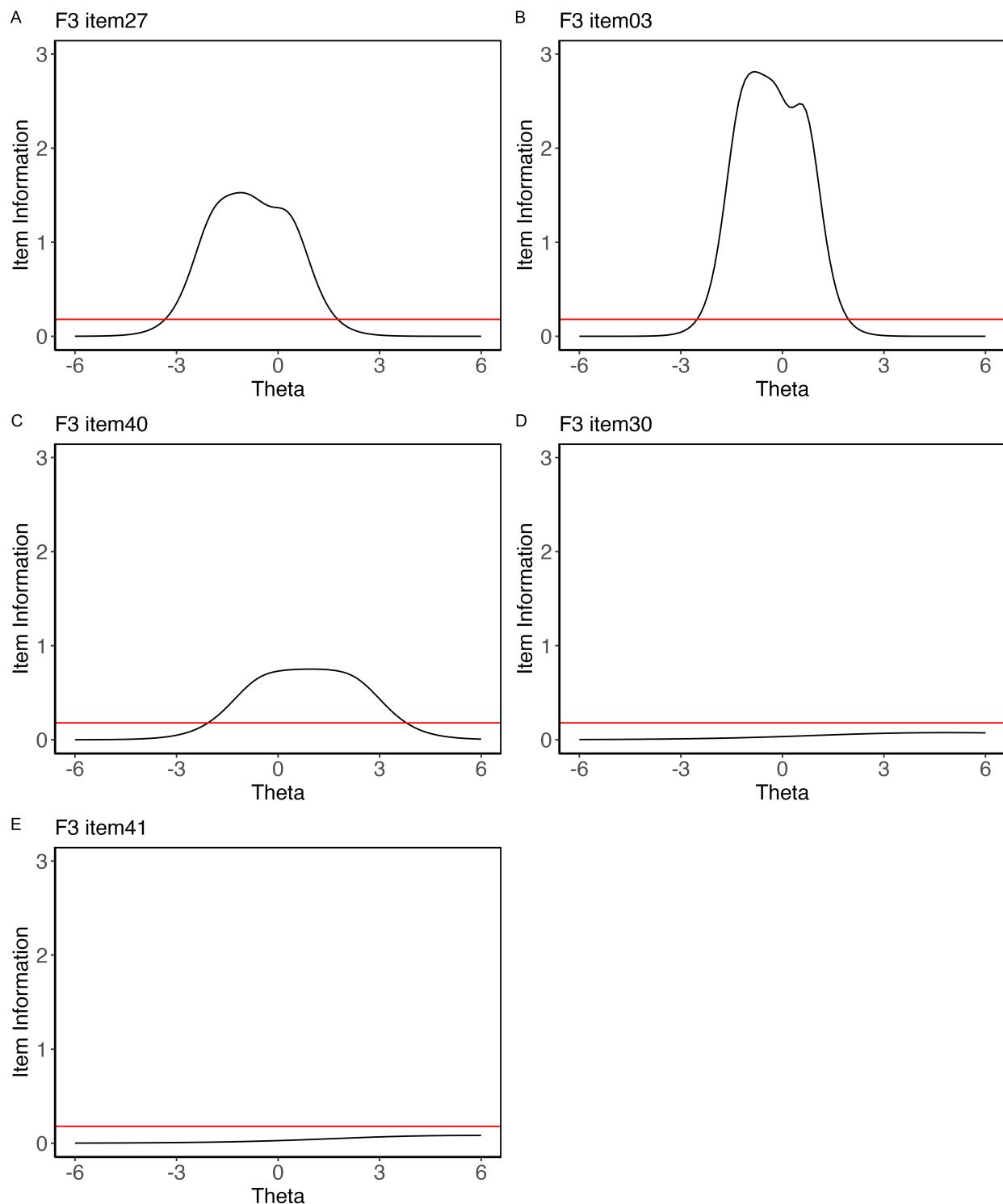
*Note.* Only loading higher than .30 is reported



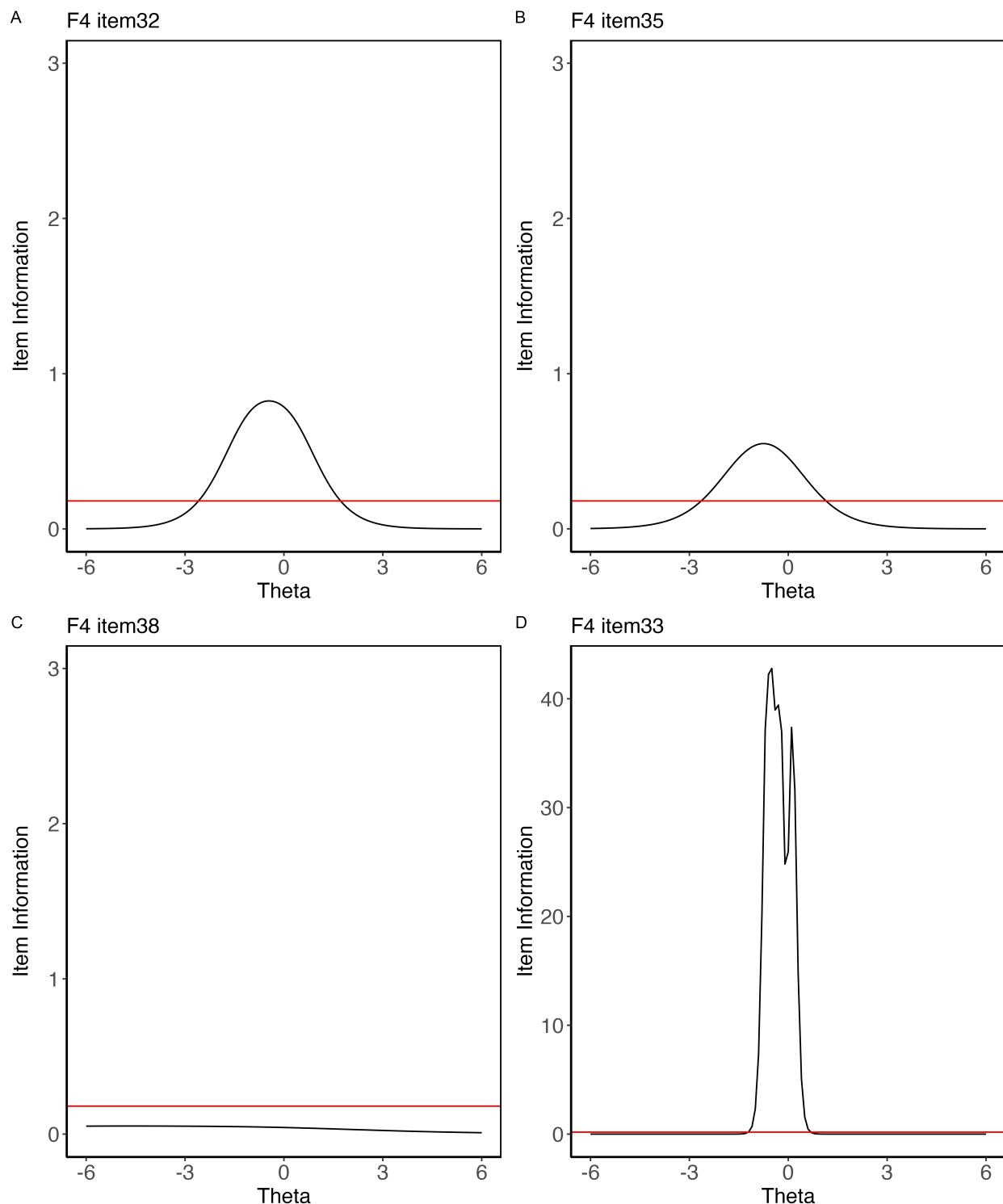
*Figure A1.* Item information curve of LEBA F1. Item 16 carried highest information among the three items



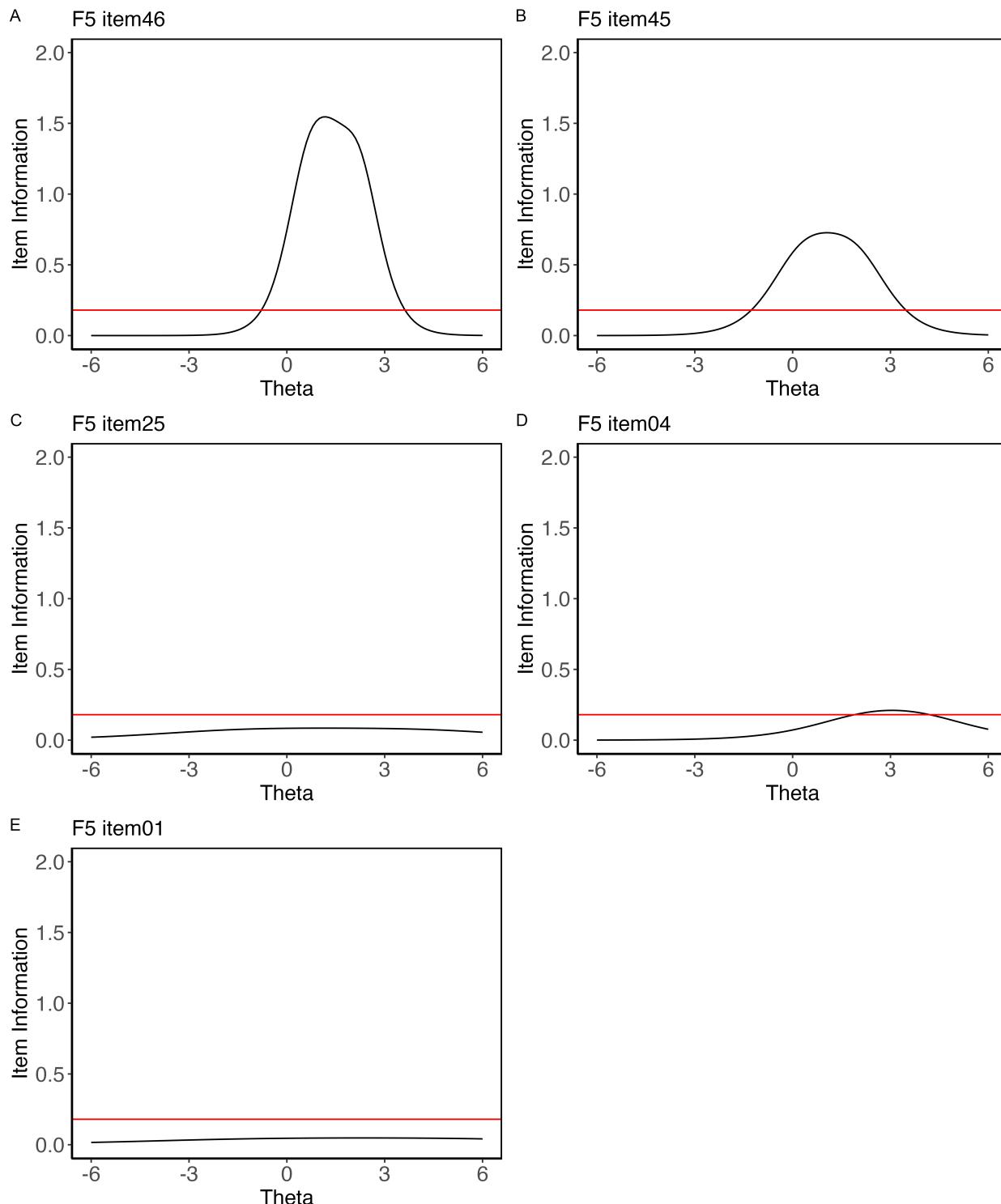
*Figure A2.* Item information curve of LEBA F2. All items carried information across the latent trait continuum. Item 09 carried the lowest information however its information peak was higher than .20.



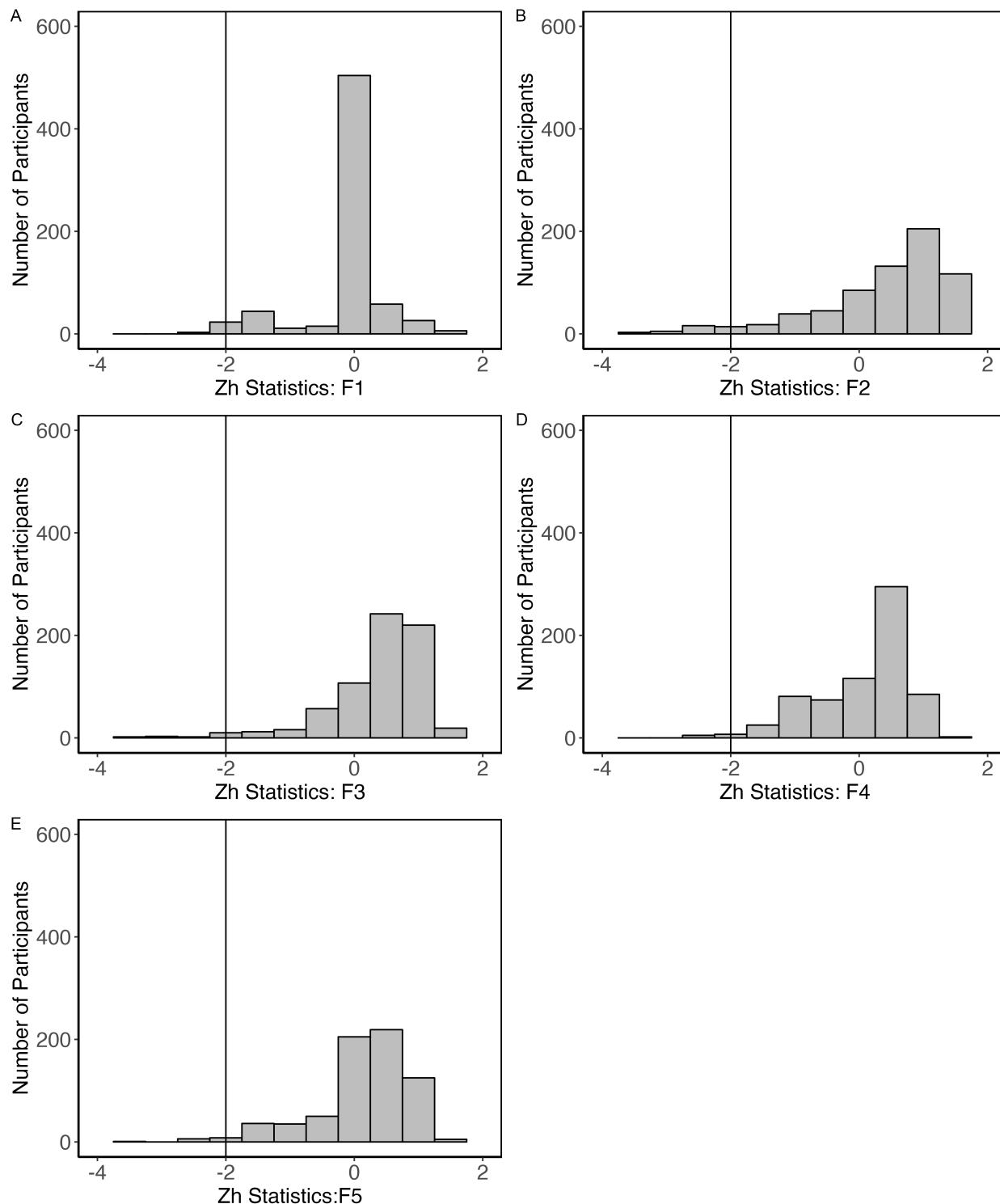
*Figure A3.* Item information curve of LEBA F3. Item 30 and 41 had relatively flat information curve with a peak lower than .20



*Figure A4.* Item information curve of LEBA F4. Item 38 had relatively flat information curve with a peak lower than .20



*Figure A5.* Item information curve of LEBA F5. Three items: 25, 04, 01 carried low information. However Item 04 had a bump at the right side of the center with a curve peak higher than .20. Item 01 and 25 had relatively flat information curve with a peak lower than .20



*Figure A6.* Person fit of the five fitted IRT models (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

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 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

Table A10 continued

item	PA1	PA2	PA3	PA4	PA6	PA5	Communality	Uniqueness
item03			0.85				0.731	0.269
item27			0.77				0.606	0.394
item40			0.72				0.533	0.467
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

852

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

Table A11 continued

Timezone	Number of Participants
Africa/Lagos (UTC +01:00)	1.00
America/Adak (UTC -09:00)	2.00
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

Table A11 continued

Timezone	Number of Participants
America/Monterrey (UTC -06:00)	1.00
America/New_York (UTC -04:00)	63.00
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

Table A11 continued

Timezone	Number of Participants
Asia/Seoul (UTC +09:00)	1.00
Asia/Shanghai (UTC +08:00)	7.00
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

Table A11 continued

Timezone	Number of Participants
Europe/Istanbul (UTC +03:00)	6.00
Europe/Kiev (UTC +02:00)	1.00
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 A6

*Demographic Characteristics: Native English Speakers*

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

<sup>1</sup> Mean (SD); n (%)<sup>2</sup> False discovery rate correction for multiple testing<sup>3</sup> Wilcoxon rank sum test<sup>4</sup> Fisher's exact test<sup>5</sup> Pearson's Chi-squared test

Table A12

## F1

I use light therapy applying a blue light box.

I use light therapy applying a light visor.

I use light therapy applying a white light box.

I use light therapy applying another form of light device.

I use an alarm with a dawn simulation light.

## F2

I spend more than 3 hours per day (in total) outside.

I spend between 1 and 3 hours per day (in total) outside.

I spend as much time outside as possible.

Table A12 continued

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F1
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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