ORIGINAL ARTICLE

Feasibility of smartphone diaries and personal dosimeters to quantitatively study exposure to ultraviolet radiation in a small national sample

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SUMMARY

Background
In 2007, a national skin cancer prevention campaign was launched to reduce the UV exposure of the Danish population. To improve campaign evaluation a questionnaire validation using UV-dosimeters was initiated.

Aim
To show the feasibility of dosimeters for national representative studies and of smartphones as a data collection tool.

Materials and Methods
Participants were sent a dosimeter which they wore for 7 days, received a short diary questionnaire by text message each day and subsequently a longer questionnaire. Correlation between responses from questionnaire, smartphone diaries and dosimeters were examined.

Results
This study shows a 99.5% return rate (n = 205) of the dosimeters by ordinary mail and high response-rates for a smartphone questionnaire dairy. Correlation coefficients for outdoor-time reported through smartphones and dosimeters as average by week 0.62 (0.39–0.77), P < 0.001 (n = 40). Correlation coefficient for outdoor time estimated by questionnaire and dosimeters were 0.42 (0.11–0.64), P = 0.008. The subjective perception of the weather was the only covariate significantly influencing questionnaire estimates of actual outdoor exposure. We showed that dosimeter studies are feasible in national settings and that smartphones are a useful tool for monitoring and collecting UV behavior data.

Conclusion
We found diary data reported on a daily basis through smartphones more strongly associated with actual outdoor time than questionnaire data. Our results demonstrate tools and possible considerations for executing a UV behavior questionnaire validation.

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Exposure to ultraviolet radiation (UVR) is the strongest risk factor for skin cancers of all types, including malignant melanoma (1). The incidence of melanoma (world standardized incidence rate per 100 000) for men and women in Denmark increased from 1.4 and 1.9 in 1949–53 (2) to 20.5 and 25.5 in 2008–12 (3), respectively, and is still increasing (4). It is now the fourth highest melanoma incidence in the world (1).

Most Danes are fair-skinned and exposed to high UVR levels and thus have a high risk of skin cancer. Recent surveys (2007–2009) show that 35% of the population had experienced sunburn in Denmark in the summer (5), 29% had used a sunbed (6), and 45% had travelled to a sunny destination within the past 12 months (7). In 2007, a national skin cancer prevention campaign was launched with three primary foci of reducing the UVR exposure of the population; (1) Vacationing in the summer in Denmark, (2) Vacationing in sunny countries, and (3) Using sunbeds (5–7). The primary target of the campaign is to decrease the skin cancer incidences, however, due to the latency time from UVR exposure to development of skin cancer the short-term evaluation was based on skin cancer inducing behavior such as intermittent exposure; exposure duration and lack of protection i.e. sun burns, time in the sun etcetera.

The campaign has been monitored since 2007 by annual population-based surveys, where participants were asked in the beginning of September each year to recall and summarize their behavior for the past summer or for the past 12 months. Several kinds of bias could influence this data collection approach and even though this traditional way of monitoring sun-related behavior is widespread (1) there have been concerns with recall bias (8, 9) and selection bias (10). Intensive campaign pressure has increased awareness, but could also introduce social desirability bias (11). These considerations led to the initiative of a questionnaire validation project with the overall aim, to optimize the campaign, to more efficiently prevent skin cancer. The first step is, to show the feasibility of the tools for the project.

Correlation of self-reported sun-related behavior and objective measures of UVR exposure as e.g. the use of personal electronically UV dosimeters, was previously shown. Most studies used diaries to assess the sun related behavior of their participants (12–14); however, diaries may not be suitable for population-based assessment of UVR exposure. For instance, carrying a diary could influence the participants i.e. induce a change of behavior. Recently a small study validated a brief questionnaire against objective measures of UVR exposure including UV dosimeters (15).

This study shows the feasibility of reporting daily sun behavior by smartphone and using dosimeters in a national setting. Control groups and intervention effects, behavior and item response among others will be reported elsewhere. We examined smartphones, as a new media for monitoring UV behavior, especially targeting the young population, and we examined measures of outdoor time from smartphone diary delivered by text message, questionnaire, and actual outdoor time exposure registered by personal electronic UV dosimeters.

METHODS

Recruitment and study flow

Participants were recruited in May 2012, through the Facebook site and the newsletter of the Danish Cancer Society each of which has about 150 000 ‘likes’ and 150 000 recipients respectively. Totally 585 volunteered (120 males and 465 females). They completed a short demographic questionnaire, including where and when they were going on vacation and if they had a smartphone or not. Participants were eligible to this study, if they were vacationing in Denmark during the weeks 26, 28, 30, or 32 (late June to mid-August). Weeks in between were for data retrieval and dosimeter (re)distribution. Participants were randomly assigned to a dosimeter group (which were instructed to wear a dosimeter, complete a short daily sun diary, and a questionnaire at the end of the measurement period) or control group (which received the diary and questionnaire, but not a UV dosimeter) by vacation week. Participants for smartphone groups were recruited among regular smartphone users and received their diary on the smartphone. 1–2 weeks before the measurement week participants were contacted by phone to confirm their participation. Approximately 90% confirmed their participation. The remaining 10% were either not reached within 10 calls in the period 9:00 to 21:00, declined because of personal reasons (wedding, giving birth, family related deaths, change of work schedule, regret participation) or were assigned to another week due to change of plans. Upon confirmation a dosimeter was sent by regular mail, including a prepaid envelope and instructions for wearing the dosimeter. Figure 1 shows the flow of the project.

From the recruited sample, a subsample characterized by having a smartphone and planning for vacation in a study period was chosen (N = 50) (Table 1). Analyses were based on this subsample; however, some did not complete UV measurement, diary, and questionnaire. n is given in tables for available data. We examine four
measures for outdoor time named M1-M4 representing outdoor time as measured by dosimeter, diary, questionnaire (7:00–11:00, 11:00–15:00, 15:00–19:00) and questionnaire (7:00–19:00).

Diary

The participants were sent a text message with a link to a diary (short questionnaire) each of the 7 days at about 19:00. The diary included “Did you wear the dosimeter today?”, “How many hours where you outdoor between 7:00 and 11:00; 11:00 and 15:00; 15:00, and 19:00?”, “Did your skin get reddish today?”, “How was the weather today?” For each measurement day the participants also rated the weather on a scale from 1 (= sunshine most of the time) to 5 (= clouded most of the time).

Questionnaire

The participants were sent a longer questionnaire addressing their outdoor behavior in the measurement period and their use of the dosimeter e.g. “How many hours were you outdoor between 11:00 and 15:00?” and “How many days did you wear the UV dosimeter?”, “How was the weather during the measurement week?” “How much of the time spend outdoors between 7:00 and 19:00 did you wear the dosimeter?”, “When did you wear it”, “When you wore the dosimeter, were you attentive toward the dosimeter?”, “When you wore the UV dosimeter, did people around you take notice of the dosimeter or ask you about it?”. The questionnaire also included questions on knowledge and attitude toward sun related behavior. The questionnaire was developed from the annual monitoring questionnaires of the Danish Cancer Society (www.skrunedforsolen.dk), retrieved material from other researchers (16, 17) supplemented with new questions.

Ultraviolet dosimeter

The dosimeters used for this study were electronic and developed at the University of Canterbury, New Zealand (manufactured by Scienterra, New Zealand) to digitally measure personal UV exposures in behavioral studies (18). They are based on a visible-blind AlGaN photodiode and their spectral response and cosine response was previously described by Allen (15) and used by Cargill et al. and Wright et al. (15, 19). The dosimeters were configured to make time stamped measurements at 30 second intervals from 7:00 to 19:00. Wristbands were attached to the dosimeters. Measurements at the wrist were previously shown to constitute approximately 50% of the ambient UV radiation in a small study (20). More important, the wrist was chosen to ensure that participants used the dosimeters in a uniform way. The different body sites receive varying amounts of UVR for instance due to differences in Solar Zenith Angle (21),
and even though solar zenith angles also differ depending on how the dosimeters are worn, the deviation is assumed to be diminished by the uniform site.

Statistics

The dosimeters were calibrated against data from the Danish Meteorological Institute (Robertson Berger type instrument), and second degree polynomials were fitted for each badge, to convert logged data into erythemal effective units (UVI, SED). Questionnaire assessment of time was converted from the possible answers of average daytime outside: ‘not outside’, ‘0–1 h’, ‘1–2 h’, ‘2–3 h’, ‘3–4 h’, to ‘0’, ‘½ h’, ‘⅓ h’, ‘⅔ h’, ‘⅔ h’, and ‘3/4 h’, respectively, for each of the three 4-h intervals 7:00–11:00, 11:00–15:00, and 15:00–19:00 and summed for a total day-time-score. The same procedure was used on data from diaries, but in addition these answers were summed for the 7 weekdays. In the questionnaire the participants were also asked, how many hours they were outside on average from 7:00 to 19:00. To examine correlation between UV dose and time outdoors, we converted any 30 s UV measurement to 30 s of outdoor time. Then we summed measured time and dose for each participant and measurement week. The converted time measure was also used in the comparisons of questionnaire, smartphone diary and dosimeter. The

<table>
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<tr>
<th>Sample Characteristic</th>
<th>Smartphone users</th>
<th>Total volunteered</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15–24</td>
<td>12</td>
<td>73</td>
</tr>
<tr>
<td>25–34</td>
<td>12</td>
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<tr>
<td>35–44</td>
<td>6</td>
<td>108</td>
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<tr>
<td>45–54</td>
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<td>104</td>
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<tr>
<td>Above 55</td>
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<td>194</td>
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<tr>
<td>Gender</td>
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<td>120</td>
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<tr>
<td>Female</td>
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<td>465</td>
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<td>I</td>
<td>9</td>
<td>89</td>
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<td>II</td>
<td>21</td>
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<tr>
<td>III</td>
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<td>IV</td>
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<td>Northern Jutland</td>
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<td>Secondary and Short higher</td>
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<td>Middle higher (2–4½ years)</td>
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<td>216</td>
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<tr>
<td>Long higher</td>
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<td>69</td>
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<table>
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<tr>
<th>Smartphone users measurements</th>
<th>N</th>
<th>Median (Q1–Q3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVR exposure (SED/day)</td>
<td>44</td>
<td>0.82 (0.37–1.69)</td>
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<tr>
<td>M1-UVR exposure time (min/day)</td>
<td>44</td>
<td>49 (21–94)</td>
</tr>
<tr>
<td>M2-Smartphone diary time outdoor (min/day)</td>
<td>45</td>
<td>137 (81–210)</td>
</tr>
<tr>
<td>M3-Questionaire time (7–11, 11–15, 15–19) outdoor (min/day)</td>
<td>44</td>
<td>270 (210–360)</td>
</tr>
<tr>
<td>M4-Questionaire time (7–19) outdoor (min/day)</td>
<td>44</td>
<td>240 (180–300)</td>
</tr>
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</table>
comparisons of diary and dosimeter, respectively, with questionnaire measurements were averaged by week. Skin type was assigned according to Fitzpatrick (22) and self-evaluated skin tan and burn reaction upon season’s first exposure to the sun.

Descriptive statistics for continuous variables are presented as medians (inter quartile range, Q1–Q3) or means as appropriate. The stratified analysis of M1-M4 and background variables were examined graphically with boxplots. Quantitative agreement between the measurements of outdoor time (diary, questionnaire, and dosimeter), was assessed using the Bland-Altman method i.e. plotting the difference between the measurements against the mean of the measurements, to visualize systematic and random errors. Spearman rank correlation coefficients were used with the Bland Altman method. Confidence intervals for the Pearson correlation coefficients were calculated using Fisher’s transformation for small sample sizes. Assumptions of linearity and homogeneity of variance were satisfied. The normal distribution of data was tested by QQ plots and Shapiro-Wilks tests. Square root transformation of data was distributed normally, and used when data deviated from the normal distribution. Linear regression models were used to assess associations between outdoor time measured by questionnaire and diary, and dosimeter, respectively, where dosimeter minutes were the independent variable. Residuals were normally distributed. The variables region (Capital + Zealand; Northern Jutland + Central Jutland + Southern Denmark) and education (primary school; middle higher secondary and vocational school; middle higher + long higher education) were both collapsed into two binary categories for the regression analyses.

The project was sent to The National Committee on Health Research Ethics who decided that their approval was not necessary. Danish Data Protection Agency gave approval number 2012-41-0100.

RESULTS

Recruitment sample characteristics

The majority of subscribers to the newsletter and Facebook site are women (Personal communication). The distribution of phone types among the volunteers was landline (34%), regular cell phone (47%), and smartphone (51%). Forty-two percent reported smartphone as their only phone and only 3% reported landline as their only phone. The smartphone users described their internet phone use as, never user (1%), seldom user (7%), regular user (26%), skilled user (35%), and very skilled user (31%). The distribution of the smartphone subsample is shown in Table 1. A stratified analysis of M1-M4, respectively, and gender, age, region, or skin type showed no significant differences within each measure (data not shown).

Smartphone response

Forty-nine of the 50 participants completed at least one diary on the smartphone (98%). Of those who responded to at least one text message 39 respondents (79%) responded to all seven text messages. Mean (SD) response (days completed) was 6.22 (1.77). The outdoor time differed between weather ratings.

Questionnaire response

Eighty-six percent of the participants answered to the end-of-measurement questionnaire; 8% did not complete the questionnaire due to unsuccessful UV measurement. Excluding those without a measurement, the completion rate was 93%. Seventy percent, said they wore the dosimeter all the time, when they were outdoors between 7:00 and 19:00; 16%¾ of the time; 5% half the time; and 9%¾ of the time. To further describe participants’ interpretation of the instructions, they were asked about them, and 0% said they wore the dosimeter 24 h a day, 74% applied it in the morning and then wore it all day, 19% only wore it when going outside and 9% only wore it when the sun shined.

Measurement feasibility

During the study period, 65 dosimeters were distributed to 205 participants, an average of 3.15 participants per dosimeter. Of the 205 participants, 89% had successful measurements. Of the 22 participants (11%) who did not have a successful measurement, three were due to mail delivery failure, one to battery fail, four to change of plans of the participant, one to sickness, one woman who found the dosimeter too large to wear, one who found the wristband too itchy to wear, and one who could not wear the dosimeter due to using stitches/crutches. In addition two dosimeters disassembled due to accidents, two dosimeters could not transfer data when returned and six dosimeters disassembled spontaneously. The latter occurred mainly in the first week of measuring and was due to an assembly failure by the manufacturer, which was fixed for the subsequent measurements. One disassembly, however, resulted in a lost chip and only the shell of the dosimeter was returned. The dosimeter chip was
kindly substituted by the manufacturer. All dosimeters were functional after the study and available for future studies. In Table 2 is shown the use of dosimeters according to the three measures. The use reported in each of the three ways is in the same range, with the lowest fraction of days registered by dosimetry and the highest fraction reported by smartphone.

Correlation of time and dose measures

The converted UV measurements gave a correlation of 0.92 (P < 0.001) between outdoor time and dose. Correlation between time measured by UV dosimeter and time registered by smartphone diaries were moderate to high with a correlation coefficient of 0.65 (0.57–0.72), P < 0.001 for subject means with n = 44 during 241 measurement days. The same correlation analysis stratified on weekdays and weekend, respectively, yielded similar correlation coefficients; weekdays 0.67 (0.57–0.74) and weekend 0.63 (0.45–0.75). Correlation between time estimates M1-M4 is shown in Table 3. The four measures are all significantly correlated with each other. The correlation coefficient of diary and dosimeter estimates was larger than the correlation coefficient of questionnaire and dosimeter estimates.

Figure 2a shows that the dosimeters (M1) mean (SD) measures 94(70) minutes less than the participant estimated by diary (M2). The difference between the measurement methods and their means are significantly correlated (−0.65, P < 0.001) and there is a trend that the difference increases by outdoor time. Figure 2b shows that the dosimeters (M1) mean (SD) measures 225 (134) minutes less than the participants estimated by questionnaire (M3) (0.83, P < 0.001) and the difference increases by outdoor time. Figure 2c shows that the diary (M2) mean (SD) estimates are 128 (113) minutes lower than the participant estimated by questionnaire (M3). The difference between the measurement methods and their means are significantly correlated (0.53, P < 0.001) and the difference increases by outdoor time. When using a different questionnaire measurement (total estimate for day-M4) Fig. 2d shows that dosimeters (M1) only measure 169 (100) minutes less than questionnaire (M4), (0.72, P < 0.001). Also there was no significant differences between questionnaire (M4) and diary (M2), with questionnaire measuring 73 (94) minutes less than diary (Fig. 2e), (0.24, P = 0.13). Neither was there any difference between the two questionnaire estimates where M4 yields 52 min less than the 7–11, 11–15, 15–19 measure (M3), (−0.27, P = 0.07).

Regression models - perceived weather and outdoor time

The three kinds of measures are significantly correlated. To counter potential confounding we examined their relations with potential covariates; gender, age, region, education, skin type, week of measurement (objective weather), and weather (subjective). The model for questionnaire estimated minutes $Y = \beta_0 + \beta_1 \text{sqrt(dosimeter minutes)}$.
utes) + \beta_2 \text{ (weather)} was found to fit the data. The model for SQRT-transformed diary estimated minutes was similarly dependent on the weather as the only significant covariate. Test for interactions between weather and measured time were not significant, for any questionnaire or diary models.

DISCUSSION

We found a high feasibility for carrying out dosimeter studies in a sample with a variation similar to a national representative sample regarding geography, age, gender, and skin type and for collecting data by smartphone. The return rate of dosimeters was exceptionally high and participation and response rates in both diary and questionnaire were very high. We found strong correlation of outdoor time estimates between data sampled daily on smartphones and dosimeters respectively. Correlation of outdoor time between retrospective questionnaire estimates and dosimeters were moderate 0.42 (0.11–0.64), \( P = 0.008 \). The subjective perception of the

Fig. 2. Bland-Altman plots. (a) Diary-dosis (M2-M1), (b) Questionnaire1-dosis (M3-M1), (c) Diary-Questionnaire1 (M2-M3), (d) Questionnaire2-dosis (M4-M1), (e) Diary-Questionnaire2 (M2-M4), (f) Questionnaire1-Questionnaire2 (M3-M4). The units of the y-axis and x-axis are minutes. The x-axis designates the mean of the means and the y-axis designates difference between the means. Dashed lines indicate 95 % limits of agreement.
weather was identified as the only covariate significantly influencing questionnaire estimates of actual outdoor exposure. This could indicate that sunny weather gives a stronger perception of being outside, which means that reported outdoor time is overestimated relatively to actual outdoor time or vice versa. Previously it was shown that wrist worn dosimeters received approximately 50% of the ambient radiation. This could both be due to lower measurements and zero measurements caused by measurement angles between 0 and 90 degrees and above 90 respectively from SZA, the latter resulting in conversion to zero time. Also when participants turn the arm in the opposite direction of the sun the dosimeter would be shaded by the body resulting in lack of measurement. Thus despite large differences in time between the methods this approximation would bring the measured outdoor time of the dosimeter closer to the smartphone estimate. The questionnaire (Fig. 2) overestimates the outdoor time proportionally relative to smartphone diary estimate. We used two questions to assess outdoor time; a total day estimate M4 and a 7:00–11:00, 11:00–15:00, 15:00–19:00 split estimate M3. The M4 resulted in better correlation between dosimeter and questionnaire and weaker correlation for the Bland-Altman (differences and means). For comparison, the two questionnaire estimates (M3, M4) only had a correlation coefficient of 0.66.

Thieden et al. (12) previously reported measurements of UVR between 0.7 and 1.2 SED/day in Denmark depending on skin type. These results are similar to what we found and confirm the validity of the measurement method. Correlation between diary and dosimeter was higher in our sample using smartphones than previously shown by Cargill et al. In the study of Cargill et al. (15) correlation coefficients between dosimeter and questionnaire and between dosimeter and diary are very similar. We, however, show stronger correlations of dosimeter to diary and weaker correlation of dosimeter to questionnaire.

**Smartphone**

In 2011, it was estimated that 97% of the Danes had a cell phone (regular or smartphone) and 33% a smartphone. From 2008–2011 households with landline phones decreased from 76% to 58%. In our sample, more people had a smartphone compared to the most recent numbers from Statistics Denmark. This could be due to a higher socioeconomic status in our sample; however it could also be caused by the fast development in the phone market currently. We also observed a high response rate and almost 100% completion rate for those who used their smartphone in the study. Within a short period it seems likely that the majority of the Danish population will be able to conduct surveys on their smartphones (23). This emphasizes that smartphones are a valid option for data collection in this field.

**Strength and limitations**

Some of the discrepancy between dosimeter data and diary/questionnaire can be ascribed to incorrect use of the dosimeter e.g. only 70% wearing it 100% of study time, which will be important to emphasize in future research. Seventy-four % applied the dosimeter as they were instructed, while 19% only applied it when going outside which could bias the results as it is possible that they forgot the dosimeter. 9% for sure biased the analysis as they only wore it when they assessed that the sun shined. Also participants could have reckoned transportation, shopping or similar activities away from home as outdoor door time. To achieve better compliance, more detailed information should be given to the participants to avoid wrong interpretations of the instructions.

Five persons had used a sunbed within the past 12 month (four persons less than monthly, 1 person 2–3 times a month), however, we did not obtain data on sunbed use for the week(s) of measurement and as measurement time was the primary outcome in this paper a 5–10 min session of sunbed use would not bias results significantly.

Our sample was not representative of the Danish population and our participants were recruited from a base with a presumed positive attitude toward the project, however, one in 10 Danes are members of the Danish Cancer Society. The results i.e. high participation rate, high response rate and low equipment loss, indicate that it will be possible to carry out a similar study in national representative setting. However, some decline in participation, response, and perhaps loss of equipment could be expected due to a less dedicated population.

Measurement feasibility was high (89%) but can be improved as six of 22 failures were due to equipment implementation problems, one not getting information on participant’s illness, and three not being careful enough when asking for address. Thus, optimization of the process could be able to yield successful measurements in 90–95% of participants.
CONCLUSION

We show that dosimeter studies are feasible in larger national representative settings, and that smartphones are a very useful tool for monitoring and collecting UV behavior data. We find that diary data registered daily on the smartphones is more strongly associated with actual outdoor time than retrospective questionnaire data. Our results demonstrate tools and possible considerations for carrying out a UV behavior questionnaire validation.

REFERENCES