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# The validated sun exposure questionnaire: association of objective and subjective measures of sun exposure in a Danish population-based sample\*

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## Summary

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None declared.

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**Background** Few questionnaires used in monitoring sun-related behaviour have been tested for validity.

**Objectives** We established the criteria validity of a questionnaire developed for monitoring population sun-related behaviour.

**Methods** During May–August 2013, 664 Danes wore a personal electronic ultraviolet radiation (UVR) dosimeter for 1 week that measured their outdoor time and dose of erythemal UVR exposure. In the following week, they answered a questionnaire on their sun-related behaviour in the measurement week.

**Results** Outdoor time measured by dosimetry correlated strongly with both outdoor time and the developed exposure scale measured in the questionnaire. Exposure measured in standard erythema dose (SED) by dosimetry correlated strongly with the exposure scale. In a linear regression model of UVR (SED) received, 41% of the variation was explained by skin type, age, week of participation and exposure scale, with exposure scale as the main contributor. The weekly sunburn fraction correlated strongly with the number of ambient sun hours ( $r = 0.73$ ,  $P < 0.001$ ).

**Conclusions** This criteria-validated questionnaire provides evidence of the exposure that the questionnaire aimed to measure. The evidence provided showed a strong link between the objectively measured behaviour and the behaviour measured by this survey construct. The questionnaire is the first validated tool to measure the UVR exposure in a national population-based sample.

### What's already known about this topic?

- Personal ultraviolet radiation (UVR) dosimeters and diaries have previously been applied in studies of UVR.
- Previous evaluation designs were weakly correlated or less well suited for evaluation.

### What does this study add?

- Objective and subjective measures of outdoor exposure time are strongly correlated in a week-based evaluation design.
- The validated sun exposure questionnaire provides a design for reliable short-term evaluation of skin cancer prevention campaigns.

The incidence of both malignant and nonmalignant skin cancers has increased for decades in large parts of the world and especially in Caucasian populations.<sup>1</sup> Exposure to ultraviolet radiation (UVR) is the main risk factor for skin cancer<sup>2</sup> and it has been estimated that at least 80% of all skin cancers could be avoided by behavioural changes.<sup>3,4</sup> The three main sources of UVR exposure among the Danes are spare time in the summer in Denmark, sunbeds and vacations to destinations with a high UV index (UVI).<sup>5–9</sup>

Campaigns aimed at changing UVR behaviour in the general population have been launched in several countries.<sup>8,10–12</sup> The effects of these initiatives are generally evaluated through the distribution of questionnaires.<sup>13</sup> Bias (recall, selection, socially desirable answers) can potentially limit the reliability of conclusions drawn based on questionnaire data and it is thus essential that questionnaires be evaluated for validity and reliability.<sup>14–17</sup>

Few questionnaires used in the evaluation of health interventions aimed at reducing skin cancer have been tested for validity and reliability, e.g. to validate self-reported measures of UVR exposure by testing behavioural questions against objective measurements or against other self-reported data sources. These studies show that it is possible to measure various aspects of people's behaviour in the sun with validity<sup>5,18–22</sup>; however, the published studies are limited in that only specific groups were included and, therefore, the results are not valid on a population level. Most studies used diaries to assess sun-related behaviour. Diaries are not feasible for campaign evaluation, as they are an intervention themselves. Recently, a small study ( $n = 47$ ) validated a brief questionnaire against objective measures of UVR exposure, including UVR dosimeters.<sup>23</sup>

The Danish Sun Safety Campaign's questionnaires of the Danes' sun behaviour are neither tested for criteria validity against objective measures of the personal UVR exposure nor tested for reliability, and people are asked in September to recall information about the summer, e.g. the length of time they spent in the sun. The problems with these questions are the recall over a long period and the generalization of typical behaviour during the summer. Previous annual evaluations of the Danish Sun Safety Campaign examined trends, e.g. the percentage of the population that experienced sunburn; however, summers in Denmark have large climatic variations.<sup>7</sup>

The ideal evaluation objective is the number of skin cancer incidents; however, as a short-term evaluation objective this is not applicable, as skin cancer has a latency time of a minimum of 5–20 years.<sup>24</sup> Therefore, it is necessary to measure the main cause of skin cancer, the UVR exposure, by objective measurements.

Sunburn has been used as an approximate measure for UVR exposure in epidemiological research, but it is important to keep in mind that it is the radiation causing the sunburn that also causes the cancer. Sunburn is associated with the cumulative and especially the intentional UVR exposure; however, it is not necessary to experience sunburn to develop skin cancer

and therefore other measures of sun-related behaviour should complement the sunburn item in evaluation and research.<sup>25,26</sup>

Previously we reported the feasibility of the study method and we examined sources of bias and possible optimizations. We showed criteria validity in a small sample and established that UVR exposure measurement periods of 1–3 weeks were applicable and yielded questionnaire results validly reflecting the measured UVR exposure.<sup>27,28</sup>

The aims of this study were to establish the criteria validity of a questionnaire developed for monitoring and evaluating population sun-related behaviour. To our knowledge, this is the first study to validate a questionnaire on sun-related behaviour against objective UVR measurements in a national random population-based sample.

## Methods

### Study design and population

In March 2013, a random sample of Danes aged 15–65 years was drawn from the Danish civil registration system. They were mailed an invitation to participate in the study at the end of April. To be eligible to participate in the study they needed to be able to wear a personal dosimeter wristband for 1 week of their vacation in Denmark during weeks 19–35 (May–August) and complete an electronic questionnaire afterwards. The invitees signed up on the project page (<http://www.mituv.dk>) and indicated available weeks. Potential participants were then allocated to a participation week and contacted by phone at least 1 week in advance to receive instructions. Potential participants with more than one vacation week were allocated to a low season week, if available, to increase sample utilization. Participants who confirmed their participation by phone were sent a dosimeter including instructions and a prepaid envelope by ordinary mail. After participation, they returned the dosimeter for data retrieval and received a questionnaire the following week. The project had 130 dosimeters available, which were deployed in a biweekly cycle of 65 participants, i.e. 1 week of data collection and 1-week postal management and data retrieval. Figure 1 shows the project flowchart. The 488 available persons who signed up but were not included were either not reached within 10 calls made between 9:00 and 21:00, were not needed because more than 65 participants were allocated (weeks 27–29 only), or declined because of personal reasons (change of vacation plans, wedding, giving birth, family-related deaths, change of work schedule, regret participation, etc.).

The study population was chosen to be representative of the Danish population within sex, age groups (15–24, 25–34, 35–44, 45–54, 55–65 years) and region. The recruitment of the 15- to 17-year-olds required parental consent, in which case the invitation letter was initially directed to one of the parents. Persons who requested not to be chosen for research projects were excluded from the sample.

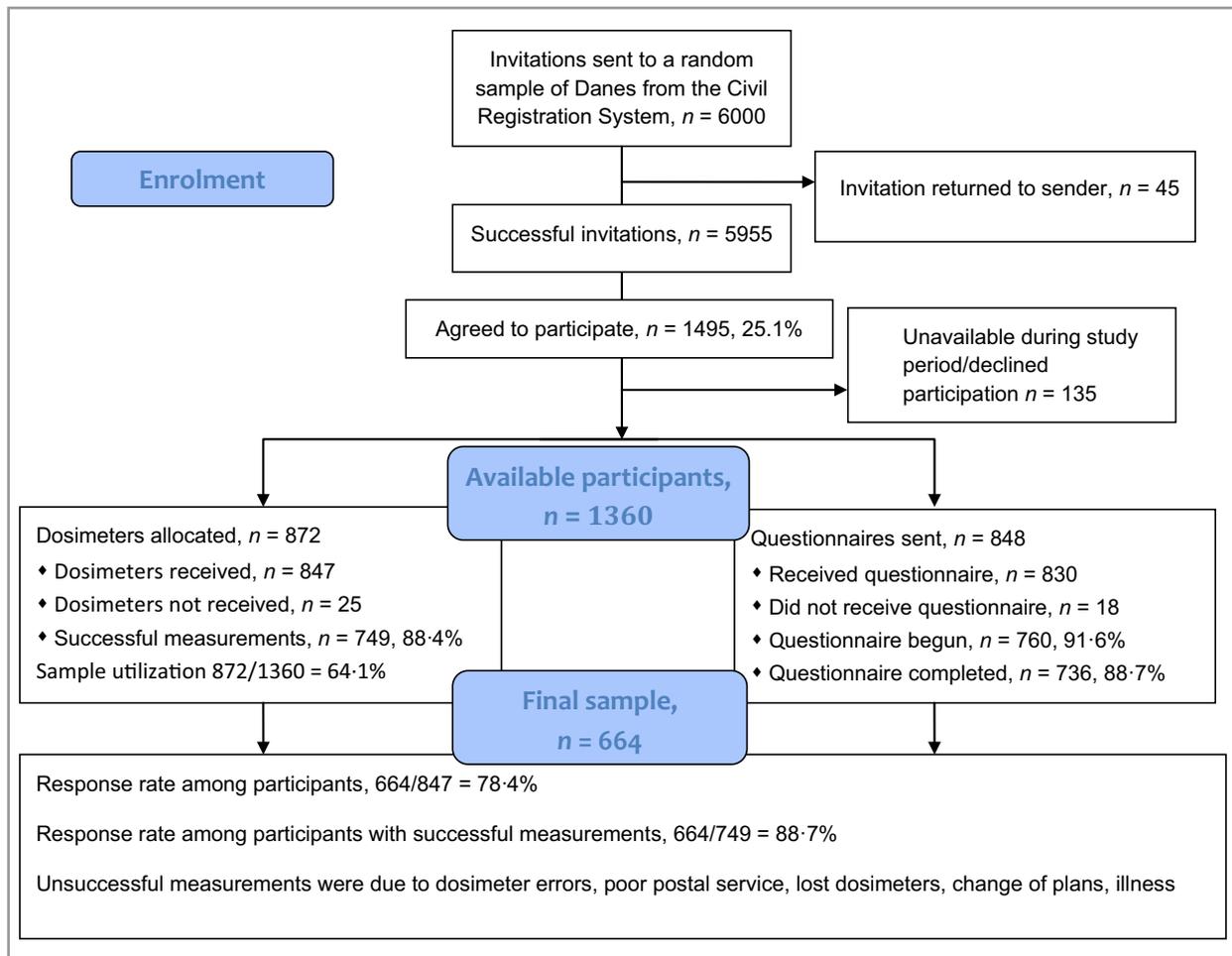


Fig 1. Study flowchart.

### Ultraviolet radiation dosimeter

The dosimeters were electronic and developed to digitally measure personal erythral UVR exposure in behavioural studies.<sup>29</sup> They are based on a visible-blind AlGaIn photodiode and their spectral response (240–320 nm) and cosine response were previously described by Allen and McKenzie.<sup>29</sup> The version used here was redesigned and manufactured by Scienterra Ltd, New Zealand, and used by Cargill *et al.*,<sup>23</sup> Wright *et al.*<sup>30</sup> and Køster *et al.*<sup>27</sup> The dosimeters were configured to take time-stamped measurements at 30-s intervals from 7:00 to 19:00. Wristbands were attached to the dosimeters. Measurements at the wrist have previously been shown to constitute approximately 50% of the ambient UVR (as received by the top of the head) in a small study.<sup>31</sup> More importantly, 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 the solar zenith angle,<sup>32</sup> 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. Furthermore, because erythral UVR exposures are

always zero when indoors and usually non-zero outdoors during daytime hours, dosimeter values greater than zero are a good representation of time spent outdoors. The calibration instrument was a Robertson Berger type instrument with a spectral response according to the CIE action spectrum.<sup>33</sup>

### Sample size, bias and confounding

The sample size was given by the restricted availability of qualified dosimeters in combination with the summer study period as well as a measurement period of 1 week. A calculation showed that a 2/3 success rate of 1105 potential participants would provide sufficient power even for subgroup analysis assuming a 0.38 correlation coefficient.<sup>27</sup> The number of invitations was based on recruitment from our pilot study.<sup>27</sup> As one aim of the project was to develop a validated questionnaire which can be used in the future without further dosimetry measurements, the participants were blinded towards this purpose to avoid the use of homemade diaries or similar behaviour book-keeping. Thus, the participants were informed only of the overall aim: 'to improve knowledge and evaluation of the Danes' sun-related behaviour'. Possible

confounding was accounted for by including personal factors (sex, age, region, skin type, education, family history, sun-protection behaviour) and external factors (ambient UVR, sun hours, week of participation) in the analysis of questionnaires reported and registered dosimeter data.

### Statistics and quantitative variables

The dosimeters were calibrated against data from the Danish Meteorological Institute (DMI) (Robertson Berger type instrument), and second-degree polynomials were fitted for each dosimeter to convert logged data into the standard erythemal effective units for irradiance ( $1 \text{ UVI} = 25 \text{ mWm}^{-2}$  of erythemally-weighted UVR) and integrated dose [1 standard erythema dose (SED) =  $100 \text{ Jm}^{-2}$  of erythemally-weighted UVR]. The DMI also provided ambient UVR data.

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 h, ½ h, 1½ h, 2½ h and 3½ h, respectively, for each of the 4-h intervals 7:00–11:00, 11:00–15:00 and 15:00–19:00, and summed for a total daytime estimate. To examine the correlation between questionnaire reported time and registered time outdoors, we converted any 30-s UVR measurements to 30 s of outdoor time. We then summed measured time and dose for each participant and measurement week. Finally, the number of days the dosimeter was worn was accounted for and average exposure per day was calculated. For the questionnaire estimation of exposure, the total daytime questions were used as a 5-point Likert scale combined with questions regarding frequency of sunbathing and spending time in the sun sitting or lying to form an exposure score. Similarly, the estimation of sun-protection behaviour was summarized in a protection scale including questions about sunscreen [sun protection factor (SPF) 15+], hat, clothing and sun avoidance. Sun protection and outdoor exposure scales are shown in Table 1. These scales were developed using Rasch analysis.<sup>34</sup> The entire questionnaire can be found in Data S1 (see Supporting Information). The self-evaluated weather was determined with a single question on average cloud cover (1–5). Skin type was assigned according to Fitzpatrick<sup>35</sup> by self-

evaluated skin tan/burn reaction to the first sun exposure of the season. Descriptive statistics for continuous variables are presented as medians (interquartile range, Q1–Q3) or means as appropriate. Confidence intervals for the Spearman correlation coefficients were calculated using Fisher's transformation. Assumptions of linearity and homogeneity of variance were satisfied. The normal distribution of data was tested by q-q 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 dosimeter, where dosimeter minutes were the independent variable and to assess associations between the exposure scale and the actual exposure measured by dosimeter. Residuals were normally distributed. The project was sent to The National Committee on Health Research Ethics who decided that their approval was not necessary. The Danish Data Protection Agency gave approval number 2012-41-0100.

## Results

### Participants

Figure 1 shows the study flowchart. Six thousand persons were invited and of those, 25% signed up for participation. We collected data from 749 successful dosimeter measurements and we received 736 completed questionnaires and for 664 persons we had complete data for both dosimetry and questionnaire with a response rate of 89%.

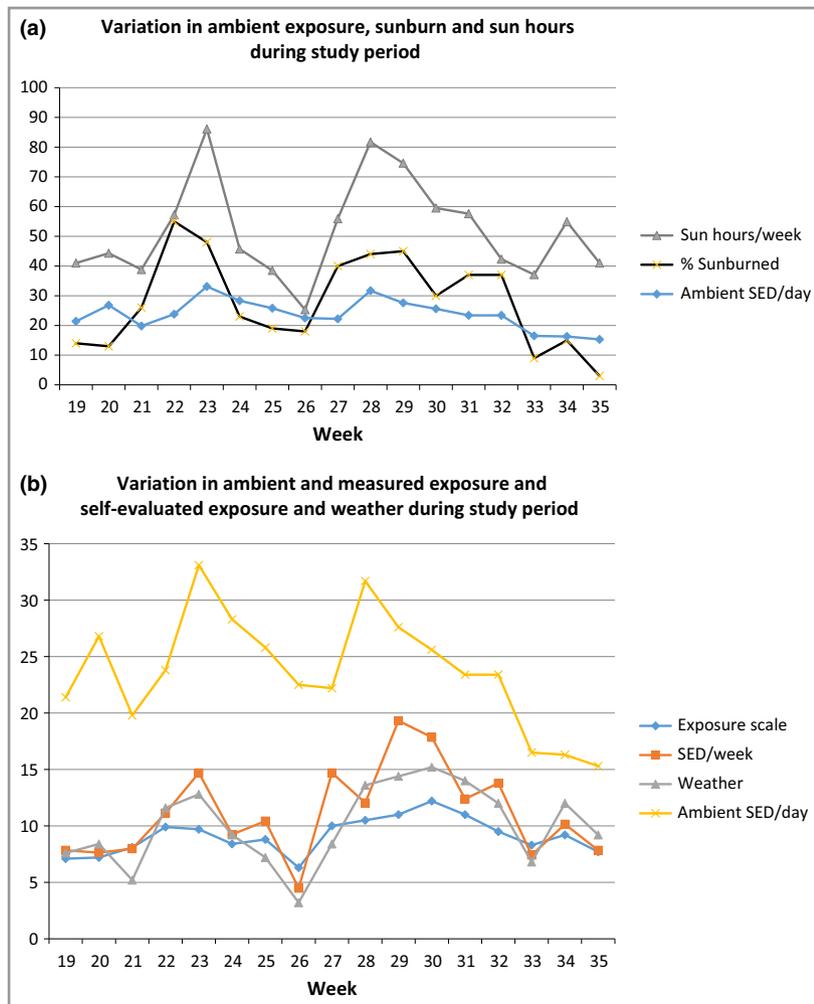
### Descriptive data

Figure 2a shows the number of sun hours, the percentage of participants sunburned and ambient radiation during the study period [data from the DMI (dmi.dk) and personal communication]. The highest UVI measurement on a single day during this summer was 7.3. It is seen that the weekly sunburn percentage and number of sun hours are strongly correlated ( $r = 0.73$ ,  $P < 0.001$ ). Figure 2b shows ambient radiation and measured exposure in SEDs together with self-evaluated exposure scale

**Table 1** Sun protection and outdoor exposure scales

Sun protection scale				Outdoor exposure scale			
Item	Mean	Rest score	Item–item	Item	Mean	Rest score	Item–item
	0–3	correlation	correlation,		0–4	correlation	correlation,
			range				range
Sunscreen SPF 15+	0.93	0.271	0.12–0.34	Outdoor exposure, 7:00–11:00	1.619	0.395	0.15–0.51
Long sleeves	0.97	0.495	0.17–0.83	Outdoor exposure, 11:00–15:00	2.473	0.473	0.26–0.57
Long trousers/skirt	1.01	0.446	0.12–0.83	Outdoor exposure, 15:00–19:00	2.483	0.513	0.24–0.57
Cap	0.43	0.198	0.08–0.73	Sunbathing	0.703	0.366	0.15–0.47
Wide-brimmed hat	0.12	0.371	0.14–0.73	Sitting or laying in the sun	1.910	0.364	0.20–0.47
Shade	1.18	0.331	0.08–0.54				
Stayed inside 12:00–15:00	0.74	0.341	0.10–0.54				

SPF, sun protection factor.



**Fig 2.** (a) Variation in ambient exposure, sunburn and sun hours during study period. (b) Variation in ambient and measured exposure and self-evaluated exposure and weather during study period. The ambient exposure is shown per day and the self-evaluated weather score (0–4) was multiplied by 4 to be fitted into the diagram. Measured exposure are median values per person. (a, b) The y-axis units are according to descriptive legends. SED, standard erythema dose.

and weather during the study period. The ambient radiation and measured exposure are significantly correlated, and the self-evaluated weather score and exposure scales are both strongly correlated with the measured exposure and each other (data not shown). Table 1 shows the composition of the sun protection and outdoor exposure scales used in this study and the single items' correlation with the scale and with each other. Use of a wide-brimmed hat scored the lowest and shade the highest on the protection scale. Clothing had the strongest correlation with total scale score. The participants' outdoor exposure time was shortest between 7:00 and 11:00 compared with the other 4-h intervals. Table 2 shows the distribution of demographic characteristics of the final sample, including sunburn and four questionnaire and dosimetry measures. The final sample included more women than men, and more persons in the age group 55–65 years than in the younger age groups. Twenty-nine per cent of the participants experienced sunburn. Sunburn decreased with age, was lower with darker skin type and increased with sunny weather. Men spent more time outdoors and were more exposed to UVR than women, which is in agreement with their own questionnaire reporting. The 15- to 24-year-olds spent the least time in the sun, while the 45- to 54-year-olds spent the most. For skin type, all four measures

increased with darker skin type. Persons with vocational education registered and reported the largest exposure and outdoor time. The same was seen for persons on vacation in the mid-season, while those vacationing during pre-season spent the least time outdoors; both pre- and post-season registered the same amount of SED exposure. Persons with their own or family-related melanoma reported and registered similarly to persons without. All four exposure measures increased by the subjective weather score in accordance with the results shown in Figure 2b.

Table 3 shows the correlation between dosimetry-registered time and questionnaire-reported time, measured SED exposure and the exposure scale, and dosimetry-registered time and the exposure scale. Time outdoors registered on the dosimeter and that reported in the questionnaire were significantly correlated for all subgroups, except for measurements in weeks of high cloud cover. Measured SED exposure was significantly correlated with the exposure scale from the questionnaire for all subgroups. Time outdoors registered on the dosimeter was also highly correlated with the exposure scale for all subgroups. There were no differences in strength of correlation between subgroups except for the Zealand region, which was slightly stronger correlated.

**Table 2** Distribution of demographic characteristics, sunburn, measures of outdoor time and ultraviolet radiation exposure in a cross-sectional sample of 664 Danes

Characteristic	Total	%	% Sunburned	Outdoor time registered on dosimeter, median (IQR)	SED/day registered on dosimeter, median (IQR)	Exposure scale score from questionnaire, mean (SD)	Outdoor time reported in questionnaire, mean (SD)
Total	664	100	29	64.5 (34.7–113.3)	1.2 (0.6–2.0)	9.2 (3.5)	308.2 (133.4)
Sex							
Male	251	38	34	77.3 (36.7–127.0)	1.4 (0.7–2.5)	9.5 (3.5)	326.8 (133.2)
Female	413	62	26	58.9 (33.4–101.3)	1.1 (0.6–1.8)	9.0 (3.5)	296.9 (132.4)
Age group (years)							
15–24	100	15	41	40.4 (22.4–74.8)	0.8 (0.4–1.6)	8.7 (3.1)	269.4 (124.7)
25–34	104	16	35	52.1 (33.0–87.5)	1.0 (0.5–1.6)	8.8 (3.1)	289.6 (125.4)
35–44	118	18	32	75.1 (37.6–117.5)	1.3 (0.6–1.9)	9.5 (3.4)	306.1 (118.4)
45–54	132	20	26	75.6 (38.8–154.9)	1.5 (0.7–2.6)	9.8 (3.9)	328.2 (151.4)
55–65	210	31	20	71.1 (40.7–121.5)	1.4 (0.8–2.3)	9.0 (3.3)	324.4 (133.1)
Skin type							
I	54	8	48	60.3 (30.5–88.9)	0.9 (0.7–1.8)	8.3 (3.8)	288.3 (152.9)
II	383	58	33	64.4 (33.7–110.0)	1.1 (0.6–1.9)	9.1 (3.3)	305.5 (126.2)
III/IV	227	35	17	65.3 (37.9–128.3)	1.3 (0.7–2.5)	9.6 (3.6)	317.4 (140.1)
Region							
Capital	187	28	28	64.8 (33.4–116.0)	1.1 (0.6–1.8)	9.3 (3.3)	308.7 (129.1)
Zealand	103	16	27	71.7 (35.8–122.2)	1.2 (0.6–2.2)	9.5 (3.6)	315.7 (138.0)
Northern Jutland	68	10	38	52.1 (32.5–89.7)	1.1 (0.6–1.9)	8.7 (3.5)	275.7 (135.6)
Central Jutland	167	25	32	65.9 (36.0–104.1)	1.3 (0.7–2.1)	9.3 (3.5)	313.5 (132.3)
Southern Denmark	139	21	23	64.3 (36.3–130.4)	1.2 (0.7–2.1)	9.0 (3.6)	311.4 (135.6)
Education (n = 658) <sup>a</sup>							
Primary school	117	18	22	56.5 (27.7–101.4)	1.1 (0.5–1.9)	9.0 (3.3)	319.0 (135.7)
Secondary school	90	14	41	52.5 (31.9–88.9)	1.0 (0.5–1.9)	8.4 (3.0)	265.3 (120.8)
Vocational	91	14	36	88.9 (36.4–157.7)	1.6 (0.8–2.7)	10.4 (3.5)	354.1 (141.3)
Higher education (<2 years)	67	10	30	65.4 (45.7–109.1)	1.1 (0.7–2.1)	8.9 (2.7)	291.9 (100.9)
Higher education (2–4½ years)	213	32	23	65.9 (35.6–109.8)	1.2 (0.6–1.9)	9.1 (3.7)	299.2 (134.5)
Higher education (> 4½ years)	80	12	33	61.4 (35.0–114.8)	1.1 (0.6–1.9)	9.6 (3.7)	328.1 (138.3)
Season							
Pre (weeks 19–24)	238	36	29	48.9 (29.1–82.8)	1.1 (0.6–1.7)	8.4 (3.2)	284.7 (129.6)
Mid (weeks 25–30)	246	37	33	83.1 (39.3–146.1)	1.5 (0.8–2.5)	9.9 (3.7)	332.6 (139.0)
Post (weeks 31–35)	180	27	22	68.0 (37.8–116.3)	1.1 (0.5–1.9)	9.3 (3.3)	305.8 (125.4)
Own or family-related melanoma							
Yes	147	22	24	60.3 (30.5–88.9)	1.4 (0.7–2.5)	9.0 (3.4)	303.3 (130.4)
No	517	78	30	60.3 (30.5–88.9)	1.4 (0.7–2.5)	9.2 (3.5)	309.6 (134.3)
Weather (n = 663) <sup>a</sup>							
1 (Most of the time sunny)	191	29	38	101.3 (58.6–157.4)	1.7 (1.1–2.7)	11.3 (3.5)	373.7 (137.2)
2	176	27	34	76.8 (44.3–117.7)	1.3 (0.8–2.1)	9.3 (3.2)	309.9 (129.5)
3	152	23	23	51.5 (31.5–86.5)	1.0 (0.6–1.8)	8.6 (2.7)	287.6 (111.6)
4	83	12	20	42.5 (25.1–70.9)	0.9 (0.4–1.5)	7.7 (2.6)	269.3 (108.7)
5 (Most of the time cloudy)	61	9	11	29.5 (16.7–38.6)	0.6 (0.2–1.0)	5.6 (2.4)	201.1 (110.0)

IQR, interquartile range; SED, standard erythema dose. <sup>a</sup>Missing data.

## Regression analysis

In Table 4, we have examined the relationship between objective and subjective measures and factors influencing this relationship by linear regression. The 'timescale' and 'outdoor exposure scale' calculations determine the validity of the tool

we have developed, while the 'exposure measured by dosimeter' calculations explain factors of radiation received by the dosimeter. Table 4 (timescale) shows factors explaining the questionnaire-assessed outdoor time. The model includes outdoor time registered by the dosimeter, the subjective perception of the weather and education and explains 35% of the

Table 3 Correlation between registered and reported measures of ultraviolet radiation exposure (n = 664)

Characteristic	Total	Correlation between outdoor time registered on dosimeter and outdoor time reported in questionnaire	Correlation between SED/measurement day and exposure scale from questionnaire	Correlation between outdoor time registered on dosimeter and exposure scale from questionnaire
Total	664	0.53 (0.47–0.58)***	0.54 (0.48–0.59)***	0.53 (0.48–0.59)***
Sex				
Male	251	0.60 (0.52–0.67)***	0.56 (0.47–0.64)***	0.57 (0.48–0.65)***
Female	413	0.49 (0.41–0.56)***	0.52 (0.45–0.59)***	0.51 (0.43–0.58)***
Age group (years)				
15–24	100	0.49 (0.33–0.63)***	0.53 (0.38–0.66)***	0.50 (0.34–0.64)***
25–34	104	0.40 (0.23–0.55)***	0.48 (0.31–0.61)***	0.50 (0.34–0.63)***
35–44	118	0.52 (0.38–0.64)***	0.50 (0.35–0.63)***	0.49 (0.34–0.62)***
45–54	132	0.61 (0.49–0.71)***	0.64 (0.52–0.73)***	0.67 (0.56–0.75)***
55–65	210	0.48 (0.37–0.60)***	0.50 (0.39–0.60)***	0.48 (0.36–0.57)***
Skin type				
I	54	0.47 (0.23–0.66)***	0.54 (0.32–0.71)***	0.47 (0.23–0.65)***
II	383	0.55 (0.47–0.61)***	0.52 (0.44–0.59)***	0.55 (0.47–0.61)***
III/IV	227	0.51 (0.41–0.60)***	0.55 (0.46–0.64)***	0.52 (0.41–0.61)***
Region				
Capital	187	0.49 (0.38–0.60)***	0.55 (0.44–0.64)***	0.55 (0.44–0.64)***
Zealand	103	0.72 (0.61–0.80)***	0.72 (0.62–0.81)***	0.70 (0.58–0.78)***
Northern Jutland	68	0.49 (0.28–0.65)***	0.53 (0.33–0.68)***	0.59 (0.41–0.73)***
Central Jutland	167	0.50 (0.37–0.60)***	0.47 (0.34–0.58)***	0.48 (0.35–0.59)***
Southern Denmark	139	0.47 (0.33–0.59)***	0.49 (0.35–0.61)***	0.43 (0.29–0.56)***
Education				
Primary school	117	0.54 (0.40–0.66)***	0.61 (0.49–0.71)***	0.52 (0.37–0.64)***
Secondary school	90	0.48 (0.30–0.62)***	0.41 (0.22–0.57)***	0.39 (0.20–0.55)***
Vocational	91	0.52 (0.36–0.66)***	0.63 (0.48–0.78)***	0.56 (0.40–0.69)***
Higher education (< 2 years)	67	0.32 (0.08–0.52)**	0.37 (0.14–0.56)**	0.37 (0.14–0.56)**
Higher education (2–4½ years)	213	0.52 (0.41–0.61)***	0.51 (0.41–0.61)***	0.54 (0.44–0.63)***
Higher education (> 4½ years)	80	0.65 (0.51–0.76)***	0.60 (0.43–0.72)***	0.63 (0.48–0.75)***
Season				
Pre (weeks 19–24)	238	0.47 (0.36–0.56)***	0.50 (0.39–0.59)***	0.42 (0.30–0.52)***
Mid (weeks 25–30)	246	0.59 (0.50–0.66)***	0.59 (0.50–0.67)***	0.58 (0.49–0.65)***
Post (weeks 31–35)	180	0.45 (0.33–0.56)***	0.47 (0.35–0.57)***	0.49 (0.37–0.59)***
Own or family-related melanoma				
Yes	147	0.46 (0.32–0.58)***	0.43 (0.29–0.56)***	0.41 (0.27–0.54)***
No	517	0.55 (0.49–0.61)***	0.57 (0.50–0.62)***	0.56 (0.50–0.62)***
Weather				
1 (Most of the time sunny)	191	0.55 (0.44–0.64)***	0.53 (0.42–0.63)***	0.51 (0.40–0.61)***
2	176	0.41 (0.28–0.53)***	0.44 (0.31–0.55)***	0.35 (0.22–0.48)***
3	152	0.41 (0.27–0.53)***	0.38 (0.24–0.51)***	0.43 (0.29–0.55)***
4	83	0.46 (0.27–0.62)***	0.42 (0.23–0.59)***	0.37 (0.16–0.54)***
5 (Most of the time cloudy)	61	0.22 (–0.04 to 0.44)	0.37 (0.14–0.57)**	0.27 (0.02–0.49)*

Spearman correlation coefficients are reported with 95% confidence intervals. Significance levels: \*P < 0.05, \*\*P < 0.01, \*\*\*P < 0.001.

variation. The outdoor time registered on the dosimeter explains the largest part. Persons with primary, secondary school or higher education (> 4½ years) have higher self-reported outdoor times relative to their dosimeter measurement. The subjective perception of the weather influenced the model by higher questionnaire estimates relative to outdoor time registered on the dosimeter with increasing cloud cover, and especially the two extremes 'Sunny weather most of the time' and 'Cloud cover most of the time' differed from the

mean weather. Table 4 (outdoor exposure scale) also shows a linear regression model of the exposure scale, which includes the UVR exposure and the outdoor time registered by the dosimeter, the subjective perception of the weather, the protection scale and education level. The model explains more than 42% of the variation. The radiation registered on the dosimeter explains the largest part and the influence from the covariates weather and education is similar to the model in Table 4 (timescale). The influence of protection is unclear;

**Table 4** Linear regression models for timescale, outdoor exposure scale and exposure measured by dosimeter (SED); total N = 664

Characteristic	Type 1 SS		Type 3 SS	
	F-value	P-value	F-value	P-value
<b>Timescale</b>				
Model: $R^2 = 0.35$ , $< 0.001$				
Minutes per measurement day	290.9	$< 0.001$	163.0	$< 0.001$
Education	3.5	0.002	3.8	$< 0.001$
Weather	6.8	$< 0.001$	6.8	$< 0.001$
<b>Outdoor exposure scale</b>				
Model: $R^2 = 0.42$ , $< 0.001$				
Minutes per measurement day	8.6	0.004	8.8	0.003
Education	2.3	0.01	2.0	0.06
Protection scale	7.2	0.007	7.2	0.007
Weather	20.4	$< 0.001$	17.4	$< 0.001$
SED per day	333.5	$< 0.001$	28.8	$< 0.001$
<b>Exposure measured by dosimeter (SED)</b>				
Model: $R^2 = 0.41$ , $< 0.001$				
Exposure scale	322.0	$< 0.001$	150.3	$< 0.001$
Age	5.2	$< 0.001$	5.2	$< 0.001$
Skin type	4.0	0.02	3.9	0.02
Week of participation	5.1	$< 0.001$	5.1	$< 0.001$

SS, sums of squares.

however, persons in the highest quartile with a protection score above 9 reported less exposure. Table 4 (exposure measured by dosimeter) shows a model of the SEDs received. The exposure scale explains the largest part of the variation together with minor determinants: age, skin type and week of participation. Together they explain 41% of the variation. Exposure increases with increasing skin type, while persons younger than 35 years received fewer SEDs than the older age groups. Table 5 shows logistic regression models of sunburned vs. not sunburned. The models include sex, age, skin type, outdoor time, the protection scale and number of sun hours as a proxy for the ambient radiation. The adjusted models also included either a subjective or an objective exposure variable. Education was also examined, but not included in any of the final models. Each model yields similar results. Males were slightly less sunburned and clear trends were seen with higher sunburn associated with younger age and paler skin type. Each extra sun hour per week recorded by the DMI increases the risk of sunburn by 2%. For the model with the objective variable, each extra hour registered on the dosimeter per day was related to 50% higher odds of being sunburned. For the model with the subjective variable, each extra point in the exposure scale corresponds to approximately 15% higher risk of sunburn.

## Discussion

We were able to establish the criteria validity of a developed questionnaire for monitoring and evaluating population sun-

related behaviour and have shown the importance of a number of issues with regard to evaluation of exposure to UVR in a population-based sample. Firstly, sunburn and environmental factors, e.g. sun hours, correlates strongly and weather determinants need to be included in an evaluation because personal exposure depends strongly on the ambient UVR. Secondly, questions on UVR exposure in a week-based survey design showed strong correlation towards objective measurements of the UVR exposure in general and in all relevant subgroups. Exposure and protection scales provide knowledge tested for construct validity. Predictors of sunburn in our model were sex, age, skin type, number of ambient sun hours, outdoor time and use of sun protection.

The strengths of this study include a sample based on the Danish civil registration system, with relatively high participation and very high response rates and objective personal dosimetry measurements. In addition, we used both objective measurements for outdoor time and for radiation in our setup. Contrary to traditional studies<sup>36,37</sup> of exposure to UVR based on questionnaires, this study reduced bias from recalling past sun exposure maximally by short measurement periods and short response periods. Limitations of the study are the wrist-worn dosimeters, which were shown to register about 50% of the ambient exposure (as received on top of the head);<sup>31</sup> however, the bias introduced is assumed to be equally distributed and was described elsewhere.<sup>27</sup> Lack of compliance with use of the dosimeters could introduce bias; however, compliance was also described<sup>27</sup> and we did not register any directional bias. Persons wearing a dosimeter may be more aware of their behaviour and this could change their behaviour; however, we tested this in a smaller intervention study and did not find an effect on wearing a dosimeter.<sup>1</sup>

This paper reports on the first project including a complete UVR exposure questionnaire validation. The week-based survey design that we used showed a strong correlation between questionnaire items and objective measurements and presumably a stronger correlation than data collections of longer periods not validated (e.g. summers, years).<sup>8,37,38</sup> Correlations in this study are almost as strong as previously seen with the use of diaries<sup>5,23,27</sup>; however, questionnaires are much easier to handle in population-based data collections. Our questionnaire gives valid estimates of the outdoor time as well as the amount of UVR exposure of the participants. Outdoor time and UVR registered alone does not take into account the sun protection and sun avoidance used. Sunburn is a proxy estimate of the skin damage and skin cancer risk of the participants, as this is a combined result of exposure and protection behaviour. Our model shows that women are a little less likely to be sunburned, contrary to many previous results.<sup>8,39,40</sup> This could indicate that men underestimate or forget sunburn in long-duration data collections. The model also shows that there is a higher risk with younger age, paler skin type, increased duration of exposure and number of ambient sun hours. In the model that used the subjective measure to adjust for the exposure, the most pronounced difference was the

**Table 5** Logistic regression model for sunburn; unadjusted odds ratios (ORs) and adjusted ORs (aORs) for objective or validated subjective exposure variables, respectively. Subjective weather, region, cancer in family, education and protection was eliminated from both adjusted models (total N = 664)

Characteristic	Unadjusted		Objective exposure variables		Subjective (validated) exposure variables	
	OR (95% CI)	P-value	aOR (95% CI)	P-value	aOR (95% CI)	P-value
Sex		0.02		0.008		0.004
Female	0.7 (0.5–0.9)		0.6 (0.4–0.9)		0.6 (0.4–0.8)	
Male	Ref		Ref		Ref	
Age group (years)		0.001		< 0.001		< 0.001
15–24	2.8 (1.6–4.7)		4.1 (2.3–7.4)		3.7 (2.1–6.7)	
25–34	2.1 (1.3–3.6)		2.5 (1.4–4.4)		2.3 (1.3–4.0)	
35–44	1.9 (1.1–3.2)		1.7 (1.0–2.9)		1.6 (0.9–2.8)	
45–54	1.4 (0.8–2.3)		1.2 (0.7–2.1)		1.2 (0.7–2.1)	
55–65	Ref		Ref		Ref	
Skin type		< 0.001		< 0.001		< 0.001
I	4.5 (2.4–8.5)		4.0 (2.0–8.1)		4.6 (2.2–9.4)	
II	2.4 (1.6–3.5)		2.6 (1.6–4.0)		2.8 (1.7–4.3)	
III/IV	Ref		Ref		Ref	
Education		0.02		0.09		0.10
Primary school	0.6 (0.3–1.1)					
Secondary school	1.5 (0.8–2.7)					
Vocational	1.2 (0.6–2.2)					
Higher education (< 2 years)	0.9 (0.4–1.8)					
Higher education (2–4½ years)	0.6 (0.4–1.1)					
Higher education (> 4½ years)	Ref					
Protection scale quartiles		0.003		0.03		0.03
Q1	0.4 (0.2–0.7)		0.4 (0.2–0.8)		0.4 (0.2–0.7)	
Q2	1.0 (0.6–1.5)		0.9 (0.5–1.5)		0.8 (0.5–1.3)	
Q3	0.7 (0.5–1.2)		0.7 (0.4–1.3)		0.7 (0.4–1.2)	
Q4	Ref					
Sun hours/week	1.03 (1.02–1.04)	0.001	1.03 (1.01–1.04)	< 0.001	1.02 (1.01–1.03)	< 0.001
Exposure scale	1.2 (1.1–1.2)	< 0.001	NA		1.2 (1.1–1.2)	< 0.001
Hours per measurement day	1.4 (1.2–1.6)	0.001	1.4 (1.2–1.7)	< 0.001	NA	

CI, confidence interval; NA, not applicable.

increase in the odds ratios of the 15- to 19-year-olds. The difference could be caused by an overestimation of own exposure or a lower compliance with the use of the dosimeter. In the crude analysis of sunburn, less sun protection equals less sunburn and the same is shown when the exposure (personal and ambient) is accounted for. This result most likely is an indication that people adapt to the behaviour they have planned to engage in and is not to be interpreted as sun protection does not work; however, it is an indication that people are aware that they need protection and that the amount of exposure is the strongest determinant together with skin type. The number of sun hours is a superior risk measure to ambient SED in our analyses (data not shown), most probably due to the sun-seeking behaviour of the Danes, and the large weather variation and long winters in Denmark. Other measures may be more applicable in other climates.<sup>41</sup> The questionnaire developed and validated can be applied in short- or long-term studies that need to assess the UVR exposure in a study group or population, e.g. studies of skin cancer, sun protection, vitamin D<sup>23</sup> or even outdoor behaviour. In

addition, more precise estimates provided by the validated questionnaire will be of further value in determining the effectiveness and cost-benefit of skin cancer prevention campaigns.<sup>42</sup>

Criteria-validated questionnaires are per se superior to questionnaires not validated as the validation provides evidence for the objective behaviour. The criteria-validated questionnaire presented is a tool to measure the UVR exposure in a population. The evidence provided showed a statistically significant and strong link between the objectively measured behaviour and the behaviour measured by this survey construct. The week-based design minimizes bias from recalling past sun exposure and, for future studies and evaluation, it will give more accurate estimates and better knowledge.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

**Data S1.** Questionnaire given in Danish, translated into English. Gross scales and applied values indicated. Only successfully validated scales were applied in the final analysis.