Sun exposure behaviour among subgroups of the Danish population

Based on personal electronic UVR dosimetry and corresponding exposure diaries

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INTRODUCTION

Solar ultraviolet radiation (UVR) is known to be an important etiological factor in the development of melanoma as well as non-melanoma cancer of the skin. Malignant melanoma of the skin, CMM, is supposed to be provoked by high intermittent UVR doses, while quamous cell cancer, SCC, is more connected with the cumulative UVR dose and basal cell cancer, BCC, is believed to be provoked by both exposure patterns (Elwood and Jopson 1997; Armstrong and Kricker, 2001). Different UVR exposure patterns seem therefore to provoke different skin cancer forms and call for different sun protection strategies. In spite of this, many people want to be able to enjoy the benefits of the sun, mentally, socially and with respect to D-vitamin synthesis. A better understanding of UVR exposure patterns and corresponding UVR doses can point at the most suitable approach a person can take to lower the UVR dose, and thereby reduce the risk of skin cancer. However, no one has previously conducted studies where individual UVR exposure doses have been established through actual measurements. Apart from the ambient UVR dose available, several parameters have been debated as to their influence on the UVR dose received by a person, such as age, sex, outdoor work, sunbathing, and long lasting outdoor leisure activities (Holman et al, 1983; Herlihy et al, 1994; Diffey et al, 1996). In addition, to actually cause skin damages and add to the cumulative UVR dose of a person, the UVR dose exposed to should be transmitted into the skin. Factors as dark complexion, acquired skin pigmentation, clothing, and sunscreen use can reduce the part of the UVR dose transmitted into the skin. Yet, no one has actually measured with which power these factors influence on the UVR dose received and transmitted into the skin of an individual. My primary task was therefore to conduct a prospective study among groups of healthy Danes to assess objectively, by personal, UVR dosimetry supported by sun exposure diaries, the annual UVR dose received by an individual an to estimate the lifetime UVR dose. In addition, to establish basic knowledge about how different UVR exposure behaviour patterns influence on the UVR exposure dose received. A model to assess individual skin cancer risk including the UVR exposure pattern could help doctors and health advisers in choosing the UVR precautions needed to avoid the development of skin cancer. However, although skin cancer risk assessment was the reason for performing these studies, it is not a subject of discussion in this thesis.

AIM OF THE THESIS

The aim of this thesis was to achieve an objective, basic knowledge of the UVR exposure pattern and to reveal, which factors and with which power they influence on the UVR doses received. This would be attempted through prospective, continuous and objective studies in selected subgroups of the Danish population:

The parameters assessed were:

- The individual time related UVR dose pattern, yearly, daily, per hour and during UVR peak hours between 12:00-15:00.
- The relation of UVR dose to sun exposure behaviour during workdays, days off and holidays in and out of Denmark.
- The proportion of lifetime UVR dose received in childhood, teen years and adulthood.
- The UVR exposure received during different seasons of the year.
- The occurrence of sunburn and the connection to UVR exposure.
- The use of sunscreen and the connection to UVR exposure dose and sunburns.
- The difference in UVR exposure received in two fair-skinned European populations.

The purpose was to be able to make individual sun exposure data available for further research into skin cancer prevention, for sun protection campaigns conducted by health authorities and cancer societies, and for general sun protection advice in the clinic and through the media.

BACKGROUND

ULTRAVIOLET RADIATION

Solar UVR is part of the electromagnetic spectrum and is defined by intensity and wavelength. CIE, International Commission on Illumination has standardized the three CIE bands to be: short wave (UVC 100-280 nm), mid-wave (UVB 281-315 nm) and long-wave (UVA 316-400 nm). However, in biology the limit between UVA and UVB is normally 320 nm. Atmospheric ozone absorbs most UVC and much of the UVB, while UVA is minimally affected by the Earth's atmosphere. Solar UVR at the earth's surface comprise therefore (90-99%) UVA and (1-10%) UVB (Matsui and DeLeo, 1991). *Artificial UVR sources* include various lamps used in industry, medicine, research, and for tanning. Only sunbed used for tanning will be addressed in this thesis.

SUNLIGHT

The ambient UVR dose or the intensity of solar UVR at the earth's surface is influenced by:

1) Sun altitude. The higher the sun is in the sky, the shorter is the way through the atmosphere for sun rays and the higher the UVR intensity. During the day the sun altitude is at its maximum level around solar noon (90°) at equator and (60°) in Denmark 56°N respectively. As a consequence approximately 50% of the ambient diurnal UVR is irradiated between 12:00 and 15:00. During the year the sun altitude is highest around summer solstice. In Denmark is the daily ambient UVR dose a median of 22.5 SED in June, but 0.4 SED in December measured on the top of our hospital. Furthermore, the sun altitude is dependent on the latitude. An up to 5-fold reduction in erythema effective UVB may be seen as one moves northwards from the tropics to Northern Europe (Diffey and Larkö, 1984; Diffey 1991). In addition, at midlatitudes (28°-46°) around the world the increase in erythemally effective UVR for every degree of latitude towards equator is between 3-3,6% (Scotto et al, 1988; Godar et al, 2001; McKenzie et al 2001).

2) Atmospheric attenuation. The quality and quantity of solar UVR are modified as the sunrays pass through the atmosphere. The principal interactions in the stratosphere are absorption by ozone and scattering by molecules such as N_2 and O_2. In addition, particulate matter or air pollution can reduce the UVB radiation reaching the earth's surfaces because particles absorb, scatter and reflect the shorter wavelength much more than they affect longer wavelengths (Diffey, 2002a; Diffey, 2002b).

3) Cloud cover: UV radiation levels are highest under a clear sky but even with cloud cover, UV radiation can be high. A light cloud cover will give about 50% of the UVB energy, relative to a clear sky. Even with heavy cloud cover the scattered UVB component of sunlight often called sky radiation is rarely less than 10%. The solar infrared is better absorbed than UVR by the water particles in the clouds leading to a decrease in temperature, and the false impression that the UV radiation is low, too. It is therefore often more important at what time during the day UVR exposure takes place, than how the cloud cover is (Diffey and Larkö, 1984).

4) Altitude: at higher altitudes, a thinner atmosphere absorbs less UV radiation. With every 1000 metres increase in altitude, UV radiation levels increase by about 13% (Diffey and Larkö, 1984).

5) Surface reflection: UV radiation is reflected or scattered differently depending on the surface, e.g. fresh snow reflects 57% of direct solar radiation and as much as 171% of the sky radiation at 310 nm (Kromann et al, 1986). Likewise seawater has been reported to reflect 15%, beach sand 7%, and grass 0.6% of solar UVB radiation (Kromann et al, 1986), while calm, pure water reflects 5% only, although up to 20% is reflected from choppy water (Diffey and Larkö, 1984; Diffey, 1991). Calm, pure water is a very weak absorber of UV radiation, at least 40% UVR is transmitted through 50 cm of clear water, so swimming in either the sea or an open-air pool offers little UVR protection. In addition, swimmers would probably be exposed to a large area of the sky and so will receive both direct and scattered radiation from the sky (Diffey and Larkö, 1984; Diffey, 2002a)

INDIVIDUAL UVR EXPOSURE

The sun is the main source of human UVR exposure. The UVR dose a person receives from solar exposure is basically determined by: 1) *UVR intensity* and 2) *exposure duration*.

UVR dose = UVR intensity x exposure duration. However, 3: *exposure geometry*, 4: *sun exposure behaviour of the individual,* and 5: *UVR protection* can either reduce or increase the UVR dose actually transmitted into the eyes and the skin of an individual.

Exposure geometry deals with the fact that the amount of UVR received at different body sites depends on the orientation towards the sun and reflection from the ground surface (Kromann et al, 1986; Vishvakarman et al, 2001). It is of vital importance for the size of the UVR dose measured, at which body position a UVR dosimeter is placed. Comparisons of UVR dosimeter data are therefore dependent on whether the same dosimeter position has been used. In the literature, dosimeters have been attached at different anatomic sites including the wrist, cheek, forehead, chest, shoulder, back, leg, and top of the head (Holman et al, 1983; Rosenthal et al, 1990; Herlihy et al, 1994; Kimlin et al 1998; Parisi et al, 2000b). The effect of UVR on the eye (ocular exposure) is far more affected by geometrical factors than skin exposure (Sliney, 2005 & 1994); however, ocular UVR exposure will not be dealt with in this thesis.

Sun exposure behaviour is a crucial factor affecting the UVR doses. According to previous studies, UVR exposure received within the same time interval cannot be assumed to be a constant fraction of ambient UVR exposure for different people. Due to the manner they act in the sun, some consistently receive a higher or lower UVR dose compared to others belonging to the same apparently homogenous group (Diffey et al, 1996).

Recreational behaviour such as sunbathing and sunbed use, beach going, holidays in sunny countries, and outdoor sports influence the UVR exposure dose (Autier et al, 2000; Herlihy et al 1994). An analysis of the influence of different sun exposure behavioural parameters seen in a greater context is therefore needed.

Occupational behaviour: Outdoor work is known to give raise to higher UVR doses than indoor work (Kimlin et al, 1998). However, none have compared the recreational UVR exposure of outdoor and indoor workers, except for an Australian group comparing weekend and weekdays exposure over a few days in spring, finding that outdoor workers received the highest UVR dose during weekdays while indoor workers received the highest dose during weekends (Parisi et al, 2000a).

UVR skin protection such as the use of clothing and hats can reduce the absorbed UVR doses considerably but only sunscreen as UVR protection will be addressed in this thesis (Bech-Thomsen and Wulf, 1991;1992; Laperre, 2003).

ERYTHEMA ACTION SPECTRUM

Different action spectra are used to weigh the different actions of UVR. In this thesis the focus will be on the erythemal (or sunburning) effect of UVR, which is mainly caused by UVB. The International Commission on Illumination, CIE, erythema action spectrum by McKinlay and Diffey, 1987 has therefore been used to weigh the erythemal action of UVR in our studies, as shown in Figure 1. The erythema potential of UVB is about 500 times the potential of UVA. The UVR erythema dose is therefore highest when the UVB content is highest as described in the paragraph about sunlight (Wulf, 1994).

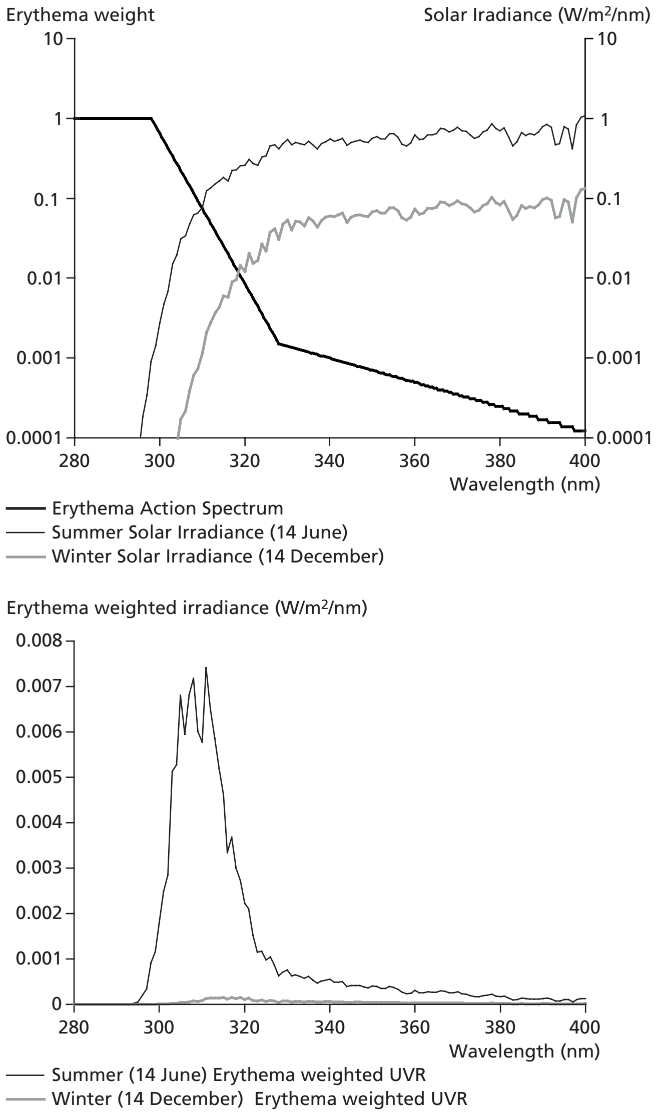

Figure 1. A. The solar irradiance for one day in summer and winter in Denmark 56°N and the erythema action spectrum. B. The erythema weighted irradiance for the same two days. Erythema action spectrum: (McKinlay and Diffey, 1987). Solar irradiance spectra:(Paul Eriksen, DMI, Danish Meteorological Institute, personal communication).

MEASUREMENT OF INDIVIDUAL UVR EXPOSURE

Just recently an invited review has been published about ultraviolet radiation exposure in youth to assist standardization of measurement procedures and facilitate comparisons among the different UVR dosimeter studies (Wright and Reeder, 2005). Different methods have been used to establish knowledge about individual UVR exposure. The knowledge is primarily obtained by retrospective interviews or self reported surveys (Østerlind et al, 1988; Westerdal et al, 1992; Danish National Bord of Health, 2000; Godard et al, 2001). The questionnaires rely on the memory of the individual and can easily be biased (Weinstock et al 1991; Brandberg et al, 1997). Others have included data on ambient UVR measurements (Vitasa et al, 1990; Rosenthal et al, 1991). However, it has been argued that the inter-individual UVR exposure varies too much to use ambient measurements to determine the individual UVR exposure (Diffey et al, 1996). Several studies have been performed with personal UVR dosimeters. The dosimeters used are integrating devices accumulating the UVR doses received. The polysulphone film dosimeter developed by Davis et al in 1976 has been used in most studies (Holman et al, 1983; Diffey, 1984; Larkö and Diffey, 1983; Rosenthal et al, 1990; Herlihy et al, 1994; Knuschke and Barth, 1996). Other types are biological dosimeters using uracil molecules, DNA, bacteriophages and bacteria or thermoluminescence in CaF_2 crystals (Quintern et al, 1992; Moehrle and Garbe, 2000a; 2000b; Kuluncsics et al, 2002; Mills et al, 2005; Wulf and Gniadecka, 1996b). After a certain UVR dose they get saturated and can therefore only be used for a short period of time. Besides, they do not permit an assessment of the magnitude or the changes in exposure rate during the measurement period and provide only a cumulative erythemally weighted UVR dose. These dosimeters are valuable in personal UVR dosimetry studies as long as they are used to measure UVR doses in controlled situations as a tennis match where a cumulative dose is sufficiently illustrative (Holman et al, 1983; Herlihy 1994). They are also useful to investigate exposure geometry where several dosimeters are used to compare UVR doses on different body sites (Diffey et al, 1977; Herlihy et al, 1994). However, to relate UVR doses to the time the use of electronic UVR dosimeters is necessary (Wulf, 1996). Electronic dosimeters capable of making time-stamped UVR measurements have been developed, but they have been too unhandy to be worn continuously during a long-lasting study (Diffey and Saunders 1995; El Naggar et al, 1995; Wulf and Gniadecka, 1996a). Only one investigation has been conducted with personal electronic time-stamped dosimeters. However, they were not wearable but were used as small ground stations placed nearby the subjects during sunbathing at the beach (Autier et al, 2000). To be able to continuously follow and quantify the personal UVR exposure it is necessary to use an electronic, wearable UVR dosimeter capable of storing the measurements with a time stamp.

UVR MEASUREMENT UNIT

Comparing the findings in personal UVR dosimeter studies is difficult. Studies report UVR exposure in different units such as J/m^2, kJ/m^2 and MED, minimal erythema dose. However, MED is used both as a physical unit (1 MED = 200 J/m^2) and the biological unit MED equivalent to the UVR dose needed to provoke a just perceptible erythema on unexposed buttock skin 24 hours after UVR exposure. To use the biological unit MED as a physical unit in inter-individual comparisons is unreasonable because the MED is not a standard measure of anything but express the variable nature of individual sensitivity to ultraviolet radiation. Variables, which affect the MED, include skin pigmentation, previous light exposure, and anatomical site (Diffey, 2002a; 2002b). In the last 10 years the physical unit SED (standard erythema dose) has been widely used in UVR dosimetry (Wulf and Lock-Andersen, 1996; Diffey et al, 1997a;1997b). Where 1 SED is equivalent to an erythemal effective radiant exposure of 100 J/m^2 using the CIE action spectrum, normalized to 298nm (McKinlay and Diffey, 1987). It is equivalent to the UVR dose needed to provoke a just perceptible erythema on white skin in the most sensitive of a group of sensitive people 24 hours after exposure. This means that the number of SED needed to reach 1 MED depends on the skin pigmentation of the individual and has a range of (1-25 SED). As the damages caused by UVR in an individual depends on the individual's MED, only a physical unit as SED can be used in inter-individual comparison of UVR doses received. MED should be reserved to express the sensitivity to UVR exposure of an individual, as done in a skin phototest (Wulf and Lock-Andersen, 1996; 1997b; Diffey, 2002a).

REQUIREMENTS AND SELECTION CRITERIA

Before the studies of this thesis could be conducted several requirements and selection criteria should be met and limitations and assumptions should be defined in order to achieve our goal of the most precise quantification of UVR exposure.

REQUIREMENTS FOR STUDY EQUIPMENT NEEDED

- A personal, electronic UV dosimeter, small and easy to wear, which measures time-stamped UVR doses in SED. Data must be transferable to a computer along with the time, and it must function during a long-lasting study without maintenance.
- The most suitable UVR dosimeter position must be found.
- A sun exposure diary. It should be handy and easily completed, and it should be possible to scan the data from the completed diary forms into a computer.

SELECTION CRITERIA FOR THE POPULATION SAMPLE

The aim of these studies was not to collect a population sample representative of the Danish population, but to select an age-span group of children, adolescents, and indoor workers as the adult part. In addition, to include subgroups with expected high UVR exposure as outdoor workers, people engaged in outdoor sport, and people considering themselves as sun worshippers.

In our population sample, the proportion of subjects younger than 20 years will equal that in the Danish population overall, while adults engaged in outdoor work, outdoor sport, and sun worship will be overrepresented. Thus, we will select an adult population sample that might have a higher UVR exposure than the Danish population. As the sample population would be relatively small it is important to secure certain homogeneity with regards to skin type, and lack of skin disorders. And to select groups living under similar ambient UVR conditions to be able to provide reliable data and fulfil the earlier mentioned aims.

- *Same ethnicity:* To select a relatively homogenous group with regards to skin type, all participants should be skin type I-IV and ethnic Danes of Danish or Scandinavian ancestry.
- *No skin disorders:* To secure that skin disorders did not influence on the sun exposure, subjects should not be included if they had a medical history of: Psoriasis, skin cancer or malignant melanoma of the skin or if they had atopic eczema or polymorphic light eruption at present.
- *Similar ambient UVR conditions:* To secure comparable UVR conditions at least during workdays and schooldays and most of the days off, the subjects should be living and working in the Copenhagen area within a radius of 0-15 km from our hospital and the ambient UVR dosimeter. The sample population would thus be urban or suburban and not comprise any rural population.

Selection criteria for the subgroups within the age-span group

- *Children and adolescents:* Were selected from schools and kindergartens situated within the same vicinity.
- *Indoor workers:* The main part of the indoor workers that served as the adult part of the age-span group was recruited among employees at our hospital. Hospital employees were thus overrepresented in our study. However, former questionnaire based

studies have indicated that there are no difference in sun exposure behaviour among doctors and nurses compared to people outside the health sector (Morrison, 1996; Darling and Ibbotsson, 2002; Sciamanna et al, 2002).

Selection criteria for the subgroups with high UVR exposure

– *Sun worshippers:* People who define themselves as sun worshippers.
– *Outdoor workers:* Municipal gardeners were chosen, because they work and live in the city area under the same ambient UVR condition as the rest of the subgroups.
– *Golfers:* Golf was chosen as outdoor sport, since it has previously been documented that patients with basal cell carcinoma (BCC) are more often golfers than age, sex and residential matched controls (Lock-Andersen and Wulf, 1997).

Further description of the selection and recruitment of subjects are described in the methods section and in the actual papers.

REQUIREMENTS FOR SUBJECT DATA
TO BE INCLUDED IN DATA ANALYSIS

Some of the subjects were participating for more than one year. Subjects are therefore referred to as sun-years, where 1 sun-year is defined as 1 subject participating in 1 summer-half-year. To have sufficient data per sun-year for comparative analysis, a sun-year is only included in the data analysis if there is UVR dosimeter measurements and corresponding diary information for more than 30 days and at least 21 days in June, July, or August. To compare the individual UVR doses, we adjusted the observation period to a year, knowing that the received UVR during winter is almost negligible, except for winter holidays in sunny places and sunbed use. The estimated annual UVR doses were calculated based on the individual measured daily doses, and for missing days as the same part of ambient UVR found on comparable days with measurements, by separating days on/off work and being inside/outside Denmark.

MATERIAL AND METHODS

STUDY POPULATION

The studies presented in these papers were performed in Denmark (latitude, 56 north; and longitude, 12 east). The subjects were Danes with Danish or Scandinavian ancestry, as our purpose was to investigate the UVR exposure of selected subgroups of the fair-skinned ethnic Danish population. To investigate, if the UVR exposure findings were applicable in another fair-skinned, Caucasian population sample, a group of Irish municipal gardeners from the Dublin area with Irish or British ancestry were selected for comparison with a similar group of Danish gardeners (Paper VIII). How the subjects were recruited is described in details in each of the papers. Table 1 shows the number and grouping of the subjects in the studies presented in the nine papers.

The backbone of this thesis is the studies presented in Paper III-V and IX. These studies are all based on the same population sample. An age-span group chosen to cover a age span of 4-65 years comprising: 1) children recruited from three kindergartens, two primary, and two secondary school classes, 2) adolescents recruited from three high school classes, and 3) indoor workers recruited among university students, hospital staff (Bispebjerg Hospital) and employees in a computer company. In addition, subgroups with expected high UVR exposure as, 4) sun worshippers recruited through a ladies magazine, 5) golfers, all members of the same golf club and 6) municipal gardeners and rangers from the Copenhagen area. These subjects participated in one to three summer half-years called "sun-years" (1 sun-year equals 1 subject participating in 1 summer half-year (median 119 days; range 32-176 days)). The studies comprised in total 407 sun-years of which 61 sun-years were excluded from analysis due to incomplete data. The 346 analysed sun-years comprised 285 subjects participating in one sun-year, 33 subjects (2 indoor workers, 9 golfers and 22 gardeners) participating in 2 sun-years and 14 indoor workers participating in all three sun-years. In Paper IV and IX an analysis of the excluded sun-years is shown. However, it did not reveal any differences between the excluded and included sun-years. In addition, within the mentioned subgroups, there were no significantly differences in age, sex, and skin type between the subjects participating in one, two or three years.

PARTICIPATION DAYS

Table 2 shows the distribution of participation days among the subjects (sun-years) fulfilling the inclusion criteria for analysis in each of the papers.

AMBIENT UVR EXPOSURE

Solar UV radiation was measured with an UV-Biometer model 501 (Solar Light Co. Inc., Philadelphia) on the roof of a 7-floor building at Bispebjerg hospital in Copenhagen, latitude 56°N, 12°E. The spectral response was similar to the International Commission of Illumination (CIE) erythema action spectrum (McKinlay and Diffey, 1987). The measurements are expressed in standard erythema doses (SED), where 1 SED = 100 J/m^2 normalized to 298 nm using the CIE erythema action spectrum (Wulf and Lock-Andersen, 1996; Diffey et al, 1997b). One accepted way of comparing UVR exposure among individuals is by calculating exposure as a percentage of ambient UVR doses. To give an impression of the variation of ambient UVR over the year, Figure 2 shows the ambient UVR in SED per day in 1999 in Denmark measured on the top of our hospital.

PERSONAL ELECTRONIC UVR DOSIMETER "SUNSAVER"

As described earlier we needed an electronic UVR dosimeter to make continuous time logged UVR data. As none were commercially available, which met our demands, we developed a personal, electronic dosimeter "SunSaver" in our laboratory (Heydenreich and Wulf, 2005) as shown in Figure 3. The dosimeter comprises a sensor and a data logger. It is housed together with a digital watch and serves as a wristwatch. A Silicon Carbide Photodiode (JECF1-IDE; Laser Components; Germany) was chosen as sensor, which is only sensitive in the range 200-400 nm. The sensor has a built-in diffuser and has cosine response. The spectral response is similar to

Table 1. The number and grouping of the subjects in each paper and which years the studies took place.

	Subjects, N (Age range, years) [%Male]					
	Paper I 1998	Paper II 1998	Paper III-V + IX 1999-2001*	Paper VI 1999	Paper VI 1999-2001	Paper VIII 2001
Children			96 (4-15) [45]	45 (4-12) [49]	4 (10-16) [50]	
Adolescents			30 (16-19) [43]	35 (13-19) [23]	2 (17-19) [0]	
Indoor workers	20 (25-69) [35]	44 (20-69) [50]	121 (21-64)[41]	62 (20-64) [42]	46 (19-70) [40]	
Sun worshippers			53 (21-63) [8]			
Golfers			37 (27-68) [68]	22 (21-67) [59]		
Gardeners, DK			70 (25-60) [91]			23 (31-61) [91]
Gardeners, IE						34 (24-69) [88]
Total	20 (25-69) [35]	44 (20-69) [50]	407 (4-68) [49]	164 (4-67) [42]	52 (4-70) [40]	57 (24-69) [90]

*) In paper III-V and IX subjects are referred to as sun-years, where 1 sun-year equals 1 subject participating in 1 summer half-year (median 119 days; range 32-176 days).

Table 2. Number of participation days analysed per subject (sun-year) and sum-days per study presented in the nine papers.

Paper no.	Topic	Participation days analysed per subject Median days (range)	Summation of analysed participation days Sum-days	UVR dosimeter Name (Type) UVR dose type
I	Reliability of wrist position for personal UVR dosimetry. a) 1 day study and b) 2-weeks study	a) 1 b) 14 (8-26)	11 126	VioSpor® (Spore-film) Cumulative
II	UVR doses on workdays and holidays	13 (4-23) workdays 17 (8-26) holidays	511 669	VioSpor® (Spore-film) Cumulative
III-V	III UVR exposure doses and behaviour IV Sunburn and UVR exposure V Sunscreen and UVR exposure	119 (32-176)	39068	SunSaver (Electronic) Time-stamped
VI	Lifetime UVR dose	112 (32-137)	16668	SunSaver (Electronic) Time-stamped
VII	a) Summer and winter UVR doses b) Sun-holidays in winter	a) 258 (163-348) b) 7 (1-14)	4893 196	SunSaver (Electronic) Time-stamped
VIII	Comparison of UVR behaviour of Danish vs. Irish outdoor workers	100 (40-123)	5640	SunSaver (Electronic) Time-stamped
IX	Compliance and Data reliability	137 (129-148)	54943	SunSaver (Electronic) Time-stamped

VioSpor®, BioSense, Bornheim Germany (Quintern et al, 1992). SunSaver (Heydenreich and Wulf, 2005).

the CIE erythema action spectrum (McKinlay and Diffey, 1987). The data logger controls the sensor which was set to measure every 8th second and to store an average of the last 75 measurements every 10 minutes along with the time. The measurement range of the dosimeter is 0.1 SED/hour to 23 SED/hour. The UVR dosimeter is battery driven. It can run for 145 days without maintenance, and the data can be transferred to a personal computer. The subjects were instructed to wear the UVR dosimeter in place of their usual wristwatch – worn uncovered by the sleeve, on the dorsal aspect of the wrist, protected from excessive dirt and moisture. The protocols specified it to be worn continuously, or at a minimum between the hours of 7:00 to 19:00, and during sunbed use. In addition, the dosimeter should be placed on a towel with the sensor facing upwards during swimming. UVR dose received per time-interval is one of the main subjects in this thesis and will be described yearly, daily, per hour, between 12:00-15:00 and as a percentage of ambient in the papers (Paper III-IX).

SUN EXPOSURE DIARY

To be able to reveal the UVR exposure behaviour connected with the UVR doses received the subjects were provided with a diary. A folded piece of A4 cardboard comprised a diary month on the inside and instruction about the study on the outside as shown in Figure 4. This diary was used in Paper III-IX. It was a shortened version of a more comprehensive diary used in Paper II. We chose a higher compliance to a few questions rather than a lower compliance to a more extended diary. Questions about amount of sunscreen applied, skin area covered with sunscreen, use of hat and sunglasses were deliberately left out. The diary covering the first month was handed over with a thorough instruction. The subjects were to cross "yes" or "no" to questions about sun exposure. We considered a "yes" response to: *Did you sunbathe today? (Sitting or lying in the sun with upper body or shoulders exposed to get a tan or Have you exposed your shoulders or upper body outdoors today?* to indicate, "risk behaviour", since a significant part of the body would be exposed to the sun. A thorough description of the efforts done to increase diary compliance can be found in Paper IX.

SUN EXPOSURE QUESTIONNAIRE

All participants filled in the same questionnaire, which was used to

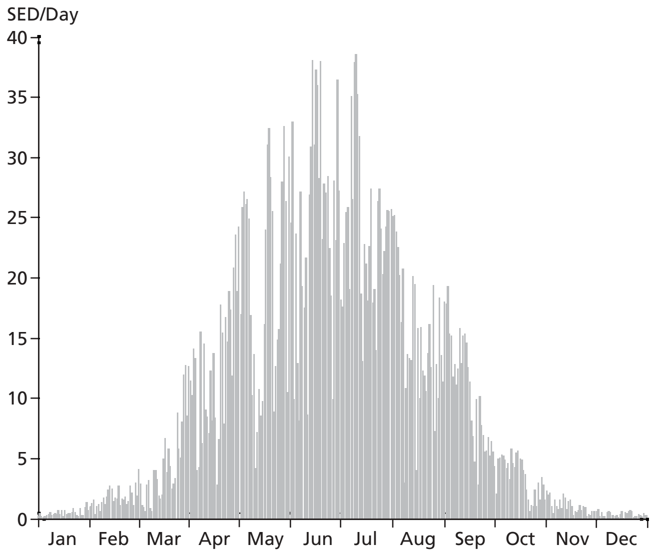

Figure 2. Distribution of ambient UVR in Denmark in 1999 in SED per day.

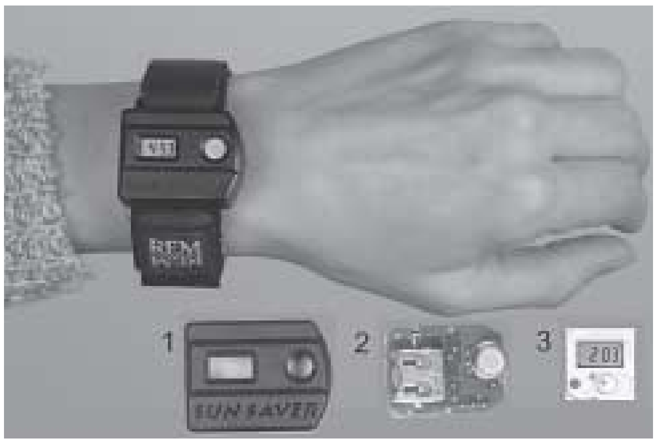

Figure 3. Personal, electronic, UVR dosimeter "SunSaver" worn on the wrist. 1: The housing, 2: The UVR data logger with the sensor and battery, 3: The watch, a separate unit. (Heydenreich and Wulf, 2005).

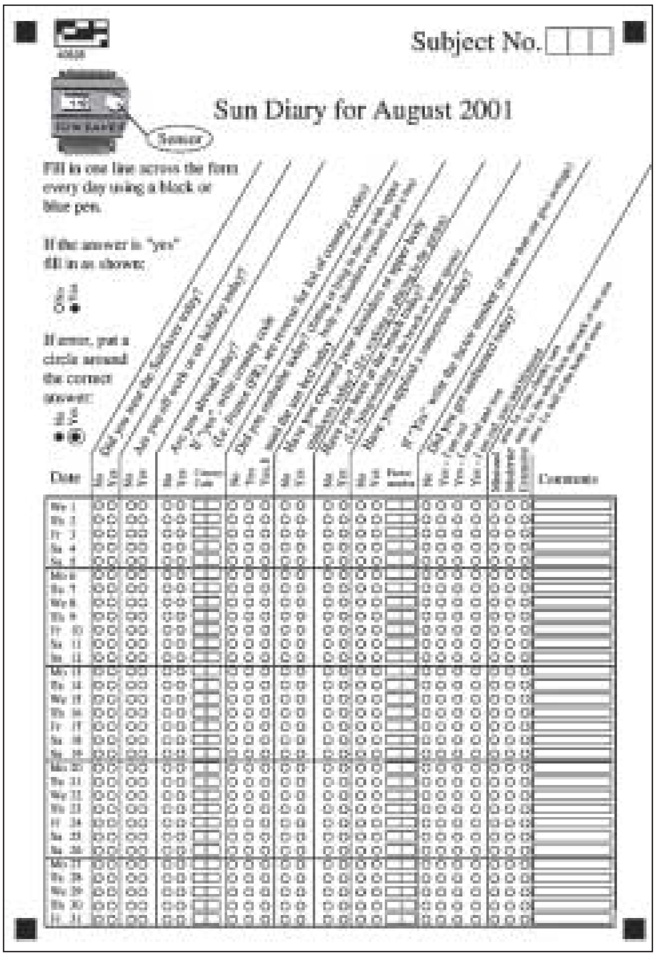

Figure 4. Sun exposure diary for one month.

obtain retrospective data about the participants' sun habits (Paper III-VI and VIII). However, in a PhD thesis from our department based on the sun exposure data as well, it was shown that no significant connections could be found between the actual UVR exposure dose and most of the retrospective exposure data from the questionnaire (Sandby-Møller, 2004; Sandby-Møller et al, 2004a; 2004b; 2004c). We therefore only used a few of the questions from the questionnaire in our analysis. In Paper VI we used questions about number of sunbed sessions earlier in life and the number of hours gardening and/or performing outdoor sport in the month of July. In Paper VIII where we compared the Danish and Irish gardeners, we used a couple of questions from the questionnaire as we compared number of subjects living in a house with a garden, history of outdoor work, sunbathing habits, and attitudes to sun tanning, sunburn episodes earlier in life, number of sun holidays in hot climates, and the number of hours engaged in outdoor leisure activities such as sport or gardening in the month of July.

SKIN TYPE AND PIGMENT PROTECTION FACTOR (PPF)

In 1988, Fitzpatrick published a scale to assess sun reactivity. It was a very simple six-grades classification system with 4 grades for Caucasian and 2 grades for brown and black-skinned people. It is performed as a very brief questionnaire on individual sunburning tendency and ability to tan after the first unprotected sun exposure in the summer. The exposure dose is standardized to the time needed to receive 90mJ/cm^2 (Fitzpatrick, 1988) corresponding to 9 SED. Translated into Danish circumstances the classification of the four Caucasian skin types I-IV is based on what people say their typical responses are to 2 h of unprotected sun exposure first time in the summer (May-June) around noon on a cloudless day (Lock-Andersen thesis, 2000). The subjects should describe their tendency to burn and their ability to tan after one such exposure (see skin type under definitions). Our subjects reported their skin type in a written questionnaire. To try to obtain a more objective and reliable measure of sun sensitivity, we therefore also assessed the individual UVR sensitivity objectively, expressed as the pigment protection factor (PPF) by a skin reflectance meter (UV-Optimize, Model Matic 555, Matic, Naerum, Denmark) (Wulf, 1986; Wulf, 1993; Lock-Andersen and Wulf, 1996; Wulf and Lock-Andersen, 1997b). PPF equals the number of SED needed to elicit just perceptible erythema on unexposed buttocks but can also be used to indicate the UVR sensitivity on other body locations. The PPF values measured before and after sun exposure in the summer season were referred to as minimum PPF and maximum PPF respectively. We used the minimum PPF measured on the buttock to express the constitutive skin type. While the minimum PPF on the shoulder was used as an indicator of the pigmentation acquired during risk behaviour earlier in life, as the shoulder is a body part considered only UVR exposed during risk behaviour.

CONDUCTING THE STUDY

The studies presented in Paper III-VIII are all based on sun exposure diaries and personal UVR electronic dosimeter readings. Paper IX presents the efforts made during these studies to obtain a high compliance and thereby a higher reliability of the sun exposure data.

GENERAL EFFORTS TO INCREASE COMPLIANCE

Since the participation period was at least a summer season, a great deal of effort was put on making the subjects wear the UVR dosimeter and complete the diary. To obtain the highest possible compliance, the study was performed on the premise that the participants were doing the study for us and not vice versa. E-mail contacts were regularly established with as many of the participants as possible. Our private phone and mobile phone numbers were printed on the diaries. In addition, the subjects were told not to hesitate to contact us, if they had any problems also during the evenings, weekends and holidays. Thorough study information was given at the start and written in the diaries, too. All the subjects but the sun worshippers were part of a group and team spirit was encouraged within the groups. All subjects were promised and given detailed information about their individual sun exposure records. The adolescents' group had UVR included in their biology curriculum and a workshop was arranged for them at our laboratory after study completion. The golfers were offered a full skin examination by our professor.

EFFORTS TO INCREASE UVR DOSIMETER RECORD RATE AND DIARY COMPLETION RATE

UVR Dosimeter maintenance was an important issue in order to prevent loss of UVR data and we aimed at solving UVR dosimeter malfunction within 24 hours. In case of dosimeter malfunction, we asked the subject to come to our ward, if this was not possible, we picked the dosimeter up at the home/workplace, repaired it and mailed or delivered it back the same day. Furthermore, we went with a laptop to all the teams twice and tapped the dosimeters on the spot and gave each participant a print of their individual UVR dose curve. This was done to emphasize the importance of wearing the UVR dosimeter every day, and to show to the participants that important findings came out of measuring their individual sun exposure. Furthermore, we made a detailed collection plan for the diaries to increase the number of collected and completed diaries (Paper IX).

RESULTS AND DISCUSSIONS:
PREVIOUS STUDIES AND OWN INVESTIGATIONS

COMPLIANCE AND DATA RELIABILITY

Previous studies

Compliance is only briefly discussed in most UVR dosimeter studies. Nearly all studies are conducted with UVR badges only showing cumulative UVR doses. The UVR data are mostly collected on a daily basis in a few days of a season and supplemented with information about activities in a questionnaire. The total exposure in a season or a year is then extrapolated from these few days' measurements (Dwyer et al, 1996; Kimlin et al, 1998). Therefore compliance in those studies is difficult to compare with our results. In a British study 180 children and adolescents wore UVR badges on the chest during a period of 13 weeks and 58% of UVR dosimeters and exposure records were selected for analysis (Diffey et al, 1996). Another study was conducted in Australia over an 18-month period. Twelve mail deliverymen and five physical education teachers were wearing polysulphone dosimeters on 3-5 body sites and it seems that approximately 20% of the UVR badges were collected (Vishvakaman et al, 2001). In our studies, we aimed at obtaining and reporting a high subject compliance and data reliability.

Own investigations and discussions
Since our purpose was to relate the actual UVR dose to the actual exposure behaviour over a period of months, the dosimeter used had to be easy to wear and comply with for the subjects. Dosimeter position was therefore important. In Paper I and II we investigated possible dosimeter positions using the UVR-sensitive spore-film filter dosimeter system (VioSpor®, BioSense, Bornheim Germany) (Quintern et al, 1992). We concluded that the wrist position is a practical and convenient body site for personal dosimetery yielding reliable results.

Paper IX shows the compliance and data reliability of the electronic UVR dosimeter studies presented in Paper III-VIII. All studies were based on personal time-stamped UVR dosimeters worn on the wrist in a summer-half-year and corresponding data on sun exposure behaviour reported in sun exposure diaries. This gave us a unique opportunity to control the reliability of the subjects' diary completion. We found that the subject compliance rate (Percent days where the diary was completed and the UVR dosimeter was worn) was a median of 93.5% (range 89.8-97.6%). The total sun exposure record rate (Percent of participation days with both UVR dosimeter and diary records and where the UVR dosimeter was worn) was a median of 84.1% (55.2-95.5%). Children, adolescents and golfers had lower sun exposure record rates than the rest of the groups ($P<0.05$). No significant difference was found between males and females ($P=0.15$). Diary completing mistakes, which we were able to correct, were found in 3.1% of the days. Children made more completing mistakes than adults ($P=0.001$). The average estimated error rate, found by comparing the diary records “yes” or “no” to have worn the dosimeter with the UVR dosimeter readings being either zero or above zero, was 3.3% and was higher for children (6.3%) and adolescents (3.6%) than the adult groups (2.4%). We thus found a high subject compliance rate and data reliability due to the use of electronic, wristwatch UVR dosimeters, maintenance service within 24 hours, action plans for collecting diaries, and by scrutinising data for errors and mistakes just after collection.

COMPARING DATA FROM YEAR TO YEAR

Previous studies
None of the earlier UVR dosimeter studies have lasted more than one year.

Own investigations and discussion
We calculated *the mean percentage of the ambient UVR* dose received in each sun-year. No significant differences in *the mean percentage of the ambient UVR dose* were found among the sun-years obtained from subjects participating in two succeeding years. The mean percentage of the ambient UVR dose received did also correlate significantly in two succeeding years (1999 vs. 2000; r= 0.61, $P=0.02$ (n=23)), (2000 vs. 2001; r= 0.67, P<0.001 (n=37)) but not in 1999 compared to 2001. When comparing UVR data from 1999 to data from 2001, considerable differences were found in mean percentages of ambient UVR dose for 7 out of the 15 subjects. This can be explained by altered life situations. 4 got considerably less UVR doses in 2001, one moved from a house with a garden to a flat in the city, one student graduated and got a full-time occupation, two became parents during the end of 2000 and therefore had not the same possibility for outdoor recreational activities. Of the three getting considerably more UVR exposure in 2001: two went to Southern Europe for holidays in 2001 and one person had another working schedule with 2 weeks on duty and 2 weeks off allowing for more outdoor activities in the days off.

For the 14 subjects participating in all three seasons an analysis of variance showed no significant differences either between the subjects or the years when comparing mean percentages of ambient UVR dose received for each person each year. In addition, the number of days off with risk behaviour (sunbathing or exposing upper body), where the highest UVR doses were measured, correlated significantly in all three seasons (1999 vs. 2000; r= 0.47, $P=0.03$ (n=23)), (2000 vs. 2001; r= 0.38, P<0.02 (n=37)), (1999 vs. 2001; r= 0.60, $P=0.02$ (n=15)). This indicates stability in a person's sun exposure from year to year, which allowed us to pool data from the subjects taking part in 2 or 3 years and to compare UVR doses received during the different years.

The fact that different life situations can give rise to different UVR exposure is probably the weakest point in our investigation when we calculate life UVR exposure from a single year. However, our and another study trying to estimate the lifetime exposure based on UVR dosimeter estimates only show minor differences among the age groups but a wide UVR dose range within the age groups (Diffey et al, 1996), (Paper VI). The same results are found in reviews based on sun exposure questionnaires (Godar et al, 2001; Godar, 2001; Godar et al, 2003; Godar, 2005). These results support our theory that some people seem to seek the sun and outdoor activities throughout their life while others feel uncomfortable in the sun.

UVR-EXPOSURE AND AGE

Previous studies
No personal UVR dosimeter studies have compared UVR exposure among children and adults, while several studies have addressed the UVR exposure among children and adolescents (Rosenthal et al, 1990; Herlihy et al, 1994; Dwyer et al, 1996; Gies et al, 1998; Moise et al, 1999a; Moise et al, 1999b). However, these studies have focused on UVR exposure during a few days' activities e.g. in summer camps, during outdoor sports, or during weekends versus schooldays. Only one dosimeter study has compared the UVR exposure among school children, home workers and outdoor workers (Kimlin et al, 1998). The UVR doses among home workers and school children were found to be on the same level, while the outdoor workers received a significantly higher UVR dose. The most comprehensive UVR dosimeter study of children's UVR behaviour was made in Britain among 180 children. It lasted 13 weeks with measurements between 08:00 and 18:00 during weekdays and weekends. The conclusion was that 9-10-year-old children got a higher UVR dose than 14-15-year-old adolescents (Diffey et al, 1996). In addition, the study disclosed that some individuals day after day received a significantly lower or higher UVR doses than their peers. Based on this we wanted to measure the UVR dose and behaviour among different age groups to assess possible differences during a life span.

Own investigations and discussion
We found that there was no significant correlation between age and annual UVR dose either within the total population or among the adults (Paper III). However, among the subjects below 20 years of age, we found an increase in annual UVR dose of 5 SED more per year (r=0.23, $P=0.03$). In contrast to others, we found that the teenagers received a higher annual UVR dose than the younger children (Diffey et al, 1996; Dwyer et al, 1996). A possible explanation could

be that we have measured personal UVR doses over a whole summer season, including holidays. Our data show that the highest UVR doses were received during July where all the children and teenagers and most of the adults had vacation, which means that they all have more or less the same opportunity to have sun exposure. In addition, if children should have more sun exposure than teenagers and adults, one would expect it should be during schooldays, where they have more spare time to spend in the sun. This was also the case, since children received 0.4 SED per schoolday, significantly more than adults who received 0.26 SED per workday, but not significantly more than the teenagers. However, when it comes to the total annual dose the UVR exposure dose received during schooldays matters very little compared to the UVR exposure dose received during holidays and days off. Due to the Danish welfare system, almost all Danish preschool children spent the weekdays in nursery or kindergarten while their parents are at work. These children usually have their lunch and nap indoors at noontime, when the ambient UVR is at its highest and in addition, the young children instinctively seek the shade on the hottest days. So although the younger kids have greater opportunity to get higher UVR doses in practice they get lower doses than the older children. When it comes to the adult groups no significant age related differences in UVR exposure were found. However, there was a trend towards a higher UVR exposure among people in the early twenties or above fifty, before or after the child-raising age. This was probably because they had more spare time and more money to spend on sun holidays and other outdoor activities. Our results were in line with American findings based on retrospective telephone interviews assessing hours spent outdoors (Godar et al, 2003) (Paper VI). We also found, within all age groups, a large dose range from 17 SED-980 SED in estimated annual UVR dose, which indicates that the size of UVR dose is not related to age but to the individual sun exposure behaviour (Paper III).

PROPORTION OF LIFETIME UVR DOSE RECEIVED BY CHILDREN, TEENAGERS, AND ADULTS

Previous studies

In an American study it was estimated that 80% of lifetime UVR dose was received before the age of 18 years (Stern et al, 1986). This estimate was based on the assumption that children and adolescents have more spare time and thereby more outdoor activities resulting in more UVR exposure than adults. This statement has been the fundamental principle since 1986 and the study has been cited in more than 200 papers and has been used as background for UVR protection campaigns since (www.who.int/phe/uv; www.skincancer.org; www.epa.gov/sunwise/kids.html).

By actually measuring UVR doses in different age groups continuously during a longer period we would try to verify or reject the theory that children and adolescents get a higher proportion of the lifetime UVR exposure dose than expected corresponding to their age.

Own investigations and discussion

By scrutinizing our dosimeter results we could reject the American results from 1986 as we found that the subjects before the age of 20 years did not get a higher proportion of lifetime UVR than expected corresponding to their age (Paper VI). This was also confirmed in a recent American study based on ambient UVR measurements and telephone interviews about number of sun exposure hours among 9386 Americans (Godar et al, 2003). This study, there was representative for the continental United States population, proved that Americans did not get a higher lifetime fraction of UVR before the age of 18 than expected. Although it has not actually been measured by personal dosimetry, it seems that Americans throughout the year received a higher proportion of ambient UVR than the Danes (Godar et al, 2001; 2003). The American children should therefore theoretically have an opportunity to get a higher exposure on schooldays and thereby a higher UVR lifetime exposure fraction compared to the Danish children, but this was not the case, when we compared our results with the results by Godar's group. Stern has questioned our results due to our small population sample size and has argued that the higher UVR doses among adult Danes is related to the longer holiday period in Denmark compared to the U.S. (Stern, 2005). However, the holiday length is more or less the same, 4-6 weeks, all over Europe. In addition, nowadays children are rarely outdoors on their own without their parents. The habit of transporting children by car or school bus to all activities has been practiced for decades and to a much higher degree among Americans than among Danes. Furthermore, the computer and television activities, which now more than ever occupy children from preschool age and onwards, result in a decrease of outdoor activities (Godar, 2003), (Paper III). Therefore the estimation of children being more UVR exposed than adults is not valid today. A viewpoint, which has recently been brought forward, is that although children's exposure pattern may be changing with recent growth in indoor recreational activities, this does not necessarily mean that exposure patterns are healthier (Wright and Reeder, 2005). For example it is possible that intermittent exposure, which is implicated in melanoma development, may be increasing (Elwood and Jopson, 1997; Marks, 2000). Yet, sun protection campaigns that encourage children and adolescents to reduce their UVR exposure, especially high dose exposure during risk behaviour, is still important to reduce skin cancer later in life.

UVR EXPOSURE AND SEX

Previous studies

The earlier dosimeter studies conducted on children and adolescents have all shown that boys received a higher UVR dose than girls (Dwyer et al, 1996; Diffey et al, 1996). No dosimeter studies have compared UVR doses among men and women.

Own investigations and discussion

For the total group and the individual adult subgroups no significant differences in estimated annual UVR exposure were found between males and females (Paper III). In subjects below 20 years of age, girls received a median of 175 SED (range 69-556 SED) significantly higher than the boys, 116 SED (range, 20-310 SED). There was no significant difference in mean daily UVR doses on schooldays. The girls' higher UVR doses compared to the boys' were solely due to significantly more days with risk behaviour (20 days vs. 10 days, $P<0.01$). The female UVR exposure pattern with more risk behaviour days continued during adolescence and adulthood. Compared to men, women had more risk behaviour days (17 days vs. 8 days, $P<0.01$), and more women (53% vs. 39%) had more days with UVR doses above 10 SED, mean (2.2 days vs. 1.4 days, $P= 0.06$). The women received the greatest part of their UVR doses in peaks i.e. during sunbathing, while the men had a more even exposure. This was the case within all the subgroups. On the other hand, it seems that females generally are more aware of the dangers caused by UVR, as they also used sunscreen more often than males (Paper V). However, American men reported a higher UVR exposure than the American women in the telephone interview study (Godar et al, 2001). A probable explanation for this difference could be that the Americans were not asked about their holiday exposure. The same fixed UVR dose of 78 SED was estimated for 3 weeks holiday for both male and female Americans. The holiday UVR exposure matters a lot in the cumulative UVR dose among the Danes, while UVR dose on workdays generally was of minor importance. If American females are more engaged in risk behaviour as sunbathing than American males during holidays, whereby the annual UVR dose among American females may increase to the level of the males is still an open question. An investigation of the risk behaviour pattern during holidays is therefore needed among male and female Americans to reveal that.

Table 3. UVR doses in SED and number of days with risk behaviour among the skin types.

Skin Type	N	UVR per day		Estimated annual UVR in SED		No. of risk behaviour days		UVR in SED per risk behaviour day	
		Median	(Range)	Median	(Range)	Median	(Range)	Median	(Range)
I	26	0.7	(0.2-1.7)	153	(31-293)	8*	(0-37)	2.4*	(0.3-7.2)
II	83	0.9	(0.1-4.8)	153	(19-841)	10	(0-66)	3.4	(0.1-12.4)
III	180	1.0	(0.1-6.7)	173	(17-980)	13	(0-93)	3.2	(0.5-22.1)
IV	56	1.2**	(0.1-4.0)	205**	(22-685)	20**	(2-53)	3.5	(0.5-16.1)

*) Significantly lower than Skin Type III & IV (P<0.05).
**) Significantly higher than Skin Type I-III, (P<0.03) (Paper IV).

UVR EXPOSURE, SKIN TYPE, AND PIGMENT PROTECTION FACTOR (PPF)

Previous studies

It is a well-known fact that fair skinned people are more sensitive to the sun and more easily get erythema than dark-skinned people. Which means that a greater part of a fixed UVR dose is transmitted into the skin in a person with a light complexion compared to a person with a dark complexion. A skin photo-test stating the individual MED (minimal erythema dose) is the best way to assess a person's UVR sensitivity (Lock-Andersen and Wulf, 1996). It is therefore a standard method for determining the UVR sensitivity in patients before UVR treatment of skin diseases in the clinic. As photo-testing is time consuming and requires special equipment, other methods to assess the photo-type have been tried especially for use in epidemiological studies. Although it is not very accurate and has been criticised scientifically (Wulf and Lock-Andersen, 1997b, Harrison and Büttner, 1999), the most widely used method for determining skin phototypes is the Fitzpatrick classification system (described under Methods) (Fitzpatrick, 1988). In a Danish case control study, self-reported skin type was found to be a risk factor both for (BCC), basal cell cancer and (CMM), cutaneous malignant melanoma (Lock-Andersen et al, 1999). The skin type of the subjects has not been reported in most of the major UVR dosimeter studies (Diffey et al, 1996; Kimlin et al, 1998; Gies et al, 1998, O'Riordan et al, 2000; Vishvakarman et al, 2001). In two dosimeter studies the skin type of subjects were reported, but not related to the UVR exposure doses received (Dwyer at al 1996; Autiers et al, 2000). The objectively measured pigment protection factor, PPF, as described in the methods section, has been shown to relate to the minimal erythema dose, MED, found in photo tests on unexposed buttock skin (Lock-Andersen and Wulf, 1996; Wulf and Lock-Andersen, 1997b). We decided to explore in a real life setting, if either skin type or PPF on the buttock or on the shoulder relates to the individual UVR exposure behaviour or the UVR dose received during the study.

Own investigations and discussion

The distribution of self reported skin type was, skin type I: 7.5%, II: 24.0%, III: 52.0% and IV: 16.2%, not applicable 0.3% (Fitzpatrick, 1988). Compared to earlier Danish studies it seems that our group overestimated their skin type (Lock-Andersen et al, 1998a; 1998b; Lock-Andersen et al, 1999). However, the earlier findings were assessed during interviews where the subjects could be guided. In addition, also in a Swedish study, self-assessment led to overestimation of skin type (Boldeman et al, 2004b). We found a trend towards an increasing UVR exposure dose from skin type I through IV. However, only subjects with skin type IV were found to have significantly higher UVR doses and more days with risk behaviour than subjects with lower skin type (Table 3).

The constitutive skin type was measured objectively before the summer season on the UVR unexposed buttock and expressed as the pigment protection factor, called "Minimum PPF on the buttock". The minimum PPF on the buttock was found to be significantly different among the skin types except among subjects with skin type I or II. While the minimum PPF measured on the upper back/shoulder was significantly different among all the skin types and increased with the skin type as shown in Table 4 .

Table 4. Minimum PPF values measured on the shoulder and on the buttock.

Skin Type	Min. PPF on the shoulder		Min. PPF on the buttock	
	Median	(Range)	Median	(Range)
I	5.6*	(3.1-8.0)	4.3**	(2.7- 7.0)
II	6.7*	(3.1-10.2)	4.4**	(2.1-7.0)
III	7.6*	(3.6-11.4)	4.6*	(2.3-10.4)
IV	8.5*	(6.1-12.5)	5.6*	(3.4-10.3)

*) Significantly different from all other skin types (P<0.01).
**) Significantly different from skin type III & IV (P<0.04).

People with high UVR exposure have a tendency to report themselves as having a higher skin type than the skin type corresponding to their constitutive skin pigmentation (Paper IV). We have the impression that when reporting their skin type, people are not referring to the UVR sensitivity on their unexposed buttock skin, but rather to the UVR sensitivity of their upper body. The minimum PPF measured on the shoulder before sun exposure in the summer season could be considered an objective measure for the skin type acquired through sun exposure earlier in life, since the upper body/shoulder is only UVR exposed during risk behaviour. Our results showed that the minimum PPF on the shoulder correlated significantly with the estimated annual UVR dose (P< 0.001, r= 0.3), and with the UVR dose per day (P<0.001, r= 0.3). In addition, the PPF on the shoulder correlated with number of days with risk behaviour (P<0.001, r = 0.3), and the UVR dose received on risk behaviour days (P<0.03, r=0.12). Which indicates that the higher the PPF on the shoulder before the summer season, the more time has been spent in the sun with risk behaviour earlier in life. This is further confirmed by the fact that the PPF measured on the shoulder after the summer season also correlated significantly with the estimated annual doses (P< 0.001, r = 0.3) (Paper IV).

As seen in Table 4, there is a large overlap between the PPF values found among people within each skin type. Thus we are not able to estimate the skin type alone based on the PPF value alone. However, as the PPF value on the shoulder correlates with the UVR exposure dose, the PPF value on the shoulder and the difference in PPF value found on the buttock and the shoulder could be an indicator of the sun exposure dose and pattern.

HOW SUN EXPOSURE BEHAVIOUR INFLUENCE UVR EXPOSURE DOSE

As described in Paper III, the UVR dose received depends to a large degree on the exposure behaviour. In the following the UVR doses received during different behaviours are therefore presented in different sections. Based on the information from the completed diaries in the summer study, we distinguish between *workdays* and *days off*. On *workdays*, we further distinguish between *outdoor workers (gardeners)*, and the *age-span group (children, adolescents and indoor workers)*, as the last group is usually occupied indoors during workdays, and therefore only have the possibility to be outdoors in the morning or the afternoon on workdays. For children and adolescents are schooldays and days in kindergarten considered workdays. On *days off* we distinguish between *risk behaviour* and *non-risk behaviour*. On days *off with non-risk behaviour* we used golfers as the example, because golfers are the only subgroup receiving a major part of their UVR dose during non-risk behaviour on

Table 5. The distribution of UVR doses and numbers of workdays and days off in Northern as well as Southern Europe, and during risk and non-risk behaviour for the sun-years with the mentioned behaviour. The data are given in median (IQR, Inter quartile range).

	Workdays or schooldays				Days off in Northern Europe				Days off in Southern Europe			
	Non-risk		Risk		Non-risk		Risk		Non-risk		Risk	
	SED/days	(IQR)	SED/days	(IQR)	SED/days	(IQR)	SED/days	(IQR)	SED/days	(IQR)	SED/days	(IQR)
A: UVR dose/day												
Total	0.3	(0.2-3.9)	1.6	(0.8-2.8)	0.6	(0.4-1,0)	3.2	(0.6-4.9)	0.7	(0.3-1.7)	6.2	(3.6-19.3)
Children	0.2	(0.1-0.4)	0.9	(0.5-1.9)	0.5	(0.2-0.7)	3.1	(1.6-4.8)	0.5	(0.3-2.2)	6.9	(3.3-9.7)
Adolescents	0.3	(0.2-0.5)	1.8	(0.7-3.3)	0.4	(0.3-0.9)	4.1	(3.0-6.7)	0.1	(0.1-0.3)	8.4	(7.5-14.7)
Indoor workers	0.2	(0.1-0.3)	1.1	(0.7-2.0)	0.5	(0.3-0.8)	2.9	(1.9-4.5)	0.9	(0.5-1.6)	4.5	(2.5-6.5)
Sun worshippers	0.2	(0.2-0.5)	1.5	(1.1-2.4)	0.7	(0.5-0.9)	3.6	(2.3-4.4)	0.6	(0.1-1.7)	6.3	(3.2-12.1)
Golfers	0.4	(0.2-0.7)	0.8	(0.6-3.6)	1.2	(0.9-1.8)	3.4	(1.9-4.6)	0.9	(0.5-3.9)	5.4	(4.3-6.1)
Gardeners	1.2	(0.9-1.5)	3.0	(2.0-3.9)	0.9	(0.5-1.3)	4.0	(1.8-5.3)	2.3	(0.8-6.6)	9.2	(6.2-11.8)
B: Days												
Total	55	(42-70)	1	(0-5)	41	(29-53)	8	(3-14)	3	(1-6)	7	(3-13)
Children	47	(34-54)	2	(0-6)	39	(27-52)	10	(4-16)	1	(0-5)	7	(5-14)
Adolescents	44	(35-50)	2	(1-5)	43	(34-63)	13	(5-21)	4	(1-4)	6	(0-14)
Indoor workers	64	(52-74)	1	(0-4)	38	(28-53)	7	(2-9)	3	(1-6)	7	(2-9)
Sun worshippers	53	(38-73)	3	(1-7)	41	(33-57)	12	(8-22)	2	(1-4)	8	(6-13)
Golfers	44	(21-61)	0	(0-1)	38	(26-60)	6	(2-14)	6	(1-9)	8	(0-12)
Gardeners	65	(48-78)	2	(0-6)	45	(32-52)	3	(1-9)	2	(1-7)	7	(5-7)

days off. The *days off with risk behaviour* are further divided into *UVR exposure in summer in Northern Europe*, and *UVR exposure in summer in Southern Europe*. Furthermore UVR exposure during sunbed use is presented in a special section.

The following sections in Results and Discussions are mainly based on Paper III-V, which describe the UVR exposure behaviour during 346 sun-years in a summer half-year of a median of 119 days (range 32-176 days). Whenever possible the UVR exposure is related to the estimated annual UVR dose as described on page 10. When it is not possible the UVR exposure dose is related to the total measured dose in a sun-year.

The two sections *UVR exposure during sun holidays out of Denmark in winter* and *Seasonal variations in UVR exposure* are based on Paper VII, with actual UVR measurements the whole year round.

Table 5 gives an overview of UVR exposure dose and time during the above mentioned behaviours. It should be kept in mind that not all subjects participate in all the different behaviours, e.g. only 13% of the gardeners compared to 34% of the total population had sun holidays in Southern Europe. Table 4 in Paper III shows in details the distribution of subjects, who went on holidays to the South.

UVR EXPOSURE AND WORK

The UVR exposure of gardeners on workdays

Previous studies

Several UVR dosimeter studies have been carried out measuring UVR exposure at selected body sites of outdoor workers over shorter periods (Holman et al, 1983; Larkö and Diffey, 1983; Rosenthal et al, 1991; Herlihy et al, 1994; Gies et al, 1995; Kimlin et al, 1998; Moehrle and Garbe, 2000a; Moehrle et al, 2000b). In a recent Australian paper UVR dosimeter measurements were performed during four hours on 493 outdoor workers in the building and construction industry (Gies et al, 2003). These outdoor workers received a median of 2 SED per hour or 26% of the ambient solar UVR. However, there was a large dose range from 0.06 SED to 6.42 SED per hour depending on the actual outdoor occupation. It has been estimated by the International Agency for Research on Cancer, IARC, that indoor workers in the mid-latitudes (40°-60° North) received an annual facial dose of 100 to 400 SED and that outdoor workers received a 2-3 times higher dose (IARC, 1992). The American Conference of Governmental Industrial Hygienists, ACGIH, had set a threshold limit to the face for outdoor workers of daily UVR exposure corresponding to 1.1 SED/day according to the CIE erythema action spectrum (ACGIH, 1999). Among Australian mail deliverymen and physical education teachers, an occupational UVR dose of 120 and 440 kJ per m^2 or 1200 to 4440 SED were found annually, resulting in daily UVR doses far above the recommended ACGIH threshold dose (Vishvakarman et al, 2001). Also among professional Alpine mountain guides a median of 1273 SED was measured in annual occupational UVR exposure dose (Moehrle et al, 2003). When adding 250 SED to cover holidays and leisure time more than twice the expected total UVR dose for outdoor workers was received among the mountain guides. We decided to examine the UVR exposure of outdoor workers not only during workdays but also during leisure activities. We have chosen municipal gardeners as an example of an outdoor occupation, as they are working and living very much under the same ambient UVR conditions as the rest of the subgroups in our study. In addition, we wanted to compare the gardeners UVR exposure with a group of indoor workers and sun worshippers to identify differences and similarities.

Own investigations and discussion

In our study, only the gardeners as outdoor workers had the major part (median 58%) of their UVR exposure dose on workdays (Paper III). We have shown in Paper I that the UV dose received to the wrist is half the UV dose received to the top of the head. If we therefore multiply our annual UVR doses from the wrist by 2 we would obtain UVR exposure data comparable to ACGIH and IARC. The gardeners in our study received 1.6 SED per day to the wrist and probably about the double to the top of the head, which is above the recommended UVR threshold level (ACGIH, 1999). From the wrist UVR measurement in our study we calculated that the median estimated annual UVR dose to the top of the head for the indoor workers was 264 SED (range, 34-1682 SED) and for the outdoor workers (gardeners) 448 SED (range, 108-1338 SED), or 1.7 times more than the indoor workers and lower than the 2 to 3 times higher dose estimated by the IARC, 1992, (Paper III). The dose span measured objectively by our dosimeters was thus much wider than estimated by the IARC, although it has been reported that some individuals receive considerably greater or smaller UVR doses than the rest (Paper III); (Diffey et al, 1996; Dwyer et al, 1996).

When we compared Danish and Irish gardeners, we were very surprised to find that although ambient UVR was 10% higher in Ireland and the Irish had longer working hours, the Danish gardeners received a significantly higher UVR dose on workdays (Paper VIII). By scrutinizing our data we disclosed that part of the difference was due to the fact that the Danish gardeners had their half an hour lunch breaks between 11:00 and 12:00, while the Irish gardeners had their half an hour break, from 12:00 and onwards. This implies that the Danes worked outside all hours in the period from 12:00 –15:00, while the Irish were inside at noon when the UVR peaks. If the Danish gardeners postponed their lunch break to start at noon, they could reduce their UVR exposure with 10%. Although the gardeners as outdoor workers received significantly higher UVR doses compared to indoor workers as described in Paper III, there is no legislation or government programme relating to the UV radiation protection of outdoor workers in either Ireland or Denmark. However, in 2004 a new EU directive relating to minimum health and safety requirements regarding the exposure of workers to physical agents, including UVR, came into effect and should be implemented in the member states before 2008 (Directive 2004/40/EC, 2004). Unfortunately, UVR from sunlight was withdrawn so that only UVR from artificial sources remain on the final list of agents in the Directive. Nevertheless, we think that studies such as ours may be useful when developing UV radiation protection strategies for outdoor workers in the future. This study highlights that simple measure such as the scheduling of indoor activities like lunch breaks during peak ambient UV radiation can significantly reduce the total occupational exposure.

The UVR exposure of the age-span group on workdays

Previous studies

Children's UVR exposure during schooldays has been investigated in UVR dosimeter studies. UVR measurements over a few days have been extrapolated to express the weekday and weekend UVR exposure in the four seasons (Gies et al, 1998; Parisi et al, 2000a). The *weekend/weekday UVR dose ratio* in spring among 20 indoor workers, 85 school students and staff, and 10 outdoor workers was estimated based on logbooks and polysulphone dosimeters on manikins. The *weekend/weekday UVR dose ratio* to the hand was 3.4 for indoor workers, 2 for school students and staff, and 0.7 for outdoor workers (Parisi et al, 2000a). Only one personal UVR dosimeter study has been conducted over a three months period comparing weekday and weekend exposure among 180 children and adolescents from April to July, finding almost the same UVR dose per day during weekdays and weekends (Diffey et al, 1996). To get a clearer picture of the UVR dose variation over a longer period, we decided to follow the UVR exposure of the age-span group (children, adolescents and indoor workers) continuously over a summer half-year and thereby covering workdays, as well as weekends and holidays.

Own investigations and discussion

If children should receive a higher UVR dose than adults, one would expect that they had a higher UVR dose on workdays (schooldays). However, as mentioned earlier, children, adolescents and indoor workers in our study only received a minor part (median12-22%) of their total UVR dose on workdays (schooldays), although half of the participation days were workdays (Paper VI). When the sun peaks at noon the subjects are indoors either at work or in school. Before and after work or school, when the subjects have the possibility to be outdoors, the ambient solar UVR dose is relatively low. The UVR dose received per workday was a median of 0.3 SED (IQR 0.2 –0.5 SED) with children receiving 0.4 SED and adults 0.26 SED per workday. This small dose difference on workdays was of no importance when calculating the total annual UVR doses for the different age groups. In Denmark, lunch breaks are generally 30 minutes and the lunch is usually eaten indoors at the workplace. The schools have two breaks, 20 minutes, starting at 10:00 and 30 minutes starting at 11:30. It is not mandatory for children to be outdoors during the breaks. Besides, if the children choose to go outdoors, these breaks are before the UVR peaks at noon. The Danish break times in schools are therefore optimal seen in a UVR protecting perspective. However, as mentioned above it is important to consider break times for minimisation of UVR exposure. In an Australian study the effect of meal break times on solar UVR exposure of schoolchildren in a summer month was investigated. It was found that the UVR exposure could be reduced with 20% by varying the school meal break times alone (Parisi and Kimlin, 2000c). Furthermore, a Swedish study has shown that shady environments on a preschool playground could lower the UVR dose with 40% among 5-6-year-old children compared to children attending a preschool with a playgrounds without shady environments (Boldeman et al, 2004a). Also an Australian group suggests that shade structures should be erected in primary schools to provide areas where children can more safely undertake outdoor activities (Gies and Mackay, 2004).

However, an indicator of high UVR doses seldom being received on workdays is the fact that among the subjects without outdoor work, only 5.5% of the sunburns occurred on workdays in our study. In addition, nearly all these sunburns occurred when the subjects had risk behaviour even on a workday. As a consequence, UVR doses received on workdays add very little to the annual cumulative UVR dose in our investigations. Sun protection precautions are therefore seldom needed on workdays or schooldays except on days with risk behaviour or long lasting outdoor activities.

UVR EXPOSURE ON DAYS OFF

Previous studies

As earlier described no UVR dosimeter studies have actually measured UVR doses during days off in general but only on a few days with expected high UVR exposure as during outdoor sport, gardening, or sunbathing (Herlihy et al, 1994; Autier et al, 2000). We measured the UVR continuously including days off by our personal dosimeters and related that to the corresponding exposure behaviour.

Own investigations and discussion

The major part of UVR exposure in our summer study is taking place during days off (Paper III, Table 3). For the total group a median of 76% of the total measured UVR exposure dose was received on days off. Among children, adolescents, and sun worshippers the percentages of UVR received on days off were a median of 82%, 88%, and 85% respectively, while the gardeners received a median of 42% on days off. In our studies we do not distinguish between weekends or holidays when referring to days off. However, we discriminate between two types of exposure behaviour according to the skin area exposed as reported in the diaries. 1) *Non-risk behaviour:* All UVR exposure with the upper body/shoulders covered. 2) *Risk behaviour:* UVR exposure of at least the upper body/shoulders either during sunbathing with the intention to tan OR during e.g. gardening, or playing outdoors. In addition, we recorded whether the UVR exposure took place in Northern Europe (primarily Denmark) or in Southern Europe (primarily the Mediterranean area).

UVR exposure on days off with non-risk behaviour

Previous studies

In the UVR dosimeter studies previously performed, a comparison between risk and non-risk behaviour has not been directed specifically. The UVR dosimeter studies conducted have addressed UVR exposure received during specific outdoor activities where high UVR doses are expected such as gardening, baseball, scouting, tennis, water sports, triathlon, bicyclisme, mountaineering (Melville et al, 1991; Herlihy et al, 1994; Moehrle et al, 2000a; 2000b; Moehrle et al 2001). These studies comprised UVR dosimeter measurements on isolated days or hours only, where the UVR doses received during the different activities have been assessed and compared. The measurements were never brought into a broader context of UVR exposure during a longer period with normal daily activities on workdays, days off, and holidays. Earlier findings from our laboratory have shown that patients with non-melanoma skin cancer significantly more often were golfers than age, sex and residential match controls (Lock-Andersen and Wulf, 1997). In addition, a round of golf takes about 4 hours, where the players are out in an open golf court and thereby have the possibility to receive a high percentage of ambient UVR. We therefore decided to compare the UVR exposure of a group of golfers (outdoor sportspeople) with a group of indoor workers, outdoor workers and sun worshippers in a summer season.

Own investigations and discussion

Normal non-risk activities did not give rise to high UVR doses, as can be seen from Table 5. Among our subgroups the golfers received the highest UVR on days off without risk behaviour. Therefore special attention will be given to the golfers in this paragraph. The golfers received the highest percentage of ambient UVR, a median of 7.5% (range 3-24%). This was similar to the gardeners and sun worshippers and significantly higher than indoor workers (P<0.05) (Paper III, Table 2). Except for the gardeners who spent a median of 3.5h outdoors per day in the study period, the golfers were the group spending most hours outdoors, a median of 2.7 h per day. In contrast hereto the sun worshippers spent a median of 2 h and the indoor workers, children and adolescents all spent a median of 1.7 h outdoors per day. The golfers received a median of 63% of their total UVR doses on days without risk behaviour and thereby had an UVR exposure pattern similar to the gardeners, except that the golfers received the main part (49%) on days off, while the gardeners received their main part (51%) on workdays. There was no significant difference in estimated annual UVR dose among the golfers, the sun worshippers, and the gardeners. But the golfers and gardeners received their UVR more evenly on a daily basis, while the sun worshipper had a lower UVR dose per day but more days with peak doses above 10 SED (Paper III, Table 6). The reason why golfers more often get skin cancer may be explained by the high cumulative UVR dose received during golf sessions. Besides, golf is a sport, which people can practice in old age too, and a sport which many people take up, when they stop playing other ball games as football and tennis. The finding that golfers have practised outdoor sports in a significantly greater part of their life than the indoor workers and sun worshippers (P<0.02) support this theory. On the other hand, the golf dress code implies that only the face, the hands, the lower parts of the arms and legs are exposed during a game, even on the hottest day. This means that a smaller skin area is UVR exposed than during risk behaviour. As we have only investigated golfers, we cannot transfer our data to other sports. However, we assume that other outdoor sports taking place in the open and lasting several hours when practised, will accumulate to about the same UVR dose. It should be mentioned that two of the gardeners did mountaineering in Southern Europe, which is the reason for the high daily UVR dose on non-risk behaviour days in Southern Europe among gardeners. The only other sport we have assessed was skiing (Paper VII). Skiing in Norway until the end of February did not give UVR doses beyond the erythema threshold, while a ski trip to the French Alps in March could give 7.6 SED per day. Since only the face is exposed during skiing it is relatively easy to protect the face with sunglasses and sunscreen during a winter holiday. However, the high UVR dose received by professional ski instructors may be a health problem (Moehrle et al, 2003; Sliney, 2005). It is our opinion that on days off without risk-behaviour UVR protection against erythema is only necessary during long lasting outdoors activities.

UVR exposure on days off with risk behaviour

Previous studies

Several retrospective interview studies have assessed UVR exposure during risk behaviour especially on the beach by questionnaires (Bennetts et al, 1991; Grob et al, 1993). Only one study has measured the UVR doses received during sunbathing at the beach in Southern Europe by electronic UVR dosimetry. Among 44 young adults UVR doses were of the same magnitude as we have found in our study (Autier et al, 2000), (Paper III). However, this was a study of UVR exposure during sunbathing at the beach only. We wanted to see UVR exposure in a broader context to be able to isolate the individuals and situations with the highest UVR exposure.

Own investigations and discussion

Table 6 is a modified version of Table 5 in Paper III and shows for the total group as well as the subgroups the distribution of UVR doses and number of days off with risk behaviour outside and at the beach in Northern as well as Southern Europe. Furthermore it shows the percentage of the total UVR doses received during the different situations.

UVR exposure on days off with risk behaviour in summer in Northern Europe

In Northern Europe, the subjects received a median of 2.5 SED (IQR 1.5-3.9 SED) per day with risk behaviour *outside the beach*, and almost twice as much per day at the beach (median 4.6 SED, IQR 2.5-6.7 SED). From Paper III, Table 4 it can be seen that 84% of the subjects had risk behaviour outside the beach and 57% had risk behaviour at the beach. Among the children 90% had risk behaviour at the beach, receiving 20% of their total measured UVR dose on 4 days with risk behaviour at the beach and further 11% on 6 days with risk behaviour outside the beach. However, the distribution was very different among the subgroups in our study. The children and adolescents spent more days at the beach than any other group and received 13% and 23% respectively of the estimated annual

Table 6. UVR doses in SED per day and number of days off work/holidays for the sun-years with risk behaviour. Data are given in median, Inter quartile range (IQR). Risk behaviour indicates sunbathing or exposing shoulders or upper body.

	SED											
	Risk behaviour outside beach						Risk behaviour at the beach					
	per day	(IQR)	%	Days	(IQR)	%	per day	(IQR)	%	Days	(IQR)	%
Northern Europe Primarily Denmark												
Total	2.5	(1.5-3.9)	15	6	(3-12)	5.7	4.6	(2.5-6.7)	15	4	(2-7)	3.3
Children	1.7	(1.0-3.0)	11	5	(3-9)	5.7	4.2	(2.3-7.0)	20	5	(2-9)	4.5
Adolescents	3.1	(1.7-5.6)	16	9	(4-15)	8.6	7.5	(6.1-9.7)	33	6	(2-8)	5.4
Indoor workers	2.4	(1.4-3.2)	16	6	(3-9)	5.2	4.4	(2.9-6.4)	19	3	(1-7)	3.1
Sun worshippers	3.4	(2.3-4.3)	21	9.5	(6-18)	7.6	5.1	(1.7-6.2)	11	3	(1-6)	2.1
Golfers	3.0	(1.9-3.9)	14	5	(2-3)	5.4	6.1	(2.6-7.4)	9	2	(1-6)	2.7
Gardeners	3.1	(1.3-5.2)	9	4	(2-10)	3.5	3.6	(2.2-5.5)	5	3	(1-8)	2.7
Southern Europe Mediterranean area												
Total	3.2	(1.8-6.6)	10	4	(2-7)	3.5	6.9	(4.1-11.6)	30	6	(4-9)	5.3
Children	0.6	(0.3-2.9)	1	2	(1-5)	1.6	6.9	(3.7-10.6)	44	7	(5-13)	9.0
Adolescents	8.3	(5.3-11.6)	14	3	(3-11)	3.1	11.0	(6.6-15.0)	32	6	(5-11)	7.6
Indoor workers	2.3	(1.6-3.9)	8	3	(2-6)	3.2	5.3	(3.2-10.3	23	6	(2-7)	4.7
Sun worshippers	4.5	(2.0-11.0)	11	5	(3-8)	3.9	7.1	(3.7-12.9)	29	7	(4-9)	4.8
Golfers	3.2	(1.9-5.0)	15	6	(3-13)	4.5	6.6	(5.8-9.6)	30	6	(5-7)	5.6
Gardeners	6.4	(4.6-9.1)	13	4.5	(3-6)	3.7	11.2	(8.0-15.7)	16	7	(1-7)	5.2

% = Median percentage of total group values during the mentioned risk behaviour.

UVR dose at the beach, while the sun worshippers only received 8% of their UVR dose at the beach, where the largest skin area is UVR exposed. It is therefore alarming that the young people were more enthusiastic beachgoers than any other group. In addition, children and adolescents received their doses in peaks at the beach to an even higher degree than sun worshippers.

UVR exposure on days off with risk behaviour in summer in Southern Europe

The situation is even worse for those who were travelling to Southern Europe in summer. While only 16% of the days off in Denmark were with risk behaviour as much as 76% was with risk behaviour in Southern Europe. Very high UVR exposure was obtained on sun holidays in Southern Europe as almost the double dose were received per day compared to Northern Europe. The UVR dose per risk behaviour day *outside the beach* in Southern Europe was a median of 3.2 SED, (IQR 1.8-6.6) and *at the beach* a median of 6.9 SED, (IQR 4.1-11.6). Furthermore, the subjects were exposed to higher ambient UVR doses and stayed outdoors in more hours in Southern versus Northern Europe, on risk behaviour days at the beach thus 6h vs. 5.3h respectively. Although only 86 (25%) of the subjects had risk behaviour at the beach in Southern Europe, the median UVR dose of 44 SED they received in a median of 6 days corresponded to 25% of the estimated annual UVR dose for the total group. For the children and adolescents, who at the beach in Southern Europe received a median of 63 SED and 85 SED respectively, the UVR doses corresponded to as much as 44% of their peers' estimated annual UVR dose. Reducing the solar exposure on the few days with risk behaviour at the beach in Southern Europe can thus reduce the total UVR load considerably (Paper III).

UVR EXPOSURE AND SUNBED USE

Previous studies

There is a vast amount of literature on the adverse effects of tanning beds. In one study, 44% of sunbed users reported erythema (Boldeman et al, 1996). Another study noted that 59% of sunbed users reported skin injury as burned, blistered or peeled skin and/or rashes (Oliphant et al, 1994). A population-based, matched case-control study in Sweden reported a significantly elevated odds ratio (OR 1.8, 95% CI 1.2-2.7) for developing melanoma after regular exposure in sunbeds. The data were adjusted for hair colour, raised nevi, skin type, and number of sunburns (Westerdahl et al, 2000). However, it is not possible to distinguish between UV radiation from sunbeds and UVR radiation from extended solar exposure among sunbed users as the causal factor in the development of malignant melanoma. In recent years a link has been shown between sunbed use and squamous/basal cell carcinoma. Overall use of sunbeds has been associated with an odds ratio (OR) of 2.5 (95% confidence interval (CI) 1.7-3.8) for squamous cell carcinoma and 1.5 (95% confidence interval (CI) 1.1-2.1) for basal cell carcinoma, adjusted for sunburns, sunbathing, and sun exposure (Karagas et al, 2002). In our study, we therefore wanted to reveal if there were differences in UVR doses and behaviour of sunbed users compared to non-sunbed users.

Own investigations and discussion

In our study 44 subjects (13%) used sunbeds and had a median of 3 sunbed sessions (range, 1-23; IQR, 1-7) (Paper III-V). Thirty six percent of adolescents, 19% of indoor workers and 17% of sun worshippers used sunbeds during the study, while only 1%, 6% and 7% among children, golfers and gardeners respectively.

Sunbed users had significantly more days with risk behaviour compared to non-sunbed users (20 days vs. 12 days, $P<0.001$), days with sunbath (median 13 days vs. 4 days, $P<0.001$), days with sunscreen applied (median 9 days vs. 4 days, $P=0.016$), a higher estimated annual UVR dose (median 203 SED vs. 168 SED, $P=0.03$), a higher UVR dose per day (median 1.1 SED vs. 0.95 SED, $P=0.03$) and a higher UVR dose per risk behaviour day (median 4.6 SED vs. 3.1 SED, $P=0.04$), more days with sunburn (mean 1.7 vs. 1.1 $P<0.02$), and number of sun holidays (10 sun holidays vs. 6 sun holidays, $P<0.03$).

All sunbed users in our study sunbathed outdoors, too. Comparing sunbed users with sunbathers not using sunbeds, the sunbed users still had significantly more risk behaviour than the non-sunbed user (20 days vs. 15 days, $P<0.02$). Their estimated annual UVR dose was also higher (203 SED vs.177 SED), however, not significantly higher probably due to the big UVR dose range among the subjects. Although sunbed users did not have a significantly higher annual UVR dose than the subjects, who sunbathed without using sunbeds, the actual use of sunbeds, even just once during our study, was a marker for those having higher UVR exposure than average. Only a few of the sunbed users in our study could be considered heavy users, since 33 out of the 44 sunbed users had less than 5 sunbed sessions, and only 5 had more than 10 sessions with 23 sessions as the maximum. However it should be born in mind that the study took place in the summer half year and we do not know how many sessions these sunbed users had in winter except for 7 subjects who took part in a winter study as well (Paper VII).

The subjects in our study received a median of 173 SED in annual UVR exposure to the wrist dosimeter. The UVR dose per sunbed session was a median of 3 SED to the wrist dosimeter. By having sunbed sessions once a week a subject is thus able to almost double the annual UVR dose – or triple the UVR dose if it is taken into consideration that a person is UVR exposed to 3 SED on both sides of the body in a sunbed.

Figure 5 shows the UVR exposure pattern obtained during the participation period by one sunbed user. The high UVR peaks illustrate the days with sunbed use.

In the last few years after we have conducted our study the clear association between sunbed use and melanoma has been widely published (Gallagher et al, 2005; Young, 2004). In one large prospective cohort study of pigmentation factors and sun exposure in relation to melanoma risk, 106,379 women from Norway and Sweden were followed for an average of 8 years. Overall, regular (≥1 time/mo) sunbed use at any age was associated with a statistically significant, 55% increase in risk of melanoma after adjustment for sun sensitivity and measures of sun exposure (Veierod et al, 2003). The prevalence of sunbed use in the previous year was 10% among American youth ages 11 to 18, however, 40% among girls ages 17-18, while the prevalence was 30% in those youth whose parent using sunbeds in the previous year as well (Cokkinides et al, 2002). Also

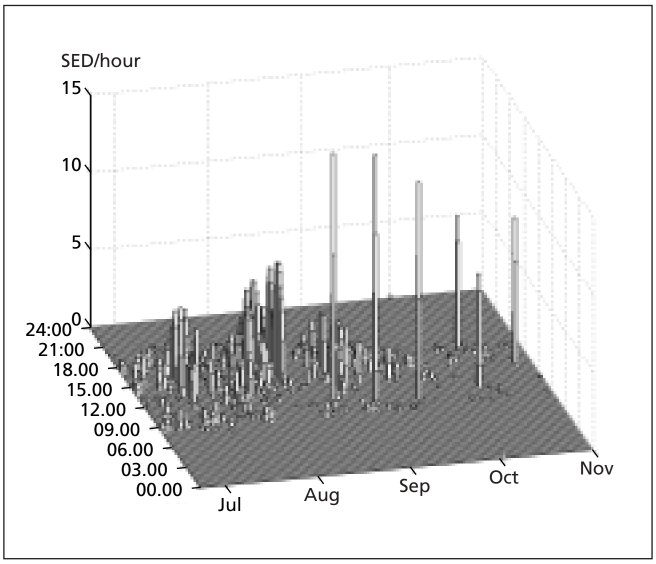

Figure 5. The UVR exposure doses received by one subject. The peaks shows the high UVR dose obtained during sunbed use.

we found that adolescents were the most eager sunbed users as 36% used sunbeds. In the latest American study the great risk of artificial UV radiation in cutaneous carcinogenesis invites regulations to limit tanning in the United States (Levine et al, 2005). On the other hand the indoor UVR tanning industry claims that using sunbed could increase the synthesis of vitamin D in the skin, and thereby relieve the lack of vitamin D, which is a problem among young and menopausal women (Grant and Holick, 2005). In a study comparing sunbed and non-sunbed users, the serum 25(OH)D level were found significantly higher among sunbed users (P<0.001) (Tangpricha et al, 2003). However, the sunbed users had also significantly more sun exposure than the non-sunbed users, 24.3h/wk vs.15h/wk (P=0.003). It is therefore not possible to tell if the higher vitamin D level was due to sunbed or solar exposure, and further studies of the connection between sunbed use and skin vitamin D synthesis are needed.

As discussed in Paper VII, sunbed use can also increase the UVR dose received in the winter half-year dramatically. The UVR dose of 3 SED received in one sunbed session is equal to the total cumulative solar UVR dose received throughout the winter half-year. Seven subjects used sunbeds in our winter study and 5 of them were among the subjects receiving the highest total annual UVR dose and the last two received UVR doses above the 25% quartile. As described earlier sunbed use is an indicator of high solar UVR exposure also in winter (Paper IV,V,VII); (Tangpricha et al, 2003). On the assumption that the use of sunbed is not replaced by solar exposure, abstinence from sunbed use is recommended as a way to reduce the cumulative UVR dose.

DAILY UVR DOSES AT OR ABOVE 10 SED

Previous studies

High intermittent UVR doses may be especially dangerous for provoking malignant melanoma, (Armstrong and Kricker, 2001; IARC 1992; Matthes,1996). None have actually studied in which situations people receive high UVR doses. As a dose of 10 SED may cause erythema on both previous sun-unexposed and sun-exposed skin in most Scandinavian subjects, we wanted to examine the distribution of days with UVR dose above 10 SED. In addition, we tried to reveal to what extent high UVR doses were connected with risk behaviour.

Own investigation and discussion

Of the subjects, 160 (46.2%) had in total 636 days on which they received doses of 10 SED or more. The distribution is shown in Paper III, Table 6. It is alarming that 38 (56%) of the children, 17 (77%) of the adolescents, and 27 (55%) of the sun worshippers received 30% of the annual UVR dose of their respective subgroups during 3 to 4 days, with UVR doses of or above 10 SED per day. Sun worshippers, golfers, and gardeners received significantly higher UVR doses (P<0.05) than indoor workers and children, while the adolescent group of high school students were in between and received significantly higher doses compared with the indoor workers. High UVR doses of or above 10 SED are linked to days off, risk behaviour and long lasting UVR exposure, as 605 (95%) of the days were days off, 555 (87%) of the days were with risk behaviour, and a median of 7.2h (IQR, 6.2h-8.3h) per day were with positive UVR dosimeter measurements. The strong correlation between UVR dose and risk behaviour shows that high UVR doses are almost only found during leisure activities with risk behaviour and not during daily outdoor activities. UVR doses above 10 SED per day were only found on 19 workdays without risk behaviour, whereof 14 days among gardeners. This emphasizes that the point of attack in reducing the UVR dose among non-outdoor workers is to reduce days and hours with risk behaviour rather than avoiding UVR exposure during daily activities. However, long lasting activities as found among outdoor workers still calls for special UVR protection.

UVR EXPOSURE AT PEAK HOURS BETWEEN 12:00 AND 15:00

Previous studies

It is a well-known fact that the highest ambient UVR doses are measured around noon. In addition, all UVR protection campaigns advise people to stay out of the sun in the middle of the day (www.who.int/phe/uv; www.skincancer.org; www.epa.gov/sunwise/kids.html). However, the diurnal distribution of UVR exposure has not previously been measured with personal dosimeters. We therefore decided to investigate the exposure pattern during all 24 hours of the day and to register the exposure between 12:00 and 15:00 specifically.

Own investigations and discussion

In Denmark from April to September, the ambient UVR dose between 12:00-15:00 was in median 43% of the daily UVR (Paper II). Paper III shows that our study population had a median of 50% (range, 20%-81%) of their UVR dose between 12:00-15:00, independent of the size of their total UVR dose. The percentage was significantly higher (P<0.05) among children and adolescents (median, 55%; range, 38%-81%) and significantly lower (P<0.02) among indoor workers (median, 48%; range, 20%-68%) and golfers (median, 47%; range, 29%-59%). The dose received between 7:00-12:00 was a median of 21% (range, 3%-48%), and from 15:00-19:00, 27% (range, 4%-66%). We found a strong linear correlation between the UVR doses received between 12:00-15:00 and the total measured UVR dose for the individual subjects (r = 0.98, P<0.01). When focusing on the hours with measurement > 0 SED, 39% of the hours were placed between 12:00-15:00, 28% between 07:00 –12:00 and 32% between 15:00-19:00.

The subjects in our study received 50% of their total measured UVR in the hours between 12:00-15:00. Even though nearly all of our participants went to work or school on half of the days they participated in the study and thus were unable to have UVR exposure around noon on these days. This emphasise that the UVR dose received on workdays/schooldays is low, and matters very little in the total UVR dose except among outdoor workers.

It is striking that on the days with 3 hours uninterrupted UVR measurements (above 0 SED) between 12:00-15:00 compared to days with 2½ hours UVR measurements between 12:00-15:00, the UVR dose received was more than the double in the first situation (3.5 SED vs. 1.7 SED). Consequently, much can be gained in UVR reduction by persuading people to have an indoor break or seeking shade at noon, for example when staying at the beach to seek inside for lunch instead of picnic outdoors.

UVR EXPOSURE DURING SUN HOLIDAYS
OUT OF DENMARK IN WINTER

Previous studies

No previous studies have been done about UVR exposure during holidays in the winter.

Own investigations and discussion

Travelling abroad in the winter half-year can completely change the individual UVR dose pattern (Paper VII). Table 3 in Paper VII shows the UVR exposure data for the 28 subjects travelling to a sunny resort for a median of 7 days (range, 1-14 days) in the winter half-year. They received a median of 4.3 SED per day (range, 0.6-7.6 SED) or 26 SED per journey (range, 3.3-71 SED). The UVR dose of 4-5 SED received on one day in Mexico in February or in Greece in October corresponds to almost twice the total solar UVR dose received by an indoor worker during the entire winter half-year in Denmark. Just as the 70 SED received by a subject over a 14-day period in Mexico in February or in Greece in October equals the total annual UVR dose for a subject with low UVR exposure. Even higher UVR doses can be received in April, where 6 other subjects received a median of 76 SED (range, 26-230 SED) in one week in the Canary Islands. It is therefore important to register number of sun holidays all year round when calculating the lifetime UVR exposure. Furthermore, if the UVR dose should be reduced, the reduction of days with risk behaviour abroad would be an obvious task area.

SEASONAL VARIATIONS IN UVR EXPOSURE

Previous studies

Little is known about UVR exposure outside the summer season and no continuous personal UVR dosimeter studies have been made in the winter-half-year. In the continental United States covering the latitudes 33°N to 45°N, the annual UVR doses received by Americans were recently estimated based on daily outdoor activity profiles and ambient UVR measurements (Godar et al, 2001; Godar, 2001). These studies were based on the assumption that the same percentage (30%) of terrestrial UV radiation is available for solar exposure all year round. The seasonal distribution of UVR exposure among Americans (except for holidays) was then estimated to be 28% in spring, 51% in summer, 15% in autumn, and 6% in winter. An Australian group examined the annual occupational UVR exposure (23.5°S) in outdoor workers by personal UVR dosimetry (Vishvakarman et al, 2001). The study revealed a 2-4 times higher daily UVR dose during the summer compared to the winter depending on dosimeter site. Unfortunately, the group did not include the recreational UVR exposure of the outdoor workers or the UVR exposure of indoor workers for comparison. In Australia (19°S) the annual UVR dose was estimated based on a few days' dosimeter measurements in each season (Parisi et al, 2000a; Kimlin et aI, 1998). In South Africa (30°S) the potential annual UVR dose was estimated on the basis of the percentage of ambient UVR received during a two weeks period in summer (Guy et al, 2003). In the Netherlands (52°N) the estimate of annual UVR exposure is mainly derived from ambient measurements (Slaper, 1987). While in the U.K. (50°-55°N) estimates of annual UVR doses are primarily based on mannequin studies (Diffey et al, 1977). In the U.K. it was estimated that indoor workers during adult life received 10% of the annual UVR dose over the 6-month period October to March (Diffey, 2002c). We wanted to focus on actual continuous UVR exposure measurements and to examine seasonal UVR exposure variations during risk and non-risk behaviour all year round.

Own investigations and discussion

In Paper VII we have focused on the UV radiation received by Danish indoor workers, in and out of Denmark, as well as during the winter compared to the summer. The total ambient UVR dose during the winter in Denmark at 56°N was 394 standard erythema doses (SED) or 10.5% of the annual ambient UVR dose. In winter compared to summer the subjects had: 1) a lower percentage of ambient UVR, 0.82% vs. 3.4%; 2) a lower solar UVR dose in Denmark, 3.1 SED (range, 0.2-52 SED) vs. 133 SED (range, 69-363 SED); 3) less time outdoors per day with positive dosimeter measurements, 10 min vs. 2 h; and 4) no exposure (0 SED) per day on 77% vs. 19% of the days. In comparison, sun holidays outside Denmark during the winter gave a median of 26 SED (range, 3-71 SED) per trip or 4.3 SED per day (range, 0.6-7.6), which was more UVR in one single day than the total UVR dose received during the course of a winter in Denmark.

As a consequence, the total annual UVR dose received by the population sample comprised: 2.6% during solar exposure over the winter in Denmark; 75.6% during solar exposure during the summer in Denmark, and 21.8% on holidays out of Denmark or from sunbed use. The annual UVR dose obtained by Danish indoor workers varied considerably. The annual solar UVR dose received outdoors in Denmark was a median of 168 SED (range, 69-378 SED) giving a five-fold UVR dose variation among the subjects. However, an almost ten-fold UVR dose variation in annual UVR dose was found, 215 SED (range, 70-659 SED), if the UVR doses received from sunbeds and during holidays to sunny countries were added. Some individuals received a 2-3 times higher or lower UVR dose than the median; not just the total dose, but also consistently on a day-to-day basis as also found in previous studies (Vishvakarman et al, 2001; Kimlin et al, 1998, Diffey et al, 1996), (Paper III and VII). If this exposure pattern is continued throughout life it will influence the chances of developing UVR-induced skin cancer. It is therefore important to identify people with high UVR load, and try to motivate them to change their UVR exposure behaviour. However, the low ambient UVR dose and the few hours spent outdoors during daylight hours in winter imply that Danish indoor workers receive only a negligible UVR dose from winter solar exposure. These doses do not represent a risk of skin cancer but create concern about insufficient skin vitamin D production (Brot et al, 2001).

UVR EXPOSURE AND SUNBURN

Previous studies

A goal in skin cancer reduction and protection is to identify the individuals with high UVR exposure and among them particularly those with a low erythema threshold. In lack of methods to actually make population based objective measurements of sun exposure, sunburn number and severity is used as a surrogate endpoint to identify those people. Contrary to skin cancer that takes years to develop, sunburn is a side effect of UVR exposure, which can be seen within 24 hours.

Sunburns play an important role in the development of skin cancer, especially malignant melanoma (Elwood and Jopson, 1997; Armstrong and Kricker, 2001). The relationship between sunburn and phenotype, age, sex, and behaviours that place a person at risk of sunburn has been reported by many researchers, who conducted retrospective interviews or self-reported surveys (Østerlind et al, 1988; Westerdahl et al, 1994; Stott, 1999; Purdue et al, 2001; Davis et al, 2002), these studies are subject to recall bias. In an Australian study adolescents used polysulphone badge dosimeters. The UVR exposure behaviour and sunburn was registered over 4 weekend days in late spring showing a positive association between UVR dose and occurrence of sunburn. Comparing the odds of sunburn among those with a UVR dosimeter reading in the highest third with odds of sunburn among those with a dosimeter reading in the lowest two third gave an odds ratio OR = 14.8 (Dwyer et al, 1996). Also an electronic UVR dosimeter-based investigation of the connection between UVR exposure dose, hours of exposure and use of sunscreen during sunbathing showed a positive association between UVR dose per sunbathing day and occurrence of sunburn (Autier et al, 2000). We aimed at identifying groups inclined to sunburn by age, skin type, and type of work. In addition, we wanted to characterize a sunburn day objectively by the UVR dose received at different times of the day, number of UVR exposure hours during the whole day, between 12:00 and 15:00, ambient UVR, and the type of behaviour.

Own investigations and discussion

In our prospective study, (Paper IV), 59% of the subjects had at least one sunburn, which is significantly higher than was found in a Danish population study on sun behaviour where only 28% recalled having been sunburned (Danish National Board of Health, 2000). However, a Swedish study reported that people underestimate the number of sunburns when recalling (Brandberg et al, 1997). Among our subgroups, golfers and gardeners had the lowest number of sunburns and also the lowest number of days with risk behaviour. Adolescents had the highest number of sunburns: 64% experienced sunburn, and 32% had 3 or more per season as a consequence of a high number of days with risk behaviour. Our data showed that sunburn and UVR dose per sunburn day peaked at the age of 20 and decreased with age in adults, which is in agreement with other studies (Stott, 1999; Boldeman et al, 2001). Even among children, 50% reported sunburn, while in the Danish population study (Danish National Board of Health, 2000), only 16% of the parents interviewed recalled that their children had been sunburned the summer in question. In a follow up study in 2004, only 14% recalled that their children had been sunburned (Danish National Board of Health, 2005). An explanation for this discrepancy with our results could be that sunburn in children is a sign of parental negligence and therefore unconsciously underestimated.

Paper IV, Table 2 shows that the subjects received the double UVR dose on sunburn days compared to non-sunburn days with risk behaviour (median 5.6 SED vs. 2.2 SED, P<0.01) and had significantly more sun exposure hours (median 6.4h vs. 4.5h). In addition, the subjects more often applied sunscreen on sunburn days, and the highest UVR doses were found on sunburn days with sunscreen applied (Paper V, Table 5). This indicates that sunburns occur when people know they will engage in risk behaviour and expect extended UVR exposure, but 1) the sun protection factor of the sunscreen they used was too low, 2) the sunscreen layer was too thin or unevenly spread, or 3) the sunscreen was applied only when being in the sun rather than before (Bech-Thomsen and Wulf, 1992; Wulf et al, 1997; Diffey, 2001; Robinson and Rademaker, 1998; Taylor and Diffey, 2002).

The study showed that a typical day when sunburn occurred in Denmark was a day off (91%) in May through July (90%) with risk behaviour (79%) and a median of 6.4 hours' exposure, of which 2.8 hours fell between 12:00-15:00. During a sunburn day, there was a high ambient UVR dose (>25 SED) of which the participants received a median of 21%. Sunburn is thus primarily occurring on hot unclouded days off in the summer during risk behaviour since a great part of the body is sun exposed for several hours. Secondly, during outdoor work or other long lasting outdoor activities such as golf. It also indicates that people at our latitude without outdoor work only get sunburned on workdays if they take part in outdoor activities for several hours mainly around noon.

Males reported more sunburn than females in the Danish retrospective interview study (Danish National Board of Health, 2000 and 2005). While our results based on daily diary reports showed more sunburns in female subjects than in male (P<0.01) both in the total group as well as in the age-related group of children, adolescents and indoor workers. As 79% of the sunburns occurred during risk behaviour, this finding suggests women and girls engage in more risk behaviour than men and boys. As sunburn episodes are often linked to malignant melanoma, the higher sunburn rate among females might explain the higher incidence of malignant melanoma in women (Danish National Board of Health, 2004).

Identifying the differences in exposure among those, who experienced sunburns and those who did not, although they performed risk behaviour, could be a way to find focus points for future sun protection campaigns. Paper IV, Table 4 shows that the 127 participants without sunburns had significantly fewer risk behaviour days compared to the 173 with sunburn (13 days vs. 16 days, P<0.01), and significantly lower UVR dose on risk behaviour days (2.8 SED vs. 3.6 SED, P<0.01), however, no significant differences in UVR dose per day or annually. In addition, the non-sunburned did also apply sunscreen on significantly fewer days than the sunburned (2 days vs. 7 days, P<0.01). Campaigns to prevent sunburns should thus aim at reducing the UVR peak doses by reducing the number of days and noon hours exposed with risk behaviour. The campaigns should be directed at adolescents, young adults, and sun worshippers, as they were the groups with most risk behaviour. Among golfers and gardeners campaigns to prevent sunburns should emphasize the importance of protecting the face, neck, and arms during extended sun exposure.

UVR EXPOSURE AND SUNSCREEN

Previous studies

It has been demonstrated that daily sunscreen use prevent the development of squamous cell carcinomas (Green et al, 1999) but, it is still discussed whether the use of sunscreen per se actually reduce or increase the melanoma incidence. An increasing incidence of melanoma due to sunscreen use has been argued (Westerdahl et al, 1995; Østerlind et al 1988). Two recent meta-analyses have been inconclusive as to whether the use of sunscreen is a risk factor rather than a protective factor for melanoma (Dennis et al, 2003; Huncharek et al, 2002). However, as uniformly shown in prospective controlled sunscreen trials (Naylor et al, 1995; Thompson et al, 1993; Gallagher et al, 2000) sunscreen use gives skin cancer protection and reduces the lifetime UVR dose. Applying sunscreen is the only way available to reduce the UVR dose and prevent sunburns, if a person wants to sunbath in full sun. Several case control studies had argued that the use of sunscreen encouraged people to stay out longer in the sun (Autier et al, 2000; 2001; Westerdal et al; 1995). However, this viewpoint is not supported by findings from a Danish interview study among 808 Danish beachgoers, where sunscreen use was found not to influence mean exposure time (203 minutes) at the beach (Stender et al, 1996). Thus it seems that other factors than use of sunscreen determine the duration of sun exposure. We therefore wanted to enlighten the reason for sunscreen use and in a real-world setting we measured the UVR exposure dose and behaviour in conjunction with sunscreen use.

Own investigations and discussion

Our findings about the connection between sunscreen use and UVR exposure are described in Paper V. We found great variations in sunscreen use within and among our subgroups. Sunscreens were applied in a median of 5 days per sun-year (range, 1 day among gardeners to 16 days among sun worshippers). Ten percent of females and 41% of males never used sunscreen (range, 9% among children to 45% among gardeners). Sunscreen use was correlated with risk behaviour (sunbathing or exposing the upper body) ($r = 0.39$; P<0.001), and more than half of the subjects only applied sunscreen during risk behaviour. Females used sunscreens on more days but also had more risk behaviour days without sunscreen protection than males (8 days vs. 4 days; P<0.001). This could give the false impression that sun worshippers, mainly females, were better protected during UVR exposure than e.g. the gardeners, mainly males, who seldom used sunscreen but had less risk behaviour. Sunscreen use was not correlated with age and a disturbing fact uncovered was that children had as much unprotected risk behaviour as adults. On the days with risk behaviour the participants applied sunscreen more often in Southern than in Northern Europe (86% vs. 20% of the days; P<0.001). The UVR doses received on the UVR dosimeter were significantly higher on days when sunscreen was applied (P0.03). In Paper III we revealed that high UVR doses were correlated with risk behaviour, and further more that people usually get small UVR doses on days without risk behaviour. The practice of using sunscreen during risk behaviour only seems very sensible, however, the problem is to persuade people to use sunscreen on *all* days with risk behaviour.

Why apply sunscreen?

It has been argued whether sunscreen is used as a tanning aid to avoid sunburn, as a remedy to be able to stay out longer in the sun or as a way to reduce exposure dose. A recent randomized controlled study tested the impact of high protection sunscreens on sun exposure behaviour in French seaside resorts finding no differences in exposure time whether a high protection or basic protection sunscreen was applied (Dupuy et al, 2005). It was reported that 96% of this population sample, which mainly comprised middle aged women, intended to get a tan during their summer vacation week. These participants viewed sunscreen more as tanning aid to avoid sunburn than as a way of limiting UVR exposure. This theory is supported by our findings that sunscreen was much more frequently used by the subjects during risk behaviour, especially in southern Europe. This may indicate that people know they will be exposed to high UVR doses and thus apply sunscreen to avoid sunburn and then as a result reduce their UVR dose. Thus, sunscreen use is often associated with intentional tanning and can be associated with high

UVR exposure. This viewpoint is strengthened by the fact that the subjects in our studies who applied sunscreen on most days were also the subjects with most days with risk behaviour. This excess UVR exposure may increase the risk of skin cancer and may occasionally result in sunscreens being misidentified as a risk factor for skin cancer (Autier et al, 1995; Beitner et al, 1990; Graham et al, 1985; Westerdahl et al,1995; Autier et al, 1998). Based on our results and the data from Dupuy's group, it has been argued that the truth is rather that sunscreens sometimes could be identified as a marker for those having a high UVR exposure and thus also at risk for receiving the highest carcinogenic doses of UVR (Naylor and Robinson, 2005; Robinson, 2005).

As presented in Paper VII, it should be kept in mind that sunscreen is not needed during solar exposure in the winter half year from October to March at latitudes above 50° as in Denmark, since the UVR doses received during this period are negligible (Paper VII); (Wulf, 1994; Diffey, 2002c). In addition no UVR precautions are needed from November to February during holidays to latitudes above 45°, while precautions are needed the whole year around at lower latitudes.

CONCLUSIONS

THE MAIN CONCLUSIONS FROM THE NINE STUDIES INCLUDED IN THIS THESIS

UVR dose range

There was a huge variation in annual UVR exposure dose within the total population sample, median 173 SED (range, 17-980 SED). A similar variation range was found within all the subgroups. The inter-group variation in annual UVR dose was from median 132 SED among indoor workers to median 224 SED among gardeners. The intra-group variation was thus greater than the inter-group variation.

Age

There was no significant correlation between age and annual UVR dose either within the total population or among the adults. However, among the subjects below 20 years of age we found an increase in annual UVR dose of 5 SED more per year. There was a trend towards a higher UVR exposure among adults in the early twenties or above fifty before or after the child-raising age.

Lifetime UVR dose

Young people before the age of 20 years did not get a higher proportion of lifetime UVR than expected corresponding to their age.

Sex

There was no significant difference in annual UVR dose between males and females in the total population sample. But, among children, girls received a significantly higher UVR dose than boys due to more days with risk behaviour. This exposure pattern, with women having more UVR peak days than men, was also found among adolescents and adults.

Skin type and PPF

There was a trend towards higher UVR exposure with increase in skin type. Skin type IV had a significantly higher UVR exposure than skin type I to III. The higher the pigment protection factor, PPF, measured on the shoulder before the summer season, the more time had people spent in the sun with risk behaviour.

Workdays

The age-span group (Indoor workers, children and adolescents) did only receive a median of 12-22% of their total measured UVR dose on workdays (schooldays). The UVR dose received on workdays adds thus very little to the cumulative UVR dose.

Outdoor workers: The gardeners received the main part of their UVR exposure on workdays. Postponing the indoor lunch break to start at noon was calculated to give a reduction in UVR exposure of at least 10% among Danish gardeners.

Days off

On days off, which represented 48% of the participation days, 76% of the total UVR dose was received. The range was from 42% among gardeners to 87% among adolescents.

On days off with non-risk behaviour, which represented 37% of the participation days, 27% of the total UVR dose was received. Only the golfers received the main part of their total UVR exposure, 49%, on days off without risk behaviour.

On days off with risk behaviour, which represented 9% of the participation days, 36% of the total measured UVR dose was received. Children, adolescents and sun worshippers received respectively 51%, 68% and 60% of their UVR dose during days off with risk behaviour.

Risk behaviour in summer in Southern Europe: The subjects travelling to Southern Europe received in a median of 6 days at the beach 44 SED, or 25% of the annual UVR dose. The children received 63 SED and adolescents 85 SED or 44% of the annual UVR dose at the beach in Southern Europe.

On sun holidays during the winter out of Denmark: Sun holidays in autumn and spring in the Mediterranean area and in winter in tropical areas gives UVR doses per day corresponding to a summer day in Denmark.

Sunbed use

Sunbed users received a 21% higher annual UVR dose and had 66% more risk behaviour days than non-sunbed users.

UVR dose ≥10 SED/day

High UVR doses are linked to risk behaviour as 87% of the days with UVR doses above 10 SED were with risk behaviour.

UVR dose at noon

Fifty percent of the total measured UVR dose was received between 12:00-15:00.

Seasonal variation

Indoor workers received a negligible UVR dose from solar exposure in Denmark in the winter-half-year.

Sunburn

Sunburns were highly correlated to risk behaviour. Sunburns were not found during breaks on normal indoor workdays (schooldays).

Sunscreen use

Days with sunscreen correlated with days “sunbathing with the intention to tan,” indicating that sunscreen was used to avoid sunburns. The subjects having most risk behaviour days were also the subjects applying sunscreen on most days. However, sunscreen was only applied on 30% of the risk behaviour days.

Study compliance

In long lasting UVR dosimeter studies, high subject compliance rate and data reliability were obtained by 1) being service minded but persistent, 2) using a dosimeter easy to wear and offering dosimeter maintenance service within 24 hours, 3) using a simple diary form, and 4) scrutinizing data for errors and mistakes just after they were collected.

UVR PROTECTIVE CONSIDERATIONS

AMERICAN DERMATOLOGISTS’ SUGGESTIONS FOR REDUCING LIFETIME UVR DOSES

Based on our Paper V and the studies by Dupuy et al, 2005; and Mahler et al, 2005, the American dermatologists Mark Naylor and June Robinson, made the following suggestions to reduce UVR exposure in an editorial in Archives of Dermatology (Naylor and Robinson, 2005):

"The sun-protection program is just now beginning to experiment with cost-effective, evidence-based approaches, such as the use of UV photographs to change attitudes and the use of sunless tanning lotion to change sun-protection behaviours (Mahler et al, 2005). We are moving beyond reliance on knowledge-based information provided by the media toward empowering people with the tools to change. Our sun-protection campaign is ready to move from preaching to teaching. Individual empowerment strategies may be borrowed from the methods physicians use with their patients to enable smoking cessation. These adapted sun-protection strategies are as follows:

1. Set a date to stop deliberate tanning.
2. Review past experiences with sunburns and unprotected exposure to find what worked and what did not. Use past behavior to predict future behavior and suggest ways to use sun protection in the future.
3. Anticipate the challenges and develop strategies to overcome them. For instance, if a pale appearance does not look healthy to the individual, then help him or her learn how to use self-tanning lotions, or to substitute weight loss and exercise as a healthy alternative for enhancing self-esteem and pride in physical appearance.
4. Make a pact with other family members in the household to use sun protection and to remind each other to use it. Daily reinforcement from others in the household is a powerful influence.

These measures can and should be carried out for individual patients. It will be more difficult to change public attitudes, which create the milieu for high-risk behavior. It is time that physicians, public health officials, and the public commit to a long-term national strategy that will begin to change public opinion and reverse the current trend of increasing skin cancer prevalence."

SUN ADVICE GIVEN BY DANISH CANCER SOCIETY 2006

The four sun advice given in Denmark inspired by the WHO's recommendations are short and sensible:

1. Avoid the midday sun
2. Stay in the shade
3. Put on light clothes
4. Apply sunscreen

The UVR exposure data obtained from the studies of this thesis reveal for the first time the objective connection between UVR exposure behaviour and the resulting UVR dose among individuals. These UVR exposure data indicate that the sun advices are not followed, as 50% of the UVR dose is received around noon and sunscreen is only applied on 30% of the days with risk behaviour (Paper III and V).

OWN SUGGESTIONS FOR REDUCING LIFETIME UVR DOSES

As Naylor and Robinson, I find that the best way to reduce harm from UVR exposure is to create UVR exposure strategies rather than just preaching abstinence from sun exposure. It may seem easier to comply with sun reduction strategies in Denmark with its comparatively few days with high ambient UVR doses. However, the Scandinavians seek to the beaches when a "hot" and unclouded summer day arises, as it is hard to say if tomorrow brings another day of beach weather. This risk behaviour often without UVR protection leads to high intermittent UVR exposure, known to provoke malignant melanoma (Elwood and Jopson, 1997; Armstrong and Kricker, 2001). Along with their fair skin colour, this UVR exposure pattern may be the reason why the Scandinavians peak the malignant melanoma curve (DeVries and Coebergh, 2004).

The UVR exposure data from the studies in this thesis suggest that small changes in the UVR exposure pattern can give large reductions in UVR dose. A more balanced description of which situations people actually receive high UVR doses and what could be gained in dose reduction by changing sun exposure habits are therefore needed. Especially among Scandinavians and other Northern Europeans to emphasize that to reduce lifetime UVR dose it is necessary to either reduce time with risk behaviour or to reduce the UVR dose transmitted into the skin during risk behaviour by sun protection means such as seeking shade, using clothes, hats, or sunscreens.

A slogan for an UVR reduction campaign could be:
When you take off your clothes – you get high UV dose!

IF PEOPLE STILL WANT TO STAY IN THE SUN,
WAYS TO REDUCE THE UVR EXPOSURE DOSE

- Concentrate on sun exposure reduction and sun protection on days off with risk behaviour, when the main part of the annual UVR dose is received.
- Reduce time with risk behaviour during high UVR intensity, or perform risk behaviour at times when UVR intensity is lower.
- Schedule breaks indoors or in the shade if sunbathing during high UVR intensity.
- Postpone sun holidays to August or September when ambient UVR is reduced to 66%-50% compared to June and July.
- Schedule breaks and meetings indoors at UVR peak hours.
- Apply sunscreen on all days with risk behaviour or during long lasting outdoor activities.
- Learn proper use of sunscreen.
- Avoid sunbed use, as it adds to the cumulative UVR dose.

On basis of these advices people will be able to create their individual UVR strategy in summer in Northern Europe or during sun holidays the year round, so they can enjoy sun exposure without exceeding the UVR threshold doses

FUTURE RESEARCH

Through the nine studies performed we have gained new insights and a better understanding of the relation between UVR exposure and behaviour in different age and occupation groups. However, new questions have also been raised, which will, hopefully, be answered in future studies as suggested below:

- A follow-up study among a group of our participants to further examine if sun exposure behaviour is constant throughout life.
- A follow-up study among a group of our participants with either high-UVR-dose or low-UVR-dose in summer to investigate a possible influence of summer UVR doses on vitamin D level in winter.
- A UVR dosimeter study investigating if Scandinavians moving to the Mediterranean area changed their sun behaviour to match that of the Mediterranean's, avoiding sun exposure around noon.
- Continuous UVR dosimeter studies in countries with high year-round ambient UVR.
- A worldwide, prospective, multicenter, UVR dosimeter study investigating differences and similarities in young Caucasians' sun exposure behaviour at different latitudes.
- A behavioural study to identify role models for tailoring sun smart UVR exposure strategies by comparing people who do risk behaviour without applying sunscreen and without getting sunburned with people who are getting sunburned although they apply sunscreen.
- A study to identify people with a high risk for skin cancer based on the collected UVR data and phenotypic characteristics, with the purpose of revealing a special UVR risk exposure pattern.
- A UVR dosimeter study of UVR exposure and behaviour in a rural population.
- A UVR dosimeter study of UVR exposure and behaviour among

people with cutaneous malignant melanoma (CMM) and basal cell carcinoma compared to matched controls.
- UVR dosimeter study of the solar UVR exposure in a group of heavy sunbed users compared to a group of sun worshippers but non-sunbed users.
- An electronic UVR dosimeter study with dosimeters placed both on the chest and the back to investigate the preferable orientation towards the sun and its possible influence on the UVR dose received among people with known high or low UVR exposure dose.
- A study investigating if use of modern sunbeds with only small amount of UVB could raise the vitamin-D level in the blood.
- To develop models for individual skin cancer risk assessment.

SUMMARY IN ENGLISH

Solar ultraviolet radiation (UVR) is known to be the most important etiological factor in skin cancer development. The main objective of this thesis was to achieve an objective, basic knowledge of the individual UVR exposure dose pattern and to reveal the factors and with which power they influence on the UVR dose among the Danes. Eight open prospective, observational studies and one study analyzing the compliance and reliability of data were performed in healthy Danish volunteers with an age range of 4-68 years. The subjects were chosen to cover an age span group of children, adolescents, and indoor workers and in addition, groups with expected high UVR exposure, sun worshippers, golfers, and gardeners.

We developed a personal, electronic UVR dosimeter in a wristwatch (SunSaver). The subjects wore the UVR dosimeter that measured time-stamped UVR doses in standard erythema doses (SED) and completed diaries with data on their sun exposure behaviour. This resulted in corresponding UVR dosimeter and diary data from 346 sun-years where one sun-year is one person participating in one summer half-year (median 119 days). The annual UVR doses were calculated based on the personal and ambient measured UVR doses.

We found a huge variation in annual UVR exposure dose within the total population sample, median 173 SED (range, 17-980 SED). The inter-group variation in annual UVR dose was from median 132 SED among indoor workers to median 224 SED among gardeners. No significant correlation was found between annual UVR dose and age either within the total population or among the adults. But the subjects below 20 years of age had an increase in annual UVR dose of 5 SED per year. Young people before the age of 20 years did not get a higher proportion of the lifetime UVR dose than expected (25%) when assuming a life expectancy of 80 years. There was no significant difference in annual UVR dose between males and females in the total population sample. But, among children, girls received a significantly higher UVR dose than boys due to more days with risk behaviour (sunbathing or exposing shoulders outdoors). This exposure pattern, with females having more risk behaviour than males, was also found among adolescents and adults. Sunbathing or exposing shoulders (risk behaviour) outside the beach resulted in a median of 2.5 SED per day in northern Europe and 3.2 SED per day in southern Europe, while the corresponding values were 4.6 SED and 6.9 SED per day at the beach. UVR doses above 10 SED per day were connected with risk behaviour. The subjects had a median of 13 days with risk behaviour (range, 0-93 days). The subjects used sunscreen on a median of 5 days (range, 0-130 days), but have a median of 7 days with risk behaviour without sunscreen applied (range, 0-47 days). They had a median of 1 sunburn per sun-year (range 0-10). Fifty percent of the UVR dose was received between 12:00 –15:00. Only the gardeners received the main part of their UVR dose on workdays.

CONCLUSIONS

- High UVR doses are connected with risk behaviour. Reduction of cumulative lifetime UVR dose could be obtained by minimizing risk behaviour.
- Sunburns were highly correlated to risk behaviour.
- Use of sunscreen correlated with days “sunbathing with the intention to tan,” indicating that sunscreens were used to avoid sunburn during risk behaviour.
- Scheduling lunch breaks and other breaks indoors at noon, where ambient UVR peaks, could reduce the occupational UVR exposure significantly.
- In the winter-half-year in Denmark the UVR dose received from solar exposure is negligible and no UVR precautions are needed.

This study documented that high subject compliance rate and data reliability could be obtained in long-time UVR dosimeter study as ours by being service minded but persistent, offering dosimeter maintenance service within 24 hours and scrutinizing data for errors and mistakes just after data collection.

ABBREVIATIONS AND DEFINITIONS

ACGIH: The American Conference of Governmental Industrial Hygienists.

BCC: Basal cell carcinoma of the skin.

CMM: Malignant melanoma of the skin.

CIE: Commission International de l’Eclairage (The International Commission on Illumination).

Constitutive pigmentation: Skin pigmentation on UVR unexposed skin on the buttock.

Day off: Day where a subjects has crossed “no” in the diary to be at work (for children and adolescents in school or kindergarten). We do not discriminate between weekends and holidays.

Facultative pigmentation: Acquired skin pigmentation obtained by UVR exposure.

IARC: International Agency for Research on Cancer.

IQR: Inter quartile range: from 25% to 75%.

MED: Minimal erythema dose in an individual is the dose necessary to elicit just perceptible erythema 24 hours after UVR exposure.

Participation days: Number of days a subject participated in the study per sun-year.

PPF: Pigment protection factor, an objective measure of the photo protection afforded by skin pigment and stratum corneum corresponding to the unexposed buttock. PPF corresponds to the number of SED (Standard erythema dose) expected to induce just perceptible erythema by a MED photo-test on the buttock.

Risk behaviour: Day where a subjects has crossed “yes” in the diary to have: Sunbathed in the sun (or used sunbed) with the intention to tan OR exposed the upper body or at least the shoulders in the sun.

SCC: Squamous cell carcinoma of the skin.

SED: Standard erythema dose. 1 SED = 100 J/m^2 at 298 nm using the CIE erythema action spectrum. It is equivalent to the UVR dose needed to provoke a just perceptible erythema of white skin in the most sensitive of a group of people 24 hours after exposure.

Skin type: Self-reported skin type (Fitzpatrick, 1988) based on what a person recalls as his typical reaction to 2h (in Denmark) of unprotected sun exposure first time in summer according to the following classification: Skin type I; Always burn, never tan; Skin type II: Usually burn, tan less than average (with difficulty); Skin type III: Sometimes mild burn, tan about average; Skin type IV: Rarely burn, tan more than average

	(with ease); Skin type V: Brown-skinned people; Skin type VI: Black-skinned people.
SPF:	Sun protection factor (used to mark sunscreens protection capacity). The higher the factor – the higher the protection.
Sunburn day:	A day where a subject had crossed "yes" in the diary to have been sunburned.
Sun-year:	Subjects are referred to as sun-years, as some of the subjects participated for 2 or 3 years. 1 Sun-year is 1 subject participating in 1 summer half-year (of median 119 days; range 32-176 days).
SunSaver:	Personal, electronic UVR dosimeter developed in the department of dermatology, Bispebjerg Hospital, Copenhagen, Denmark.
UVA:	Long wave ultraviolet radiation with a wavelength of 315-400 nm.
UVB:	Mid-wave ultraviolet radiation with a wavelength of 280-315 nm.
UVC:	Short-wave ultraviolet radiation with a wavelength of 100-280 nm.
UVR:	Ultraviolet radiation with a wavelength of 100-400 nm.
Workday:	Day where a subjects has crossed "yes" in the diary to have been at work (for children and adolescents in school or kindergarten).

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