Sunscreen use at Danish beaches and how to improve coverage

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This review has been accepted as a thesis together with four original papers by University of Copenhagen 21th of December 2017 and will be defended on 8th of May 2018

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Dan Med J 2018;65(4):B5476

The four original papers are:

I. Heerfordt IM, Philipsen PA, Wulf HC. Sun behaviour on the beach monitored by webcam photos. Public Health 2018 Jan 9;155:88-90. (1)

II. Heerfordt IM, Philipsen PA, Larsen BØ, Wulf HC. Long-Term Trend in Sunscreen Use among Beachgoers in Denmark. Acta Derm Venereol 2017 Nov 15;97(10):1202-5. (2)

III. Heerfordt IM, Torsnes LR, Philipsen PA, Wulf HC. Sunscreen use optimized by two consecutive applications. Submitted.

IV. Heerfordt IM, Philipsen PA, Wulf HC. How useful is the advice: "Fill up a handful of sunscreen and spread it all over your body"? To be submitted.

BACKGROUND

Prevention of skin cancer

Exposure to solar ultraviolet radiation (UVR) is the main risk factor for developing skin cancer. This applies to all the common skin cancer types: cutaneous malignant melanoma (CMM), basal cell carcinoma (BCC), and squamous cell carcinoma (SCC) as well as actinic keratosis (AK), a precursor to SCC (3-6). CMM, being the most lethal of the 3 tumor types, is probably primarily provoked by high intermittent UVR doses (7;8). BCC is probably mostly triggered by high intermittent UVR doses as well, whereas SCC is most often provoked by cumulated UVR exposure (9-11). Consequently, it is advisable both to avoid sunburns and to reduce the received lifetime cumulative UVR dose (12).
To prevent skin cancer the World Health Organization (WHO) and many other health organizations recommend that the general population limit their exposure to UVR by seeking shade, avoiding sun exposure around noon, wearing protective clothes, and applying sunscreen (12;13). A campaign started by "Center for Disease Control and Prevention" (a United States federal agency, www.cdc.gov) has focused on increasing the amount of sunscreen used by introducing the following rule of thumb: "Fill up a handful and spread it all over your body. Yes, we said "handful". You need that much for good coverage" (14). This instruction has also been adopted by other local campaigns (15;16). The idea is that the size of a hand increase with increasing body size. It is believed that the recommendation is easy to understand and the goal is that sunscreen users should apply 2 mg sunscreen per every cm² skin accessible (17). It has, however, to our knowledge never been tested how this advice works in practice.
In 2016 a Cochrane systematic review searched for randomized trials assessing the effect of sun protection on the prevention of keratinocyte carcinomas (18). The study only found one suitable trial on sunscreen use but found no studies investigating the effect of protective clothing or seeking shade.

Shade and clothing

Shade will protect a person from direct sunlight but the person is still affected by indirect UVR which is between 50% and 95% of the total UVR, depending on the type of shade (19). The view of visible sky from the shade is related to the amount of indirect UVR received (20). Thus a beach umbrella offers only limited sun protection and beachgoers using beach umbrellas as the only protection often get sunburned (21). The shade from large trees provides much more effective protection than a beach umbrella (19). Generally, people who report to seek shade often on sunny days also report fewer sunburns (22). The same applies to wearing clothes, which is also related to a decreased risk of sunburns (22). Different textiles offer very different protection, depending on textile type and colour. The protection corresponds to between less than SPF 5 or more than SPF 50 (23;24). There are many different ways to label UVR protective clothes and no labeling is mandatory (12). Users can only make a guess of the degree of protection.
Sun protection is most essential around noon where UVR is most potent (25). In addition to shade and clothing, sunscreen can be used as sun protection.

Sunscreen

Numerous observational studies have investigated sunscreen's potential to prevent skin cancer and have reported different results (26). It is very difficult to study the effect of sunscreen in an observational study design due to the many confounders influencing both sunscreen use and skin cancer risk, e.g. extensive sun exposure, light skin colour, and family history of skin cancer (27;28). A randomized controlled design is essential to get an unbiased result. To date, only one randomized controlled study of sunscreen use and skin cancer risk has been performed involving 1,621 participants from the general population in Nambour (Australia) (29). The study compared daily sunscreen application with optional sunscreen use over a period of 4.5 years and found sunscreen capable of preventing CMM and SCC but not BCC (30-32). The results of the study are listed in **Table 1**. Sunscreens have also proved to delay the formation of AK (33;34).

TABLE 1: *Effect of daily sunscreen use on development of skin tumours (30;31). There were just as many participants in the group randomized to daily sunscreen use as to the group with no daily sunscreen use. The participants applying sunscreen daily developed fewer SCCs and CMMs than the participants with no daily sunscreen use. The formation of BCC was similar in the two groups (30;31). Abbreviations: BCC = basal cell carcinoma, SCC = squamous cell carcinoma, and CMM = cutaneous malignant melanoma.*

Skin cancer type	**Number of developed tumours**	
	Daily sunscreen use	No daily sunscreen use
BCC	153	146
SCC	28	46
CMM	12	23

The effect of sunscreen is entirely dependent on its use. Obviously it has no effect on skin areas not covered (missed areas). On covered areas the labeled sun protection factor (SPF) and the applied quantity of sunscreen determine the effect. Therefore, it is important to be able to investigate the distribution of sunscreen on the body. Previous studies have estimated the applied quantity of sunscreen containing fluorescent dyes by measuring fluorescence intensity (35-37). Another study investigated the skin in black light to determine the size of areas left without sunscreen (38). In this thesis we introduce the use of sunscreen's ability to absorb black light to determine the size of skin areas left without sunscreen as well as quantities of sunscreen applied at specific skin sites.
The ability of sunscreen to prevent sunburn is tested after application of a quantity of 2 mg sunscreen per cm^2 skin and is labeled at the sunscreen bottle as SPF. For example, if a quantity of 2 mg/cm^2 sunscreen is labeled as "SPF 20" it means that 95% of the burning UVR is blocked and 5% (1/20) is transmitted to the skin. As a consequence the skin can tolerate a 20 times larger UVR dose without getting sunburned compared to the same skin without sunscreen (39). In real life situations sunscreen is often applied in a quantity of around 0.5 mg/cm^2 which is much less than 2 mg/cm^2 (40). Participants in the skin cancer prevention trial in Nambour (Australia) applied a median quantity of 0.79 mg/cm^2 (41). The effect of sunscreen decreases with decreasing applied quantities (42). The effective SPF is 1 when a sunscreen quantity of zero is applied corresponding to an unchanged skin tolerance to UVR. The relation between effective SPF and applied sunscreen quantity has been investigated in 6 human *in vivo* studies listed in **Table 2**.

TABLE 2: *A summary of studies investigating the relationship between effective sun protection factor (SPF) and applied quantity of sunscreen. The exponential relation between effective SPF and applied quantity fits better than the linear model when the applied quantities of sunscreen approaches zero.*

Study	**Number of tested sunscreens (SPF label)**	**Range of tested quantities, mg/cm^2**	**Found relation between effective SPF and quantity**	**Effective SPF according to the conducted model when the sunscreen quantity is zero**
(43)	3 (20-25)	0.5-2.0	Linear	Report 3 linear models with the following effective SPFs when the sunscreen quantity is zero: 0.3, 1.0, and 3.5
(44)	6 (30-50)	0.5-2.0	Linear	Report 6 linear models with the following effective SPFs when the sunscreen quantity is zero: -5, 0.1, 0.5, 1.3, 2.5, 2.7
(45)	4 (4-55)	0.5-2.0	Linear for label SPF 4-15. Exponential for label SPF 30-55	Effective SPF = 1.0
(42)	1 (4)	0.5-4.0	Exponential	Effective SPF = 1.0
(46)	3 (5-30)	0.5-2.0	Exponential	Effective SPF = 3
(47)	2 (30-35)	0.5-2.0	Exponential	Effective SPF = 1.0

Each of the studies found the best relation between effective SPF and applied quantity to be either a linear or an exponential model (42-47). As sunscreen is often applied in very small quantities close to zero it is important that the model fits for small applied quantities and the effective SPF approaches 1 when the applied quantity approached zero. The exponential relation between effective SPF and applied quantity fits better than the linear model for small applied quantities (**Table 2**). Consequently an exponential relation is assumed in this thesis, with the following exponential equation: Effective SPF = label SPF^(application quantity/(2mg/cm^2)) (42;46;47). Examples of effective SPF in different circumstances are shown in **Table 3**.

TABLE 3: *Interpretation of sun protection factor (SPF). The label SPF has only small impact on the percentage of burning ultraviolet radiation (UVR) blocked whereas applied quantity has a big influence.*

Label SPF	**Applied quantity, mg/cm^2**	**Effective SPF**	**Blocked UVR, %**
50	2.0	50.0	98

50	0.5	3.7	62
20	2.0	20.0	95
20	0.5	2.1	53
15	2.0	15.0	93
15	0.5	2.0	49

UVR doses can be measured in standard erythema doses (SED) which are weighted according to its potential to induce erythema in human skin (48). During a sunny summer day an average non-tanned Caucasian not using any sun protection becomes sunburned after approximately 30 minutes (corresponding to a UVR dose of about 3 SED) in the sun around noon (25;48;49). Uniform application of 0.5 mg/cm^2 sunscreen from a bottle with SPF labeled 20 will expand this period to about 63 minutes (25;42). People with lighter skin tolerate less UVR (down to 1 SED) whereas people with darker skin can tolerate more UVR (up to 20 SED) without getting sunburned (49;50). By getting tanned a person can resist approximately the double amount of UVR without getting sunburned (51). Tanned skin is also protected against DNA damage to a certain degree (52). Protecting against small quantities of UVR may also be advisable, as even doses too small to induce sunburn can induce DNA damage in skin cells (53). DNA damage is more frequently found in skin cancer and skin cancer precursors than in healthy skin (54;55).

Prevention of skin cancer in Denmark

The studies in the present thesis were conducted in Denmark, where the incidence of CMM is increasing and is among the highest in Europe (56;57). The registration of keratinocyte carcinomas is not consistent, but the incidence in Denmark is increasing and high, being by far the most common type of cancer in the country (58).

Two studies by Thieden et al. (59;60) investigated 340 Danes wearing personal electronic UVR dosimeters and found that many Danes had an intermittent sun exposure pattern and received a high proportion (approximately 30%) of their total annual UVR dose on 3 to 4 days a year only. The Danes often reported to have been on the beach on days with high UVR exposure (59). This thesis investigates how Danish men and women protect themselves against UVR on these risk days.

The increasing incidence of skin cancer in Denmark is seen in spite of an ongoing sun safety campaign directed at the general population since 2007 (61), a paradoxical situation also seen in other countries (56;62;63). To design and readjust future sun safety campaigns knowledge about the actual sunscreen use is valuable (64). Knowledge about sunscreen use is also important in order to evaluate the effect of sunscreen on Vitamin D photosynthesis and skin exposure to ingredients in sunscreen.

From direct measurements of sunscreen use at beaches in Denmark before launching of the campaign in 2007 it is known that beachgoers used very small quantities of sunscreen. In 1992, beachgoers applied a mean quantity of sunscreen of 0.49 mg/cm^2 calculated from weighing the sunscreen container before and after sunscreen application (65). In 1994, 65% of beachgoers at a Danish beach reported to have used sunscreen the actual day and stayed at the beach for about 3.5 hours in average (66).

After the launch of the Danish Sun Safety Campaign all information about sunscreen use in Denmark is based on questionnaire surveys which entails a risk of recall and social desirability bias (67). In this thesis direct measurements of sunscreen use after 2014 are presented (*Study II-IV*). Additionally, two methods for optimized sunscreen use are tested in practice (*Study III* and *IV*).

THESIS OBJECTIVES

The overall aim was to achieve basic knowledge about sun protection with sunscreen among beachgoers in Denmark. Other aims were to establish a method to investigate sunscreen distribution on the body and to test two approaches to optimize the used amount and body distribution of sunscreen. Furthermore time and duration of a beach visit and use of protective clothes among beachgoers were determined to investigate the risk the beachgoers expose themselves to.

Methods to obtain aims:

- Counting of beachgoers and cars parked at the beach to estimate time and duration of a beach visit.
- Asking beachgoers about sunscreen use on the actual day at the beach.
- Weighing of sunscreen containers before and after sunscreen application on the beach and in the laboratory.
- Establishing a link between changes in areas of darkness in pictures taken in black light and applied quantity of sunscreen.
- Evaluating sunscreen quantities applied at specific skin sites and size of skin areas left without sunscreen using a new established method for sunscreen distribution investigation.

MATERIALS AND METHODS

Study designs

The studies were classified according to Grimes's and Schulz's algorithm (68) for classification of research:

Study I: Observational, descriptive study.
Study II: Observational, descriptive study.
Study III: Experimental, non-randomized controlled trial.
Study IV: Experimental, non-randomized controlled trial.

Research approvals

Study III and *IV* were assessed by the Committee on Health Research Ethics in the Capital Region of Denmark (H-1-2014-094). The committee concluded that as the intervention in the project consisted only in application of regular sunscreen, no ethical approval was needed. The processing of information in *Study III* and *IV* was approved by the Danish Data Protection Agency (J.nr.: 2012-58-0004, I-Suite nr.:03553).

Study I and *II* were observational studies without any influences on the subjects. Therefore, it was not necessary to obtain any approval from the Committee on Health Research Ethics (H-17026711). Since *Study I* and *II* did not handle personal data the Danish Data Protection Agency has not been involved in this part of the project.

Settings and subjects

Study I and *II* are based on data from sunny days at beaches in and close to the city of Copenhagen Denmark, studying people who happened to be on the beach. *Study II* was conducted in 1997, 1998, 1999 and 2016 but only data from 2016 were included in the thesis. The studies were conducted in Danish summer time, where the UVR is strongest at 1 p.m. Weather data was extracted from The Danish Meteorological Institute (www.dmi.dk). *Study III* and *IV* were conducted in the laboratory at Bispebjerg Hospital (Denmark). Study settings are listed in **Table 4**.

TABLE 4: *Study settings and subjects.*

Study	Study years	Environment	Number of subjects	Subjects details
I	2014 and 2015	At the beach. Daily mean temperature at least 20°C. No rain. More than 10 hours of sunshine a day	2,259 beachgoers and 419 cars counted	All skin colours. All ages
II	2016	At the beach. Temperatures above 22°C. No rain	253 beachgoers in swimwear	Caucasian. 15 years or older
III	2015	Laboratory	31 partici-pants in swimwear	Caucasian. 18 years or older
IV	2017	Laboratory	17 partici-pants in swimwear	Caucasian. 18 years or older

Data collection

Sunscreen use

Frequency of sunscreen use and SPF chosen were determined by asking people at the beach. SPF was also registered by looking at sunscreen containers (*Study II*).

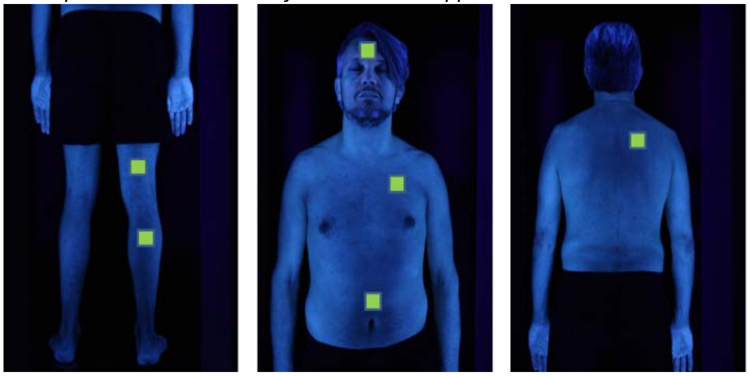
The total amount of sunscreen used by volunteers in swimwear was determined by weighing their sunscreen containers just before and after application, at the beach (*Study II*) as well as in the laboratory (*Study III* and *IV*).

Quantity of sunscreen applied to the skin was estimated using two different methods.

By one method the overall sunscreen quantity was calculated by dividing the total amount of sunscreen used with the skin area accessible for application. The total BSA was estimated by self-reported weight and height using Mostellers formula (69). The BSA not accessible for sunscreen application was calculated using Augustssons et. al model (70) for distribution of skin area on body parts to evaluate the size of the swimwear worn, soles of the feet, and area of scalp hair. The skin area accessible for sunscreen application was calculated by deducting the area not accessible from the total BSA.

By a new method established in *Study III* the quantity of sun-screen on specific skin sites was determined by changes in skin darkness in black light. Black light is absorbed by sunscreen, in-tensifying the skin darkness with increasing quantity of sunscreen. Pictures were taken in black light (TL08, Philips, The Netherlands) before and after each sunscreen application in *Study III* and *IV*. Pictures were taken with a digital camera (Canon EOS 450D, Canon Inc., Japan). The skin darkness was quantified using GIMP version 2.8.14 (www.gimp.org). *Study III* established a standard curve for the link between picture darkness and sunscreen quan-tity. This method made it possible to determine sunscreen quanti-ties at specific skin sites. In *Study III* and *IV* 6 skin sites of approx-imately 30 cm^2 each were investigated. The skin sites were varyingly difficult to cover with sunscreen and were the following: forehead, chest, upper back, belly, back of thigh, and back of lower leg, see **Figure 1**.

FIGURE 1: *Example of pictures of a volunteer taken in black light. Each of the 6 assessed skin sites are marked with a yellow square. These pictures were taken before sunscreen application.*



Additionally, the investigation in black light made it possible to quantify areas of skin left without sunscreen (missed areas). *Study III* and *IV* determined missed areas in total and in the following 11 body regions: face, ears, front of neck, back of neck, arms, back of hands, front of trunk, back of trunk, thighs, lower legs, and instep. Overview of collected data on sunscreen use is presented in **Table 5**.

TABLE 5: *Type of data collected on sunscreen use. Sunscreen quantities were measured in mg/cm^2. Abbreviation: SPF = sun protection factor.*

Study	Sunscreens studied	Overall sunscreen quantity	Missed areas, %	Specific sunscreen quantity
II	Participant's own	Collected	Not col-lected	Not col-lected
III	Actinica, SPF 50+ (Galder-ma, Switzer-land)	Collected	Collected	Collected
IV	Actinica, SPF 50+ (Galder-ma, Switzer-land)	Collected	Collected	Collected

Time and duration of beach visits and clothing worn

Clothing worn and time of beach visits were investigated using webcam photos. On sunny days the number of beachgoers was counted every hour and it was noted if they wore protective clothes or swimwear (*Study I*). The webcam was placed at the beach by the company Amager Strandpark I/S. From 2014 to 2015 the webcam took a single photo every 10 minutes of the beach and a parking lot on a sandy island in Copenhagen where the attraction is beach life, see **Figure 2**. The photos are accessible on amagerstrand.roundshot.com. It was possible to count the num-ber of beachgoers and register clothing on the photos, but identi-fication of individuals was not possible. Consequently, it was not possible to track individual beachgoers on the beach to determine the duration of their visit. Therefore, the duration of a beach visits were studied indirectly by looking at webcam photos every 10 minutes, observing car parking time. Cars observed at the same spot on 2 consecutive photos were defined as parked (*Study I*). We assume that the car parking time was identical to the dura-tion of a beach visit.

FIGURE 2: *Satellite image of Amager Beach from www.google.dk/maps. The studied beach is marked with a "B". The studied parking lot is marked with a "P". (55°39'16", 12°30'53").*

Interventions

Study I and *II* were conducted without intervention. In *Study II* beachgoers were asked to apply sunscreen as they would otherwise have done when at the beach. In *Study III* and *IV* participants were asked to follow the investigator's recommendations when applying sunscreen.

In *Study III* participants were asked to apply sunscreen as they would normally do on a sunny day at the beach in Denmark, but the participants were instructed to apply sunscreen two consecutive times with a 20 minutes interval. In this thesis the first application is called "single application". The two consecutive applications are called "double application". The sunscreen container was weighed before and after each of the two applications. The first application made it possible to check if the sunscreen used in the laboratory matched the amount used on the beach (investigated in *Study II*).

In *Study IV* participants were introduced to the rule of thumb and were asked to: "Fill up a handful of sunscreen and spread it all over your body".

Funding

Study I was conducted without funding. *Study II* was founded by the Danish Environmental Protection Agency (Denmark). Sunscreen for *Study III* was provided free of charge by Galderma Nordic AB. Except for this, *Study III* and *IV* were funded solely by Bispebjerg Hospital (Denmark).

Statistics

Data analysis was performed with IBM SPSS statistics version 22 (IBM, Armonk, NY, USA).

Normally distributed data were analysed with parametric tests whereas data not normally distributed were tested with non-parametric tests. The thesis performed paired and non-paired comparisons, tested differences in distributions, and verified correlations. Table 6 presents a list of the statistical tests used in this thesis. P-values less than 0.05 were considered significant.

TABLE 6: *Statistical tests used in the thesis.*

Situation	Statistical test
Differences in beach visitor numbers between working and weekend days	Pearson chi-square test
Differences in car parking time	Independent t-test
Comparing frequency of sunscreen use by women and men	Pearson chi-square test
Comparing SPF chosen by women and men	Pearson chi-square test
Comparing quantity of sunscreen used by women and men	The Mann-Whitney test
Investigate if quantity of sunscreen used correlates with age	Spearman's rank-order correlation
Comparing quantity of sunscreen used at the beach and in the laboratory	The Mann-Whitney test
Comparing quantity of sunscreen used after double application compared to application of a handful	The Mann-Whitney test
Comparing missed areas after single and double application in the laboratory	Wilcoxon signed ranks test
Comparing missed areas after using a handful of sunscreen and a single application in the laboratory	The Mann-Whitney test

RESULTS

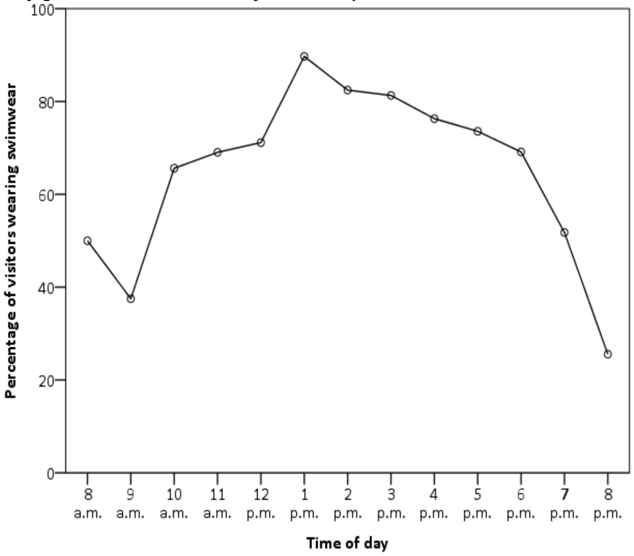
Time and duration of beach visits and use of protective clothes

In *Study I* a total of 2,259 beach visitors were counted at the beach on 11 sunny days. From 8 a.m. to 11 a.m. there were few beach visitors. After 11 a.m. the number of visitors increased, peaking at 3 p.m. on weekend days (Saturday and Sunday) and at 4 p.m. on work days (Monday to Friday). The number decreased during late afternoon and evening. There was no statistically significant difference between when people were on the beach on working days compared to weekend days ($p > 0.05$).

The duration of a beach visit in Copenhagen lasted a mean of 117 minutes (range: 20-450 minutes), estimated indirectly through parking time of 419 cars. The duration increased to 142 minutes between noon and 3 p.m. ($p < 0.001$).

Few beach visitors used protective clothes around noon (*Study I*). At 1 p.m. 90% of beach visitors wore swimwear, see **Figure 3**. Consequently, most beach visitors situated themselves with sunscreen as the only form of sun protection.

FIGURE 3: *Percentage of beach visitors wearing only swimwear at different times of the day. Most people wore swimwear at 1 p.m. The figure is based on data from Study I.*



Sunscreen use and chosen SPF

In 2016 sunscreen was frequently used by beach visitors wearing swimwear (*Study II*). Of the women, 78% reported sunscreen use, whereas only 49% of the men did, so women used sunscreen more frequently than men ($p < 0.001$). Sunscreen users used a median SPF of 20 (IQR: 15-30), regardless of sex ($p = 0.8$).

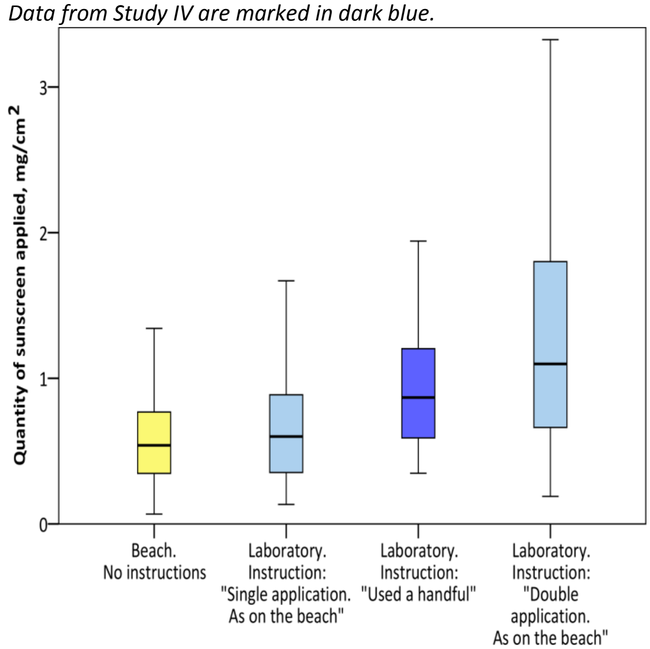
Overall quantity of sunscreen applied

In *Study II* 111 volunteers in swimwear had their sunscreen containers weighed before and after sunscreen application at the beach. In average, participants exposed a total skin area of 1.46 m^2 (SD = 0.11 m^2) to sunlight at the beach and used 8.4 g (SD = 4.7 g) of sunscreen. Assuming that the sunscreen was applied evenly over the accessible skin, the participants applied a mean quantity of 0.57 mg/cm^2 (SD = 0.31 mg/cm^2). There was no sex or age difference in quantity of sunscreen applied ($p > 0.1$).

In *Study III* 31 volunteers in the laboratory were asked to apply sunscreen as they would normally do on the beach on a sunny day in Denmark. They applied a median quantity of 0.60 mg/cm^2. Thus, the change of environment from the beach to the laboratory did not change the amount of sunscreen used ($p = 0.3$).

In the laboratory we also tested two different approaches to increase the amount of sunscreen used. One approach was to apply sunscreen two consecutive times. This was tested on 31 volunteers in *Study III*. The other recommendation was to use a handful of sunscreen to cover the whole body. This recommendation was tested on 17 volunteers (*Study IV*). The results are shown in **Figure 4**. Compared to sunscreen use at the beach without instructions the recommendation to use a handful of sunscreen increased the applied sunscreen quantity by 53% to 0.87 mg/cm^2 whereas applying sunscreen two consecutive times increased the quantity by 93% to 1.10 mg/cm^2. Both strategies increased sunscreen use significantly compared to usual sunscreen use at the beach ($p < 0.001$). Double application provided a 26% higher quantity of sunscreen compared to application of a handful of sunscreen. The difference was, however, not statistical significantly ($p = 0.2$) due to huge variation in sunscreen use (**Figure 4**).

FIGURE 4: *Boxplot showing applied quantities of sunscreen in different situations. The boxes represent the middle 50% of the data and the thick horizontal lines represent medians. The whiskers were made with Tukey method (71). Data from Study II are marked in yellow. Data from Study III are marked in light blue. Data from Study IV are marked in dark blue.*



Quantity of sunscreen applied at specific skin sites

In the laboratory studies (*Study III* and *IV*) it was possible to investigate not only the overall quantity of sunscreen applied but also the distribution of the sunscreen on the body.

As black light is absorbed by sunscreen, skin covered with sunscreen appears darker than skin without sunscreen (38). In *Study III* a standard curve was established linking darkness of a specific skin site on pictures taken in black light (D) and quantity of sunscreen applied (Q) on the skin. The following equation established the relation with nonlinear regression:

$$D = 0.379 \times 2^{-0.367 \times Q\frac{\mathrm{cm}^2}{\mathrm{mg}}} + 0.654 \times 2^{-8.051 \times Q\frac{\mathrm{cm}^2}{\mathrm{mg}}}$$

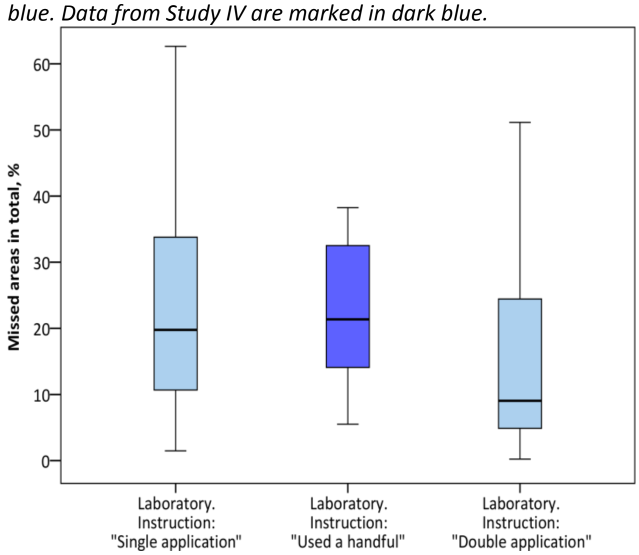
Subsequently, the standard curve was used to determine quantities of sunscreen applied at 6 skin sites, both after a single application (*Study III*) and after use of the two different recommendations (*Study III* and *IV*). Each skin site had a surface area of about 30 cm^2 and is shown in **Figure 1**.The sunscreen quantity applied at the skin sites are presented in **Table 7**. Overall, the sunscreen was very unevenly applied. The ratio between the smallest and largest quantity was the same after each application method (**Table 7**) indicating an equal unevenness. The upper back, the back of the thighs and the back of lower legs had small quantities applied. The forehead, chest, and belly had larger quantities applied. Double application provided the thickest quantity of sunscreen on all investigated skin sites, except on the upper back.

TABLE 7: *Quantities of sunscreen applied at specific skin sites after different application methods. The skin site with the smallest quantity applied after each method is underlined in red. The skin sites with the largest quantities are underlined in green. The smallest quantity as a percentage of the largest quantity was 5 % after a single application. The percentage after an application of a handful and double application were 7 % and 8 %, respectively. Abbreviation: IQR = interquartile range.*

Skin site	Quantity of sunscreen, mg/cm² Median (IQR) Instruction: "Single application. As on the beach" N = 31	Instruction: "Use a handful" N = 17	Instruction: "Double application. As on the beach" N = 31
Forehead	1.12 (0.71-2.08)	0.65 (0.28-1.38)	2.21 (1.25-2.94)
Chest	1.05 (0.65-2.06)	1.68 (1.34-2.46)	2.13 (1.17-2.63)
Belly	0.49 (0.23-1.69)	2.25 (0.70-2.47)	1.53 (0.39-2.70)
Lower leg, back	0.38 (0.08-0.61)	0.42 (0.23-1.81)	0.54 (0.11-1.76)
Thigh, back	0.22 (0.06-0.84)	0.16 (0.10-0.55)	0.49 (0.11-2.52)
Upper back	0.06 (0.01-0.44)	0.21 (0.06-0.34)	0.18 (0.02-0.55)

Missed areas
The pictures taken in black light in *Study III* and *IV* made it possible to assess the percentage of skin left without sunscreen, both in total and in the 11 different body regions. Especially after a single application, many areas were left without sunscreen. After a single application, as on the beach, a median of 20% of the accessible skin was missed. After a single application of a handful of sunscreen the median missed area was 21% and this recommendation did not decrease the size of missed areas ($p = 0.9$). Double application halved the median missed area to 9% ($p < 0.001$), see **Figure 5**.

FIGURE 5: *Boxplot showing missed areas after sunscreen application. The boxes represent the middle 50 % of the data and the thick horizontal lines represent medians. The whiskers were made with Tukey method (71). Data from Study III are marked in light blue. Data from Study IV are marked in dark blue.*



The missed areas in the different regions are shown in **Table 8**. Especially the face, the front of the trunk, the back of the hands, and the lower legs had few missed areas. The back of the trunk, the ears, and the insteps had large missed areas.

TABLE 8: *Missed areas. Median percentage of skin left without sunscreen (missed areas) in 11 body regions. Abbreviation: IQR = interquartile range.*

Body region	Missed area, % median (IQR) Instruction: "Single application. As on the beach" N = 31	Instruction: "Use a handful" N = 17	Instruction: "Double application. As on the beach" N = 31
Face	3 (1-15)	4 (3-14)	1 (1-5)
Ears	27 (7-91)	39 (6-100)	15 (3-58)
Neck, front	6 (1-30)	12 (8-22)	2 (0-15)
Neck, back	4 (0-11)	11 (4-37)	1 (0-3)
Trunk, front	7 (2-20)	6 (3-11)	1 (0-8)
Trunk, back	26 (17-39)	40 (26-47)	15 (8-32)
Arms	25 (6-36)	15 (13-31)	4 (1-27)
Hands, back	8 (3-29)	5 (1-21)	1 (0-3)
Thighs	22 (6-56)	20 (10-40)	7 (1-48)
Lower leg	5 (1-50)	5 (1-12)	1 (0-34)
Instep	24 (10-100)	42 (12-100)	10 (5-55)

Validation of picture analysis
The picture analysis method was validated separately in *Study III* and *IV*. Here follows an overall validation of the method. From all the pictures taken in the two studies the total amount of sunscreen that must have been used was estimated. This was done by multiplying the specific quantity of sunscreen applied with the skin area actually covered in each of the 11 regions. By addition of these amounts we estimated the total amount of sunscreen used by each volunteer. In regions where the specific quantity was not measured the measured quantity in the closest region was used. Sunscreen quantity was assumed to be the same all over each region. The median difference between the used amount of sunscreen estimated from the photos compared to the weighed amount of sunscreen was 1.0 g (IQR: -3.5 to 3.2) showing that the results of the two different methods are in agreement. This validates the use of pictures taken in black light as a method to investigate applied sunscreen quantities.
The fact, that people in the laboratory applied the same amount of sunscreen as people on the beach, validates that laboratory studies of sunscreen application reflects real life situations.

DISCUSSION

UVR exposure

An average beach visit around noon was estimated to last 142 minutes (*Study I*). The environmental sun doses to which the visitors could be exposed at the beach was maximally 6 SED/hour (25). Beachgoers, however, change position, alternating between lying on the stomach and on the back. A study where UVR dosimeters were attached to different body parts of beachgoers at a Danish beach in June around noon showed that the skin on the head received most UVR (72). The skin on the head received approximately 4 SED/hour, while the skin on the back of the hands received only half the dose (72). During an average beach visit of 142 minutes around noon the visitors' skin it exposed to a maximum of 14 SED. Due to the beachgoers change in position it is more realistic that the skin received a weighted UVR dose of approximately 9 SED. This is far more than an average Caucasian not using sun protection can tolerate without getting sunburned (25;51). An average non tanned Caucasian not using any sun protection can tolerate a maximal UVR dose of about 3 SED without getting sunburned. An average tanned Caucasian can tolerate about 6 SED whereas very light-skinned persons get sunburned after about 2 SED (25;51). See **Table 9**.

TABLE 9: *The table shows the largest tolerable ultraviolet radiation (UVR) dose before getting sunburned depending on sunscreen use and skin type. Groups with tolerable UVR doses below 9 standard erythema doses (SED) are coloured red. The most exposed skin is exposed to an UVR dose of about 9 SED during a beach visit of 142 minutes around noon during the summer in Denmark. Data in this table are calculated on the background of use of a sunscreen with a labeled sun protection factor (SPF) of 20 and applied quantities as found most common in Study II, III and IV.*

Sunscreen use	**Largest tolerable UVR dose before getting sunburned, SED**		
	Very light skin	Average non tanned Caucasian	Average tanned Caucasian
Non / missed areas Protected by an effective SPF of 1	2	3	6
Whiteout instructions at the beach Protected by an effective SPF of 2.3	5	7	14
Instruction: ”Use a handful” Protected by an effective SPF of 3.7	7	11	22
Instruction: ”Double application” Protected by an effective SPF of 5.2	10	16	31

Sun protection
In *Study II* beachgoers used sunscreen with a median labeled SPF of 20 and applied a median quantity of sunscreen of 0.57 mg/cm^2. The amount is in the same level as found in other previous field studies of sunscreen use (41;65;73-75). The sunscreen used on the Danish beaches in *Study II* provided the users with an overall effective SPF of 2.3 (effective SPF = $20^{0.57/2}$) (42). For an average Caucasian with tanned skin this is enough to protect against sunburn during an average beach visit around noon (*Study I*). The protection was, however, not sufficient for users with lighter skin. See **Table 9**. Two approaches to increase sunscreen use were tested in *Study III* and *IV*. After instructing the users to use a handful of sunscreen in *Study IV* they were protected by a median effective SPF of 3.7 (effective SPF = $20^{0.87/2}$) (42). An effective SPF of 3.7 is sufficient to protect against sunburn during the average beach visit except if the user have very light skin. See **Table 9**.
Study IV also showed that sunscreen was applied very unevenly and that around 21% of the accessible skin was left without sunscreen. These large missed areas are at high risk of becoming sunburned. The recommendation to apply sunscreen twice was tested in *Study III*. These users only missed 9% of their accessible skin. After double application of sunscreen users were protected by an effective SPF of 5.2 which can protect even light skin from sunburn during an average beach visit. Especially the reduction of missed areas after double application of sunscreen makes this recommendation seem most useful.
To be protected by an effective SPF, equal to the SPF labelled at the sunscreen bottle, a sunscreen quantity of 2 mg/cm^2 must be applied. **Table 10** shows that no sunscreen users at the beach, no participants instructed to use a handful of sunscreen, and only a few participants instructed to applicate sunscreen twice were protected by an effective SPF equal to the labeled SPF. It is, however, not essential to reach the SPF labeled at the bottle. It is crucial to gain sufficient sun protection depending on skin type and UVR exposure, see **Table 9**.

TABLE 10: *Proportion of sunscreen users protected by an effective sun protection factor (SPF) equal to the labelled SPF. A sunscreen user was defined to be protected by an effective SPF equal to labeled SPF if a mean quantity of 2 mg sunscreen per cm^2 skin or more was applied to the accessible skin.*

Sunscreen use	**Proportion of users protected by an effective SPF equal to the labeled SPF**
Without instructions at the beach (*Study II*)	0%
Instruction: ”Use a handful” (*Study IV*)	0%
Instruction: ”Double application” (*Study III*)	19%

Sunscreen substances
Sunscreens contain many different substances, both UV filters and other ingredients (12). In Europe, where the studies in this thesis were conducted, the sunscreen ingredients are regulated as a cosmetic product. The council regulative (2009/1223/EC) enclose a list of allowed and banned ingredients (76). The regulation request producers to draw up a product safety report for sunscreen products at the marked in EU. The safety report evaluates the substances in the product based on toxicological data and must include a safety assessment of the exposure to sunscreens ingredients. The amount of sunscreen users are expected to apply is essential to the risk assessment. The Scientific Committee on Consumer Safety recommends that manufacturers base their safety reports on an intermittent sunscreen use of up to 18 g per day used (77). **Table 11** shows how many of the participants in *Study II, III*, and *IV* used more than 18 g sunscreen.
Sunscreen users wearing swimwear in *Study II* exposed a mean skin area of 1.46 m^2 to the sun. To be protected by an effective SPF, equal to the SPF label, they need to use 29 g sunscreen each (2 mg/cm^2× 1.46 m^2), which clearly exceeds the 18 g, showing that it is not possible to be protected by an effective SPF, equal to the labeled SPF, without using more sunscreen than the stated amount in the safety report, assessing risk of exposure to sunscreen substances.

TABLE 11: *Proportion of sunscreen users who used more than 18 g of sunscreen, i.e. more than the stated amount of sunscreen in the safety report, assessing risk of exposure to sunscreen substances.*

Sunscreen use	**Proportion of users applying more than 18 g sunscreen**

Without instructions at the beach (*Study II*)	3%
Instruction: ”Use a handful” (*Study IV*)	24%
Instruction: ”Double application” (*Study III*)	45%

The results from S*tudy II* show that sunscreen users at Danish beaches generally use up to 18 g sunscreen only (See **Table 11**). If sunscreen use increases significantly in the future, e.g. by way of double application, it is required to reinvestigate safety as 45 % of participants in *Study III* applying sunscreen twice used more than 18 g sunscreen. The main concern is a possible hormone disrupting effect and reduced Vitamin D production which will be discussed in the following (12;78). Risks related to nanoparticles, allergy and cytotoxicity are well described and seem very limited (30;79-82) and will not be discussed further in this thesis.

Endocrine disrupting

Endocrine disrupting chemicals are defined as chemicals which can disrupt endocrine development in humans and animals (83). Studies on laboratory animals have indicated that UV-filters may have endocrine disruptive effects (84). UV filters are absorbed in the body after topical application and can be found in e.g. plasma and urine (85). UV filters are found in many other products than sunscreens as they protect plastic and textiles from the sun used e.g. in clothes and furniture (86). Consequently, UV filters are found in the urine of Danish children even during the winter, when use of sunscreen is unlikely, indicating another source of exposure (86;87). Despite the wide exposure to UV filters only a few experimental, *in vivo* studies have studied the possible endocrine disruptive effect in humans (88;89). Many observational studies have investigated relations between high concentrations of UV filters in human urine and many different outcomes e.g. male genital abnormalities at birth (90), birth weight (91-93), the number of spontaneous abortions (94), female fecundity (95), and semen quality (96). The results are, however, inconsistent and most studies found no associations (90;94-96) whereas other studies found contradictory results (91-93).

To date only two studies have investigated potential hormone disrupting effects of topical sunscreen application in humans (88;89). The two studies on adults by Janjua et al. found no effect of one week of daily whole-body topical sunscreen application on thyroid function or the level of reproductive hormones. The effect of daily application during a longer period has not been studied. In conclusion, the endocrine disrupting effect of sunscreen is shown in animals but the clinical relevance in humans has not yet been proven (12;88;89).

Vitamin D

Another thing worth considering when increasing the amount of sunscreen used is vitamin D. Photosynthesis of vitamin D in the skin takes place during UVR exposure and is essential for an optimal vitamin D level (97). Sufficient Vitamin D is important for healthy bones (98). Vitamin D deficiency may lead to an increased risk of a number of diseases, including certain cancers, type I diabetes mellitus, and cardiovascular disease. The literature is, however, inconsistent (99-101).

Laboratory studies with controlled sunscreen application to the entire body have shown sunscreen to decrease the amount of vitamin D formed during illumination (102;103). The reduction in vitamin D formation seems to decrease exponentially with decreasing quantities of sunscreen applied (104). Application of sunscreen providing an effective SPF 8 blocks vitamin D production almost totally (104). Application providing an effective SPF of 3 or 2 still offers good opportunity for vitamin D production (104). In *Study III* and *IV* we found sunscreen users to cover only 79% to 91% of their accessible skin with sunscreen with an effective SPF between 2 and 5. When exposed to UVR doses over 1.5 SED even radiation of 9% of the BSA is sufficient for maximal vitamin D production (105). When exposed to small doses below 1.5 SED radiation of 20% or more of the BSA is necessary for full vitamin D production (105). Overexposure does not lead to further vitamin D synthesis (97). Randomized controlled trials show that exposure to 1 SED every second week is sufficient to maintain a normal summer vitamin D level (106;107).

Studies of vitamin D level and sunscreen use in real life situations in Denmark (108) and other countries have not found a link between sunscreen use and vitamin D level (108-111). The results reflect that even small UVR doses are sufficient to avoid vitamin D deficiency and that sunscreen users in real life receive plenty UVR for vitamin D production (112;113). Consequently vitamin D production is not a rational cause for not using sunscreen on a beach visit of about 2 hours (*Study I*). Sunscreen applied in a quantity of 2 mg/cm^2 to all sun exposed skin every day could lead to vitamin D deficiency. But the sunscreen use found in *Study II, III* and *IV* is much less extensive. In addition, sunscreen is not typically used every day (108).

CONCLUSIONS

Below are the summarized main conclusions of this thesis.

An average visit at a beach in Copenhagen lasted 117 minutes and was expanded significantly around noon to 142 minutes around noon. A high percentage of beachgoers were at the beach between 12 noon and 3 p.m. where UVR is strongest. Few beachgoers wore protective clothes at midday and 90% of the visitors wore swimwear.

Seventy-eight percent of women in swimwear reported sunscreen use at the beach while 49% of men did. Sunscreen users used a sunscreen labeled with a median SPF of 20 (IQR: 15-30). Users applied a mean sunscreen quantity of 0.57 mg/cm^2 (SD = 0.31 mg/cm^2) at the beach, providing a mean effective SPF of 2.3. Both SPF chosen and quantity applied were independent of sex.

Two approaches, “Fill up a handful of sunscreen and spread it all over your body”, and two consecutive sunscreen applications were tested to increase the amount of sunscreen used. Both strategies significantly increased the total amount of sunscreen used compared to sunscreen use at the beach. The instruction: “Fill up a handful of sunscreen” increased the median quantity of sunscreen applied to 0.87 mg/cm^2 (IQR: 0.59-1.20 mg/cm^2) whereas double application increased the quantity to 1.10 mg/cm^2 (IQR: 0.60-1.85 mg/cm^2).

A method based on a link between darkness of skin in black light and the quantity of sunscreen applied was established and validated. The method made it possible to investigate the distribution of sunscreen. Sunscreen was applied very unevenly both after application without any instructions, application of a handful of sunscreen, and after double application. The face and the front of the trunk were generally well covered whereas the back of the trunk was poorly covered. After a single application, both without instructions and with a handful of sunscreen, about one fifth of the accessible skin was left without sunscreen. After double application only about a 9% of the accessible skin was missed. As especially missed areas are at risk of getting sunburned double application seems to be the better of the two strategies to increase sunscreen use.

PERSPECTIVES

The incidence of skin cancer is high, and increasing. It is of great importance to find effective ways to prevent skin cancer development. Accordingly, sun protection with sunscreen remains important.

In accordance with previous studies this thesis shows that sunscreen users only apply small amounts of sunscreen, hence the focus on methods for optimized sunscreen use. Use of the rule of thumb: "Fill up a handful of sunscreen and spread it all over your body" provided sunscreen coverage with many missed areas. Use of the recommendation to apply sunscreen two consecutive times provided a more efficient sunscreen coverage. When working to increase the amount of sunscreen overview of side effects is important. Further studies are needed to investigate if the absorbed UV filters have negative consequences for sunscreen users.

Sunscreen's ability to protect against UVR is reported as SPF and is measured as the sunscreen's ability to protect against sunburn. It has been required by EU and the Food and Drug Administration (39), probably because erythema is relatively easy to measure protection against and desirable to avoid. Protection against mutations in genes that may lead to keratinocyte cancer and CMM are, however, more important. Several studies have investigated the ability of sunscreens to protect against DNA damage and report sunscreen to protect significantly against DNA damage in the covered skin (53). All studies to date are conducted after application of sunscreen quantities of 2 mg/cm^2 (53). Studies in the present thesis show that, in real life, sunscreen is applied in much smaller quantities. Some studies suggest that the achieved DNA protection is related to SPF (114;115) but to our knowledge no studies have investigated the effect of different SPFs in the same setting. Future studies could investigate the possible correlation between DNA protection and SPF. It would be relevant to investigate sunscreen's protecting against DNA damage after application of quantities used in real life settings.

SUMMARY

Exposure to ultraviolet radiation (UVR) from the sun is the main risk factor for development of skin cancer. The incidence of skin cancer in Denmark and worldwide is high and increasing. The overall aim was to achieve basic knowledge about sun protection with sunscreen among beachgoers in Denmark. Other aims were to establish a method to investigate sunscreen distribution on the body and to test two approaches to optimize the used amount and body distribution of sunscreen. Furthermore time and duration of a beach visit and use of protective clothes among beachgoers were determined to investigate the risk the beachgoers expose themselves to.

Of the counted number of beachgoers 46% were at the beach between noon and 3 p.m. where the UVR is strongest and a mean beach visit lasted 142 minutes. In the middle of the day 90% of the beachgoers wore swimwear and sunscreen application was their only possible sun protection. More beachgoers wore protective clothes in the morning and late afternoon.

Seventy-eight percent of women wearing swimwear reported sunscreen use at the beach and 49% of men reported sunscreen use. They used a sunscreen with a median sun protection factor (SPF) of 20 (interquartile range: 15-30). The effective SPF probably decreases exponentially with decreasing quantity of sunscreen applied. Users at the beach applied a mean quantity of 0.57 mg/cm^2 (standard deviation 0.31 mg/cm^2) to their sun accessible skin, i.e. skin not covered by swimwear or scalp hair, providing a mean effective SPF of 2.3. Both SPF chosen and quantity applied were independent of sex.

Two approaches to increase sunscreen use was tested; the rule of thumb: "Fill up a handful of sunscreen and spread it all over your body", and a recommendation to apply sunscreen two consecutive times. Both strategies increased the total amount of sunscreen significantly. The instruction: "Fill up a handful of sunscreen and spread it all over your body" increased the median quantity of sunscreen to 0.87 mg/cm^2 whereas double application increased the quantity to 1.10 mg/cm^2. Sunscreen with a label SPF of 20 applied in a quantity of 0.87 mg/cm^2 provided an effective SPF of 3.7. Applied in a quantity of 1.10 mg/cm^2 provided an effective SPF of 5.2.

A method based on a link between darkness of skin in black light illumination and the quantity of sunscreen applied was established and made it possible to investigate the distribution of sunscreen on the body. Sunscreen was very unevenly applied both after application of a handful and after double application. The face and the front of the trunk were generally well covered whereas the back of the trunk was poorly covered. After a single application, either as at the beach or with the use of a handful of sunscreen, about one fifth of the total accessible skin was left without sunscreen. After double application only about a 9%of the accessible skin was left uncovered. As especially missed areas are at risk of getting sunburned double application seems to be the better of the two tested strategies to improve coverage.

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