Is the Global Solar UV Index an effective instrument for promoting sun protection? A systematic review

Nadia Italia and Eva A. Rehfuess*
Institute for Medical Informatics, Biometry and Epidemiology, University of Munich, Marchioninistrasse 15, 81377 Munich, Germany
*Correspondence to: E. A. Rehfuess. E-mail: rehfuess@ibe.med.uni-muenchen.de
Received on September 28, 2010; accepted on May 26, 2011

Abstract

Exposure to ultraviolet radiation is an important risk factor for skin cancer. The Global Solar Ultraviolet Index (UVI) was developed as a tool to visualize the amount of harmful radiation and to encourage people to use sun protection. We conducted a systematic review of the effectiveness of the UVI. We employed a comprehensive search strategy to explore the impact of the UVI on five outcome categories. Twenty-seven of a total of 260 studies met our inclusion criteria; data extraction and quality appraisal were undertaken for 25 studies, comprising 3 randomized controlled trials, 2 non-randomized intervention studies and 20 cross-sectional studies. Nearly half of these studies were from Australia and New Zealand. We found low to intermediate levels of UVI awareness and low levels of UVI understanding. Studies rated moderate or strong suggest that the UVI does not influence knowledge, attitudes, sun protection behavior or sun exposure. Overall, the findings imply that the UVI, as currently implemented, has not been successful at improving sun protection practices and reducing sun exposure among the population at large. Drawing on experience with theory-based sun protection programs, we advocate for more realistic expectations of what the UVI can and cannot achieve.

Introduction

Ultraviolet (UV) radiation is a major risk factor for melanoma and non-melanoma skin cancers [1] and is responsible for 50–90% of these cancers [2]. Globally, 60 000 premature deaths were attributed to UV radiation exposure in the year 2000 [2]. In recent decades, a strong increase in the incidence of skin cancers has been observed among fair-skinned populations [3], with Australia and New Zealand showing the highest incidence rates [4].

Skin cancer is largely preventable when appropriate sun protection measures are taken. Unlike visible light or warmth, UV radiation cannot be perceived directly. To overcome this problem, in 1995, the World Health Organization (WHO) together with several partner organizations launched the Global Solar UV Index (UVI) as a vehicle to visualize the amount of UV radiation reaching the Earth’s surface [5]. The UVI is calculated using the International Commission on Illumination reference action spectrum for UV-induced erythema on the human skin; it can be either measured directly or predicted using a radiative transfer model [6]. UVI values range from 0 up to 11+; the higher the value, the higher the risk of UV damage. The WHO defines five UVI exposure categories, ranging from low to extreme, accompanied by recommended sun protection measures, consisting of sunscreen use, wearing protective clothing and a hat and seeking shade during midday hours [5]. UVI reporting usually takes place at the level of
a city or region, based on the daily maximum value or dangerous hours; it may include cloud-adjusted as well as clear-sky values [5].

The UVI is intended to be ‘used as an integral component of a program to inform the public about UV radiation health risks and sun protection and to change people’s attitudes and behavior with respect to UV radiation exposure’ [5]. It can be employed as part of general sun protection campaigns via the mass media or targeted at specific population groups in relevant settings, such as childcare centers [7], workplaces or outdoor recreational settings [8]. Health care providers also play an important role in promoting the UVI [9].

Several years after the introduction of the UVI skin cancer rates remain high. The WHO is therefore planning to review the guidance originally provided. In doing so, it is critical to examine whether and how the UVI is being put to use in different countries and whether it represents an effective means to improve people’s sun protection behavior. To contribute to this process, we conducted a systematic review of the effectiveness of the UVI as a health promotion instrument.

Methods

We developed a detailed research protocol (Supplementary data available at Health Education Research online), which was reviewed by two experts with UV radiation and systematic review expertise.

There is a lag time of years to decades between UV radiation exposure and the development of skin cancer [10]. It is thus not sensible to investigate whether the introduction of the UVI has reduced skin cancer rates nor is it feasible to examine whether it has led to reduced sun exposure at population level. Instead, our review was guided by a logic model based on the WHO’s definition of the UVI ‘as a guide to healthy, sun-protective behavior’ [5] and the knowledge attitude behavior model [11]; a similar analytic framework was employed in a systematic review of interventions to prevent skin cancer [1]. We thus assume that the UVI promotes sun protection behaviors directly, as well as indirectly through changes in knowledge and attitudes. Ultimately, improved sun protection behaviors are expected to reduce people’s exposure to UV radiation and thus their risk of developing skin cancer (Fig. 1).

Inclusion criteria

We conducted searches for randomized controlled trials (RCT) and non-randomized intervention studies, as well as case control studies, prospective and retrospective cohort studies and cross-sectional studies.

Sunburn during childhood can significantly increase the risk of skin cancer [12, 13] but UV exposure during adulthood is also important [14]. While a majority of the burden of disease occurs among fair-skinned populations, populations with darker skin equally suffer from skin cancer. Therefore, we imposed no restriction on participants in terms of age or skin color.

We classified interventions as (i) media campaigns, (ii) programs in childcare settings, (iii) programs directed at high-UV radiation settings, (iv) programs through health care providers and (v) programs using general or personalized information, including UV meters. We adopted a broad definition of the term ‘intervention’ to comprise both proactive, specific intervention studies or programs and surveys examining familiarity with the UVI unlinked to a specific intervention study or program.

We assessed impacts of the UVI in five categories, knowledge, attitude, behavior and sun exposure. Any impact of the UVI on sun protection critically relies on people’s awareness and understanding, justifying their assessment in the separate category familiarity (Fig. 1; Table I).

Search strategy

Search terms comprised the UVI and its synonyms and a range of outcomes (Table II). Intervention and outcome search terms were combined using the Boolean operator ‘AND’ and adapted to the needs of specific databases.
We conducted systematic searches using the electronic databases Pubmed, Embase, the Cochrane central register of controlled trials, the Cochrane library, Database of Promoting Health Effectiveness Reviews, Trials Register of Promoting Health Interventions, EPPI-Center database of health promotion research, Educational Resource Information Center database, Effective Public Health Practice Project (EPHPP) database, ScienceDirect, Psychinfo and Cambridge Scientific Abstract.

We also searched the gray literature through the Global Health Database, the British library and Gray Matters: A Practical Search Tool for Evidence-Based Medicine. The bibliographies of all included studies were handsearched. Finally, we consulted experts by email, including all primary and senior authors of included studies, as well as experts collaborating with the WHO’s INTERSUN program.

As the UVI was introduced in 1995, we restricted our search to studies published in the year 1995 or thereafter. The main search language was English but we endeavored not to exclude any studies on the basis of language.

**Data collection, analysis and synthesis**

Titles and abstracts were checked regarding their relevance by one author (N.I.). The inclusion

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**Table I. Outcome measures**

<table>
<thead>
<tr>
<th>Category</th>
<th>Outcome measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familiarity</td>
<td>Awareness of UVI</td>
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<tr>
<td></td>
<td>Understanding of UVI</td>
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<tr>
<td>Knowledge</td>
<td>On role of UV radiation in increasing skin cancer risk</td>
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<td></td>
<td>On appropriate sun protection measures</td>
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<tr>
<td>Attitude</td>
<td>Towards sun protection</td>
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<td></td>
<td>Towards the intention to use different types of sun protection</td>
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<tr>
<td>Behavior</td>
<td>General sun protection</td>
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<tr>
<td></td>
<td>Use of protective clothing (e.g. hat, sunglasses, shirt)</td>
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<tr>
<td></td>
<td>Use of sunscreen</td>
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<tr>
<td></td>
<td>Seeking shade</td>
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<tr>
<td></td>
<td>Avoiding sun exposure during midday</td>
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<tr>
<td>Sun exposure</td>
<td>Time spent in the sun</td>
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<tr>
<td></td>
<td>Sunburn</td>
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</table>
criteria were (i) use of the UVI calculated/modelled according to the formula used by the International Commission on Illumination [6]; (ii) a primary study of an intervention based on the UVI and (iii) outcome measures available in at least one of the five categories (Table I). Where a decision could not be made on the basis of title and abstract alone, the full text was screened. All decisions and reasons leading to the exclusion of studies were documented.

Both authors independently extracted data from studies meeting the inclusion criteria and appraised the quality of each study using the EPHPP tool [15]. This tool awards an overall rating of weak, moderate or strong based on eight component ratings, i.e. selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts, intervention integrity and analyses. Any discrepancies in overall ratings were resolved through discussion of component ratings between authors. Given large heterogeneity in study designs, intervention types and outcome measures, statistical pooling of results through meta-analysis was not considered appropriate. Instead, we used narrative synthesis to summarize findings in each of five outcome categories. For very different outcome measures, we summarized results using the descriptive labels, ‘increase’, ‘decrease’, ‘no effect’.

### Results

Searches yielded a total of 260 studies. Electronic databases, gray literature databases, handsearches and expert consultation produced 204, 44, 4 and 8 studies, respectively. Ultimately, 27 studies met our inclusion criteria, of which two [16, 17] reported results published elsewhere [18, 19]. Finally, data extraction and quality appraisal were undertaken for 25 studies (Fig. 2; Table III; Supplementary data available at Health Education Research online).

### Overview of included studies

We identified three RCTs [23, 25, 29], two non-randomized intervention studies [7, 37] and 20 cross-sectional studies (Table III).

With nine studies from Australia and two from New Zealand, nearly half of the included studies were from countries with very high skin cancer rates. Ten studies were located in Europe, three in the UK, two in Sweden and one each in Germany, Italy, Switzerland, Finland and France. Four studies had been conducted in the Americas, two in the United States and one each in Canada and Colombia. Our search did not identify any studies from Africa or Asia.

One study addressed children in childcare settings [7]; all others were concerned with the general population. A media campaign was the intervention evaluated in 18 studies [18–22, 24, (Cancer Research UK, unpublished results; Cancer Society Finland,

### Table II. Search terms

<table>
<thead>
<tr>
<th>Intervention AND</th>
<th>Outcome</th>
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<tr>
<td>UVI</td>
<td>familiar*</td>
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<tr>
<td>solar index</td>
<td>understand*</td>
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<td>Ultraviolet radiation index</td>
<td>comprehension</td>
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<td>UVR index</td>
<td>know*</td>
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<td>UV forecast*</td>
<td>aware*</td>
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<tr>
<td>UV radiation forecast*</td>
<td>perception</td>
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<tr>
<td>ultraviolet index</td>
<td>perceive</td>
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<td></td>
<td>attitude</td>
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<td>behave*</td>
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<td>sun tan</td>
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<td>tanning</td>
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<td>sunscreen</td>
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<td>sun block</td>
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<td>sun protection</td>
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<td>midday</td>
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<td>noon</td>
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<td>dangerous hours</td>
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<td>peak hours</td>
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<td>sun avoidance</td>
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<td>shade</td>
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<td>tree</td>
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<td>indoors</td>
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<td></td>
<td>cloth*</td>
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<td></td>
<td>shirt</td>
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<td></td>
<td>sunglasses</td>
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<td></td>
<td>shades</td>
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<td></td>
<td>hat</td>
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<td></td>
<td>sun exposure</td>
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<td></td>
<td>time in the sun</td>
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<td></td>
<td>sun seeking</td>
</tr>
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203
<table>
<thead>
<tr>
<th>Study ID</th>
<th>Study design</th>
<th>Study quality</th>
<th>Country</th>
<th>Intervention type</th>
<th>Intervention focus</th>
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<tbody>
<tr>
<td>Alberink et al. [20]</td>
<td>Cross-sectional study (repeated)</td>
<td>Weak</td>
<td>Australia</td>
<td>General population; Media campaign</td>
<td>Familiarity, Behavior</td>
</tr>
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<td>Blunden et al. [21]</td>
<td>Cross-sectional study</td>
<td>Weak</td>
<td>Australia</td>
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<tr>
<td>Börner et al. [22]</td>
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<td>Moderate</td>
<td>Germany</td>
<td>General population; Media campaign</td>
<td>Familiarity, Behavior</td>
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<tr>
<td>Brünström et al. [23]</td>
<td>RCT (with four arms)</td>
<td>Moderate</td>
<td>Sweden</td>
<td>General population; Program using general or personalized information, including UV meters</td>
<td>Knowledge, Attitude, Behavior, Exposure</td>
</tr>
<tr>
<td>Bulliard and Reeder [24]</td>
<td>Cross-sectional study</td>
<td>Moderate</td>
<td>New Zealand</td>
<td>General population; Media campaign</td>
<td>Behavior</td>
</tr>
<tr>
<td>Cancer Research UK, unpublished results</td>
<td>Cross-sectional study</td>
<td>Weak</td>
<td>Great Britain</td>
<td>General population; Media campaign</td>
<td>Behavior</td>
</tr>
<tr>
<td>Cancer Society Finland, unpublished results</td>
<td>Cross-sectional study</td>
<td>Weak</td>
<td>Finland</td>
<td>General population; Media campaign</td>
<td>Behavior</td>
</tr>
<tr>
<td>Carli et al. [25]</td>
<td>RCT (with two arms)</td>
<td>Weak</td>
<td>Italy</td>
<td>General population; Program using general or personalized information, including UV meters</td>
<td>Behavior, Exposure</td>
</tr>
<tr>
<td>Carter 2005 [26]</td>
<td>Cross-sectional study</td>
<td>Weak</td>
<td>Australia</td>
<td>General population; Media campaign</td>
<td>Behavior</td>
</tr>
<tr>
<td>Carter and Donovan [27]</td>
<td>Cross-sectional study</td>
<td>Weak</td>
<td>Australia</td>
<td>General population; Media campaign</td>
<td>Behavior</td>
</tr>
<tr>
<td>Diffey and Norridge [28]</td>
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<td>Weak</td>
<td>United Kingdom</td>
<td>Program using general or personalized information, including UV meters</td>
<td>Behavior, Exposure</td>
</tr>
<tr>
<td>Dixon et al. [29]</td>
<td>RCT (with three arms)</td>
<td>Strong</td>
<td>Australia</td>
<td>Programs using general or personalized information, including UV meters</td>
<td>Behavior, Exposure</td>
</tr>
<tr>
<td>Geller et al. [18] (CDC [16])</td>
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<td>Weak</td>
<td>United States</td>
<td>General population; Media campaign</td>
<td>Familiarity, Behavior</td>
</tr>
<tr>
<td>Geller et al. [7]</td>
<td>Non-randomized intervention study (with control group)</td>
<td>Moderate</td>
<td>United States</td>
<td>Children; Childcare setting</td>
<td>Familiarity</td>
</tr>
<tr>
<td>Government Statistical Service UK [30]</td>
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<td>Weak</td>
<td>Great Britain</td>
<td>General population; Media campaign</td>
<td>Familiarity, Behavior</td>
</tr>
<tr>
<td>Harrison et al. [31]</td>
<td>Cross-sectional study (at level of early childhood services)</td>
<td>Weak</td>
<td>Australia</td>
<td>General population; Media campaign</td>
<td>Familiarity</td>
</tr>
<tr>
<td>Krebs and Swiss Cancer League [32]</td>
<td>Cross-sectional study (repeated)</td>
<td>Moderate</td>
<td>Switzerland</td>
<td>General population; Media campaign</td>
<td>Familiarity, Behavior</td>
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<tr>
<td>Kricker and Armstrong [33]</td>
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<td>Weak</td>
<td>Australia</td>
<td>General population; Media campaign</td>
<td>Familiarity, Behavior</td>
</tr>
<tr>
<td>Makin et al. [34]</td>
<td>Cross-sectional study</td>
<td>Weak</td>
<td>Australia</td>
<td>General population; Media campaign</td>
<td>Familiarity, Behavior</td>
</tr>
<tr>
<td>Purdue et al. [35]</td>
<td>Cross-sectional study</td>
<td>Moderate</td>
<td>Canada</td>
<td>General population; Program using general or personalized information, using UV meters</td>
<td>Behavior, Exposure</td>
</tr>
<tr>
<td>Reeder [36]</td>
<td>Cross-sectional study</td>
<td>Weak</td>
<td>New Zealand</td>
<td>General population; Media campaign</td>
<td>Familiarity</td>
</tr>
<tr>
<td>Sanclemente and Diaz [37]</td>
<td>Non-randomized intervention study (without control group)</td>
<td>Weak</td>
<td>Colombia</td>
<td>General population; Media campaign, programs using general or personalized information, including UV meters</td>
<td>Familiarity</td>
</tr>
<tr>
<td>Sécurité Solaire [38]</td>
<td>Cross-sectional study</td>
<td>Weak</td>
<td>France</td>
<td>General population; Media campaign</td>
<td>Familiarity, Knowledge</td>
</tr>
<tr>
<td>Wester and Paulsson [19] (Wester and Paulsson [17])</td>
<td>Cross-sectional study</td>
<td>Weak</td>
<td>Sweden</td>
<td>General population; Media campaign</td>
<td>Familiarity, Knowledge</td>
</tr>
<tr>
<td>White et al. [39]</td>
<td>Cross-sectional study</td>
<td>Weak</td>
<td>Australia</td>
<td>General population; Media campaign</td>
<td>Familiarity, Behavior</td>
</tr>
</tbody>
</table>
unpublished results) 26, 27, 30–34, 36, 38, 39]; six studies examined programs using general or personalized information materials [23, 25, 28, 29, 35, 37], two of these also employed UV meters [23, 25]. One study investigated a combination approach [37].

An Australian RCT randomly assigned employees of three consultant firms and one university in Melbourne to three different weather forecast conditions, i.e. standard weather forecast plus/minus UVI plus/minus sun protection message [29]. During 18 summer weeks, participants were emailed their forecast on Thursday and requested to report their weekend behavior through a self-administered online questionnaire the following Monday. There were no statistically significant differences between groups in reported hat use, sunscreen use, sun avoidance or sunburn. This was the only study rated strong following quality appraisal with the EPHPP tool (Table III).

An Italian RCT recruited medical students in Florence [25]. The intervention group received UV meters; both groups were asked to record their sun-related behavior in a diary during July and August. Compared with the control group, the intervention group showed longer average daily sun exposure, including during peak UV hours, and less frequently adopted protective measures. In subsequent laboratory tests, however, the UV meter underestimated actual UVI values by 20–40%, suggesting that significantly lower reported than actual UVI values may have encouraged those in the intervention group to prolong their time in the sun. This was one of several weaknesses of this study, resulting in a quality rating of weak (Table III).

The two non-randomized intervention studies received ratings of moderate [7] and weak [37]. The majority of cross-sectional studies were classified as weak; four [22, 24, 32, 35] were rated moderate given minimal selection bias, good assessment of confounders and valid and reliable data collection tools (Table III).
**Familiarity**

All but four [23, 25, 28, 29] of our included studies examined UVI awareness or understanding among the population, including two non-randomized intervention studies [7, 37] and 19 cross-sectional studies (Table IV). ‘Awareness’, investigated in 15 studies, was mostly assessed as ever having heard of the UVI. Sixteen studies explored ‘understanding’ of the UVI based on (i) open-ended questions, (ii) multiple-choice questions or (iii) the correct interpretation of a given UVI value.

General UVI awareness varies considerably between countries, showing very low levels in Germany [22] and Sweden [19] and high levels in some recent Australian studies [20, 21, 31] (Table IV). Estimates obtained from strong or moderate studies range from 27–53% [22, 35].

The six Australian studies employed different survey tools in various cities and regions, which is likely to explain some of the substantial variation. Older studies [33, 39] report lower levels, suggesting that UVI awareness may have increased over the last decade as a result of large-scale dissemination. UVI awareness tended to be lower in winter than in summer [20] and on the day of the survey than in general [21, 27, 34, 39] (Supplementary data available at Health Education Research online). Interestingly, despite similar UV radiation levels and skin cancer rates in both countries, UVI awareness in New Zealand appears to be much lower than in neighboring Australia [24], in particular among the Maori [36] (Table IV). In Switzerland, the same cross-sectional survey was conducted in five different years [32]. Levels of UVI awareness were stable over time but much higher in French-speaking than in German-speaking Switzerland [32] (Supplementary data available at Health Education Research online).

Understanding of the UVI was found to be considerably less prevalent (Table IV). When only studies rated strong or moderate are considered, however, estimates range from 17 to 55% [7, 24, 32].

In two non-randomized intervention studies conducted among school children in the United States [7] and adults resident in the city of Medellin, Colombia [37], the proportion of participants interpreting the UVI correctly rose from 25 and 2% pre-intervention to 55 and 9% post-intervention, respectively. Different outcome definitions are likely to explain the large variation in UVI understanding reported in two British studies [Cancer Research UK, unpublished results, 30] and various Australian studies [21]. Generally, the percentage of the population claiming to understand the UVI is greater than the percentage that can correctly describe or interpret it [31, 39].

**Knowledge and attitude**

Only three studies investigated the effect of the UVI on people’s knowledge [19, 23, 38] and attitude [23] (Table IV). ‘Knowledge’ and ‘attitude’ were assessed using a score in the Swedish RCT [23]; the two cross-sectional studies measured self-reported knowledge about UV radiation and skin cancer [19, 38]. Studies classified as strong or moderate suggest that the UVI has no influence on either outcome.

**Behavior**

The impact of the UVI on sun protection behavior was explored by three RCTs [23, 25, 29] and 11 cross-sectional studies [18–22, 28, 30, 32–34, 39] (Table IV). Studies collected data on ‘general sun protection’ (12), ‘protective clothing’ (2) and ‘sunscreen’ (2).

Strong and moderate studies suggest that the UVI exerts no or only a limited influence on sun protection behaviors (Table IV). Many people claiming to use the UVI do not consider it regularly to plan their sun protection [22, 33]. In the Italian RCT, the intervention group was less likely to wear protective clothing and apply sunscreen than the control group but, as discussed above, this unexpected decrease is likely to be a consequence of unreliable UV meters [25].

**Sun exposure**

Three RCTs [23, 25, 29] and three cross-sectional studies [28, 30, 35] examined sun exposure (Table IV). ‘Time spent in the sun’ was measured as (i) sunbathing [23, 29], (ii) average daily time in the sun [25] or (iii) staying out of the sun as much as possible [30]. ‘Sunburn’ outcomes included (i) days
Table IV. Results of studies assessing UVI impact on five outcome categoriesa

<table>
<thead>
<tr>
<th>Familiarity</th>
<th>Knowledgeb</th>
<th>Attitudeb</th>
<th>Behaviorb</th>
<th>Sun exposureb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awareness</td>
<td>Understandingc</td>
<td>General sun protection</td>
<td>Use of protective clothing</td>
<td>Use of sunscreen</td>
</tr>
</tbody>
</table>

**RCT**
- Sweden: No effect [23]
- Australia: Increase [29]
- Italy: Decrease [25]
- Sweden: No effect [23]
- Australia: No effect [29]
- Italy: Decrease [25]
- Australia: No effect [29]
- Sweden: No effect [23]

**Non-randomized intervention studies**
- Colombia:
  - Pre-intervention: 2%
  - Post-intervention: 9% [37]
- United States:
  - Pre-intervention: 25%
  - Post-intervention: 55% [7]

**Cross-sectional studies**
- Australia: 89%; 86% [20]
- Australia: 90% [21]
- Australia: 93% [31]
- 64% [33]
- 48% [34]
- 78% [39]
- 53% [35]
- 74% [38]
- France:
  - 70% [16]
  - 63% [26]
- Finland:
  - 18% [23]
- 45% [27]
- 16% [39]
- 59% Cancer
- Society Finland,
- unpublished results
- France:
  - 20% [21]
  - 23% [27]
- 16% [39]
- Germany:
  - 20% [21]
- 23% [27]
- 16% [39]
- France:
  - 27% [22]
- 37% [38]
- Germany:
  - 43% [24]
- 33% [36]
- Sweden:
  - 41% [24]
- 28% [36]
- Switzerland:
  - 17% [32]

spent with sunburn, (ii) a sunburn score and (iii) having suffered from sunburn during the weekend, previous summer or last year.

RCTs from Australia and Sweden found no differences between intervention and control groups [23, 29]; the Italian RCT reported longer sun exposure and more sunburns in the intervention group [25]. In two cross-sectional studies from the UK [28, 30], UVI awareness was associated with reduced sun exposure; in a Canadian cross-sectional study, it was associated with a greater risk of sunburn [35]. Based on strong and moderate studies, the UVI does not appear to influence sun exposure.

Discussion

Methodological strengths and weaknesses

To our knowledge, this is the first systematic review of the effectiveness of the UVI as a health promotion instrument. Consistent with Cochrane guidance, we used a detailed peer-reviewed research protocol and independent data extraction and quality appraisal by both authors. The fact that 10 of 25 included studies were not retrieved through electronic database searches but through gray literature databases (5), handsearches of included studies (2) and expert consultation (3) underlines the importance of a multi-pronged search strategy. We captured studies in English, German, French and Finnish but may have missed studies published in other languages. The limited ethical and practical feasibility of RCTs is a challenge for many complex public health interventions [40]. As it is often criticized that choice and implementation of public health interventions do not make sufficient use of evidence [41, 42], we attempted to assemble ‘all’ available evidence on the use of the UVI. It is therefore all the more important to assess the quality of individual studies carefully.

To do so, we explored several different scales and checklists [43–45] but eventually followed the Cochrane Public Health Review Group’s recommendation to use the EPHPP tool [15]. This tool is supposed to suit all quantitative study designs, but we discovered that several of the eight component criteria were only relevant to intervention or follow-up
studies. Despite the appeal of using a single quality appraisal tool and, at least in our case, high inter-coder reliability, we believe that it may be more informative to employ separate instruments for each of the major study designs.

We used a logic model to make our assumptions about how the UVI influences sun protection behavior and, ultimately, sun exposure transparent (Fig. 1). This was critical in breaking our overall research question down into sub-questions, guiding the selection of outcome measures and relevant search terms and interpreting results. While our model was directly informed by the WHO recommendation to evaluate whether ‘members of the general public understand the meaning of the UVI … and whether the campaign has changed people’s knowledge, attitudes and behavior with respect to sun exposure’ [5], it is nevertheless rather simplistic. Since the development of the UVI in 1995, theory-based skin cancer prevention has contributed to a much more detailed understanding of the factors that determine behavior change [46, 47]. Consistent with Social Cognitive Theory [48] and the Theory of Planned Behavior [49], psychosocial constructs such as attitudes and positive or negative outcome expectancies, subjective norms, self-efficacy (i.e. perceived behavioral control) and impediments to behavior have been found to be strongly related to sun-protective behaviors [50–54]. These insights are important in the interpretation of our findings.

Implications of findings
With only seven included studies rated strong or moderate, study quantity and quality represent a serious limitation. Moreover, public health interventions always depend on context [55], and with two thirds of our included studies coming from the English-speaking world, primarily Australia and New Zealand, it is questionable whether the results apply to all fair-skinned populations. The findings can certainly not be extrapolated to populations living in Asia, Africa or the Middle East. As shown in Table III, outcomes were frequently reported for women and men separately, showing no consistent differences in awareness, behavior or exposure. We did not conduct sub-analyses as very few studies disaggregated results with respect to age [22, 38], skin color [36], skin type [21, 24, 30, 32] socio-economic status [37, 38] or education [18, 21, 22, 24, 32].

In view of the above limitations, it is hard to draw firm conclusions but, overall, this systematic review suggests that the UVI is not an effective means for improving sun protection practices. We will explore some of the reasons for this apparent lack of success by focusing on the evidence for two major arrows in Fig. 1 and by considering which expectations the UVI can realistically meet in the context of what is known about successful sun protection programs.

UVI dissemination and familiarity with the UVI
Findings reported in studies from Europe, the Americas and the Australian continent vary markedly, mostly suggesting low to intermediate levels of UVI awareness but low levels of UVI understanding. Several studies state lack of continuous media coverage [22, 29] as an explanation for low awareness. All studies examining the source of UVI information reported that a majority of the population followed the weather forecast and gathered UVI information on television [18, 24, 30, 33, 34, 37]; newspapers were the second most frequently cited source [18, 30, 34]. People rarely seek UVI information pro-actively [22] but often find the UVI to be a useful tool [24]. Indeed, a majority of the Swedish population would like to receive daily UVI information [19].

Population-based estimates of awareness and understanding are, to some extent, coupled. Nevertheless, a majority of those aware of the UVI are unable to interpret the information correctly (Table III). Commonly reported misconceptions include confusion with the sun protection factors of sunscreens [Cancer Society Finland, unpublished results, 32, 38] or time to get sun burnt Cancer Society Finland, unpublished results, 27]. This could induce people to stay in the sun even longer when UV radiation levels are high. There appears to
be a serious need to transmit the UVI in a more meaningful way [21], for example, by linking UVI values to specific sun protection behaviors and personal exposure situations [21, 22, 31]. Graphical messages appear to have a higher impact than text messages [26] and, alongside regionally customized messages [18], may help overcome the often cited problem of limited variation in UVI values [18, 22, 27, 29].

**UVI familiarity and the knowledge, attitude, behavior exposure complex**

Few studies gauged, the impact of the UVI on knowledge, attitudes, behavior and sun exposure; taken together, they imply that the UVI may not influence any of these outcomes.

Importantly, to ensure comparability, we reported population-based figures, which may underestimate the impact of the UVI in low-awareness settings. Also, all included studies relied on self-reporting of behavior (e.g. use of sunscreen, hat and sunglasses while pursuing outdoor hobbies) or exposure (e.g. number of days with sunburn during summer). The accuracy and reliability of these measures is limited in view of recall bias and social desirability bias.

Knowledge is rarely sufficient to induce behavior change, with risk perception and health beliefs being important moderating influences [27]. For example, in the German cross-sectional study only the intention to use the UVI—but not UVI awareness or understanding—was associated with increased sun protection while on the beach, sunbathing and pursuing outdoor hobbies [22]. Overcoming habitual health behaviors represents a challenge [29], especially among those feeling that they already protect themselves sufficiently [30].

**Realistic expectations of the UVI**

A systematic review of interventions to prevent skin cancer conducted in 2002 concluded that educational and policy interventions in primary schools, as well as programs targeted at adults in outdoor recreational environments and tourism settings were effective in reducing sun exposure [1]. This review did not examine the role of the UVI but evidence for all other approaches, including stand-alone mass media or small media campaigns (the primary mode of UVI employment), was considered insufficient.

Since then we have gained a more advanced understanding of how theory-based health communication can successfully improve sun protection [50–52, 54, 56]. For example, a cluster-RCT of an intervention implemented in ski areas in the western United States and Canada achieved a significant increase in reported sun protection practices among ski area workers [50] and those guests who recalled exposure to a sun-safety message [56]. The use of multiple channels (e.g. posters, electronic signs, interpersonal communication) in multiple sublocations (e.g. lodges, chairlifts, ski and snowboard schools) facilitating exposure to the sun-safety message turned out to be critical: the reported effect was greater among those having received a higher ‘dose’ of materials or channels [56]. A careful crafting of the message is equally important, as the relative effectiveness of the use of a gain or loss frame [57] of emotional features such as humor and fear, of high versus low sensation value messages [50] and of health- versus appearance-based messages [47] depends on the target audience and underlying personal or structural barriers to and facilitators of sun protection [1, 47].

These recent studies confirm that altering sun protection behavior is complex. It is therefore unrealistic to assume that the UVI, which by definition is a number ranging from 0 to 11+ and therefore represents a relatively simple health promotion tool, can achieve changes in attitude and behavior by itself. A more reasonable expectation is that the UVI can help raise awareness of the dangers of UV radiation and highlight the importance of sun protection in the context of a comprehensive sun protection program.

**Recommendations for sun protection programs**

Despite the limited evidence base, this systematic review suggests that the UVI in its current form and in the way it is currently implemented has resulted in low to moderate levels of awareness and understanding and has had limited if any impact on
knowledge, attitudes, sun protection practices and UV radiation exposure. In view of the planned revision of the UVI guidance by the WHO, how can the UVI be employed more successfully in the future?

First, easily accessible, widespread and regular UVI dissemination as part of the weather forecast is a pre-condition for high levels of awareness. Television and newspapers are consistently reported as the main route of exposure to UVI information but are underutilized as delivery channels. Secondly, evidence to date suggests that disseminating a UVI value by itself can easily be misinterpreted. Safe sun packages consisting of graphical icons and actionable messages customized to specific exposure situations are one important way to make the concept more understandable and relevant to people’s daily lives. Thirdly, the UVI is one but not the only tool among an arsenal of approaches toward skin cancer prevention. It is most likely to be successful as part of comprehensive sun protection programs comprising multifaceted efforts to encourage safe sun habits alongside the creation of UV-protective environments. Fourthly, in planning and implementing such programs and crafting appropriate messages, we have much to learn from experience with observational learning methods, skills training and role modeling. Formative research can help define the specific role of the UVI with a given target audience and setting. Finally, given the dearth of high-quality evidence, we encourage efforts promoting the UVI to invest in well-conducted evaluation studies to help shed light on how the UVI can be employed in more effective ways in the future.

**Funding**

Eva Rehfuess gratefully acknowledges financial support from the Munich Center of Health Sciences.

**Acknowledgements**

We are grateful to Kerry Joyce and Hajo Zeeb for their suggestions toward improving the systematic review protocol and to three anonymous reviewers, whose constructive criticism greatly improved this article. We would also like to thank Emilie van Deventer and Perid Shannoun for their overall support of this project and in identifying and contacting experts. Finally, we greatly appreciated the prompt response and help of all experts and authors who provided further studies and more detailed information on included studies.

**Conflict of interest statement**

None declared.

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