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Review Article

Awareness, understanding, use, and impact of the UV index: A systematic review of over two decades of international research

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ABSTRACT

The ultraviolet radiation index (UVI) was adopted internationally to raise awareness about and encourage the public to protect their skin from skin cancer. The current paper is a systematic review of over 20 years of research investigating awareness, comprehension, use, and impact of the UVI. Thirty-one studies were included from the USA, Canada, Europe, Australia, New Zealand, and elsewhere. Awareness of the UVI varies by country, with samples from some countries demonstrating high awareness. However, comprehension and use of the UVI to inform sun safety behaviors are typically much lower. In fact, greater UVI awareness has sometimes been associated with riskier UV-related behaviors such as intentional tanning. Fewer studies have evaluated interventions, and their results have been mixed. In summary, more research is needed to determine how to help the public understand and use the UVI for effective skin protection. This review offers suggestions for future use of and research with the UVI.

1. Introduction

Ultraviolet radiation (Hofbauer et al., 2010) can cause damage to the skin and eyes as well as suppress the immune system (Meves et al., 2003). UVR is the primary and most preventable risk factor for melanoma and non-melanoma skin cancers, which affect millions of people annually worldwide (Meves et al., 2003).

The UV index (UVI) was first developed in Canada in 1992 and adopted by the United States National Weather Service (NWS) and Environmental Protection Agency (EPA) as well as the World Meteorological Organization (WMO) and World Health Organization (WHO) in 1994. The UVI, a measure of the UVR levels at the Earth's surface, was published in 1995 as a result of a collaboration between the WMO, WHO, United Nations Environment Programme, the International Commission on Non-Ionizing Radiation Protection, and the German Federal Office for Radiation Protection (World Health Organization et al., 2002).

The UVI was intended to raise awareness and alert the public to the need for sun protection in order to reduce skin cancer risk. Although various versions of the UVI existed around the world before the standardization of the Global Solar UVI in 2002, they shared many similar qualities. Despite slight changes in color scheme, labeled exposure categories, and range of values, the actual UVR levels have not changed. The values of the UVI range from 1 to 11+ and are associated with varying recommendations for sun protection. For example, at a UVI value of 3, sun protection is recommended (i.e., seeking shade during midday, increasing clothing coverage, sunscreen and hat use), and at a UVI value of 8, extra sun protection is recommended (i.e., avoid being outdoors during midday, greater emphasis on sun protection) (World Health Organization et al., 2002).

Italia and Rehfuess (Italia and Rehfuess, 2012) conducted a systematic review of 25 studies to examine the effectiveness of the UVI and its impact on five outcome categories: familiarity, knowledge, attitude, behavior, and sun exposure. Overall, the researchers found low to intermediate levels of UVI awareness, low levels of UVI understanding, and minimal influence of UVI on sun protection. The authors concluded that implementation of the UVI had not resulted in widespread improvement of sun protection or reduction of sun exposure.

The purpose of the current paper is to explore UVI awareness, use, and impact on skin cancer risk and risk reduction behaviors by extending the work of Italia and Rehfuess (Italia and Rehfuess, 2012) and including newer studies (those conducted after 2010). In order to best expand upon their work, we modeled our search strategy and data collection methods on theirs. The current paper additionally presents studies related to UVI and various outcomes organized by geographic region (North America, Australia/New Zealand, Europe, and other countries) in order to help assess potential differences in study outcomes across regions with varying public health campaigns and UVR

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levels. Use and impact of the UVI in experimental and non-experimental studies were also distinguished.

2. Methods

2.1. Search strategy

Title/abstract search terms included any of the following terms: “UV index”, “UV indexes”, “UV indices”, “UVI”, “ultraviolet radiation index”, “UVR index”, “solar index”, “UV forecast*”, “UV radiation forecast*”, “ultraviolet index”, “solar ultraviolet index”, OR “solar ultraviolet radiation”. We also combined (using the Boolean operator ‘AND’) those terms with any of the following: “familiar*”, “understand” “comprehend”, “comprehension”, “know*”, “aware*”, “perception”, “perceive”, “attitude”, “intervention”, “behavior”, OR “behaviour”. We conducted our searches of peer-reviewed published papers in PubMed, Embase, EBM (Evidence Based Medicine) Reviews, and ScienceDirect. When available, “related content” in the Wiley Online Library and bibliographies was also searched. We limited the search to humans and papers published from 1994, the year the global solar UVI was adopted by the WHO and WMO, through June 2017.

2.2. Data collection

Papers were first analyzed for relevance based on title and abstract. Papers were included that addressed any combination of the UVI search terms and outcomes. Outcomes were reviewed related to: 1) awareness or understanding of the UVI, 2) sun exposure or protective behaviors in association with UVI, and 3) impact of UVI interventions. If the preliminary screening was inconclusive, the full text was screened for relevance. Records were excluded if they were not available in English or failed to address the UVI specifically even if they included terms like “solar ultraviolet radiation” or “ultraviolet radiation”. Records were also excluded for only doing the following: assessing UVR and its adverse effects, comparing UVR measuring devices, discussing skin damage and skin cancer, measuring or assessing personal UVR exposure, or educating the public about UVI or UVR without assessment. Because of the differences in study design and outcomes among the papers, meta-analysis was not appropriate.

3. Results/discussion

3.1. Overview

See Fig. 1 for PRISMA flow diagram. Data extraction was conducted for 31 papers that were included in the systematic review. Papers were organized by outcome and into the following geographic regions: North America, Australia and New Zealand, Europe, and other. Ten papers addressed more than one outcome, and therefore, are reported more than once.

Random sampling was a common method of recruitment (n = 15), which can increase the representativeness of a sample. Other studies utilized a convenience (n = 10) or quota sampling (n = 5) strategy. Klostermann and colleagues (Klostermann et al., 2014) sampled the total population in their study. Studies ranged in sample size from 26 to 30,451, with only three studies containing fewer than 100 participants. Most non interventional studies utilized a cross-sectional design with self-reported data. This design does not allow for conclusions of causality and can be limited by selection and recall biases as well as social desirability. However, stronger designs including observations, weekly diaries, and serial cross-sectional surveys were used by Andersen and colleagues (Andersen et al., 2016), Reeder and colleagues (Reeder et al., 2016), and Alberink and colleagues (Alberink et al., 2000), respectively. Three intervention studies had a pre-post design, and five were randomized control trials. Randomized controlled trials allow for a better understanding of the true effect of an intervention on a sample. Few intervention studies reported explicit use of specified behavior change theories. See Table 1 for summaries of the studies included. The research on each outcome by geographic region is reviewed and discussed below.

3.2. Awareness and understanding of the UVI

3.2.1. USA

In the US in the 1990's, one study found that over half of television and newspaper media reported the UVI, and a similar proportion of a sample of adults reported awareness and overall understanding of the UVI. Of US television stations and newspapers surveyed by Geller and colleagues (Geller et al., 1997), 61–71% reported the UVI to the public. Seven hundred adults were also surveyed, with 64% indicating awareness of the UVI; of these, almost all were able to accurately describe the UVI (90%). However, 15% of participants reported that the UVI was difficult to understand. No more recent US studies on awareness or understanding were identified.

3.2.2. Australia/New Zealand

Awareness of the UVI has ranged from 64% to 93% in Australia (Alberink et al., 2000; Kricker and Armstrong, 1998; Harrison et al., 2007; Mair et al., 2012; Blunden et al., 2004). In one study, the UVR forecast had been viewed or heard by 64% of the sample with sources including television (80%), radio (55%), and newspapers (30%) (Kricker and Armstrong, 1998). Differences in awareness/understanding have not been found between public health officials and the general public (Kricker and Armstrong, 1998), rural and urban dwellers (Kricker and Armstrong, 1998), or men and women (Alberink et al., 2000; Kricker and Armstrong, 1998). In contrast to the overwhelming majority of participants in several studies who reported awareness of the UVI through various media outlets, fewer participants from Australia demonstrated understanding when prompted to answer knowledge questions (Harrison et al., 2007; Blunden et al., 2004; Carter and Donovan, 2007). For example, among 404 Perth residents, only 5% noticed the UVI forecast for that particular day, 61% did not understand that UVI and temperature are not directly associated, and 55% of participants did not realize that UVR levels are highest at solar noon (Carter and Donovan, 2007).

Bulliard and Reeder (2001) found that a little less than half of New Zealand participants were aware of the UVI, but 94% of those reported understanding it. However, 89% were aware of burn time (an estimate of the time it takes to burn); though, only 66% had adequate understanding of it. Similar trends in awareness and understanding of UVI were discovered among primary school students in New Zealand (Wright et al., 2015). Researchers found that although year 8 students tended to have better understanding of UVI, sun exposure, and protection when compared to year 4 students; over half (57%) of the year 8 students reported that the UVI was difficult to understand (Wright et al., 2015). Public awareness and understanding of the UVI may be lower in New Zealand than Australia, potentially due to New Zealand's concurrent and historical public use of burn time.

In summary, public awareness and general understanding of UVI is fairly high in Australia; although discrepancies exist between awareness and comprehension. Although fewer people were aware of UVI in New Zealand, a greater percentage of those people were able to adequately describe it. Some common misunderstandings include the incorrect association of UVI with temperature and not recognizing that the UVI varies throughout the day, reaching its peak around noon.

3.2.3. Europe

Overall in Europe, awareness and especially understanding of the UVI is lower compared to other regions. A study found that only 27% of the Swedish participants had heard of the UVI; although, 41% of those believed that they became better informed about UVR because of the UVI (Wester and Paulsson, 2000). In the UK, researchers found that

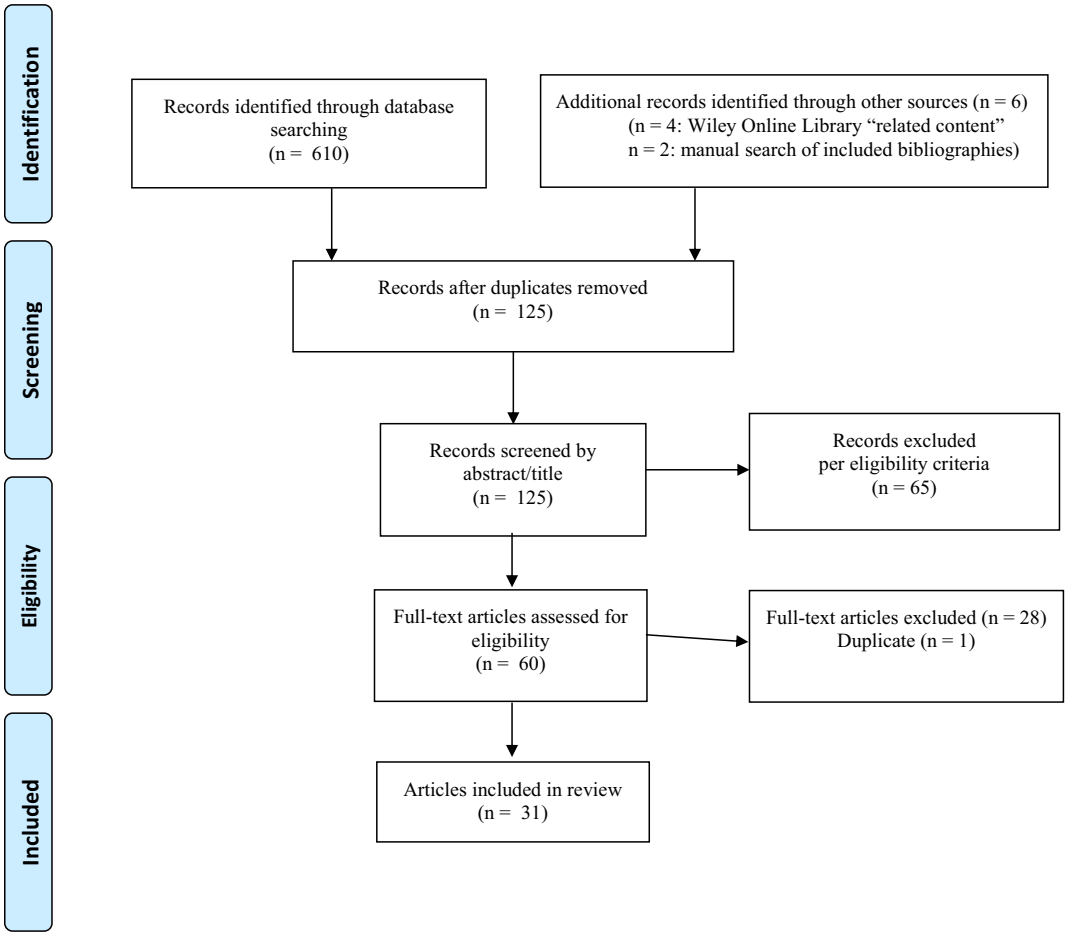

Fig. 1. PRISMA flow diagram.

67% of participants had heard of the UVI (Morris et al., 2011). However, of those, only 40% were able to correctly identify a "high" UVI value, and only 8% were able to recall the UVI value on that day.

Several studies have been conducted in Germany among varied samples that have also found low awareness and understanding of UVI. Borner et al. (2010) found that only 27% of their sample had heard of the UVI. Of those, only 18% correctly identified the meaning of it. There was a significant positive association between knowledge of UVI and level of education. Klostermann et al. (2014) surveyed parents of children in Germany and found that a quarter reported no knowledge of the UVI. Another German study found that although 30% of a sample of 40 outdoor workers were aware of the UVI, only 13% understood at what UVI sun protection is recommended. Although most participants were aware that increased UVR exposure is associated with increased risk of skin cancer, few were able to describe adequate sun protection measures (Hault et al., 2016).

Overall, less than half of Northern European study participants had some awareness of UVI, and fewer still could correctly identify aspects of the UVI. The low awareness and understanding of the UVI in Northern Europe is likely due to low media coverage and lower UVR intensity compared to regions in southern latitudes (Borner et al., 2010) This may be particularly detrimental to 1) those in an outdoor occupation who may underestimate the effects of chronic UVR exposure as well as to 2) individuals who travel to southern locations for vacation and sunburn more quickly than they had expected. Although there is some association between knowledge of UVI and evidence of higher education (i.e., at least a high school diploma) (Borner et al., 2010), low awareness and understanding remains consistent across other demographic variables.

3.2.4. Other countries

Similarly, studies conducted on student populations in China and South Africa concluded that half or fewer students reported awareness of the UVI, and even fewer understood the UVI. Chinese researchers noted that approximately half of a sample of 385 medical university students reported UVI awareness. Only 5% understood the meaning of the UVI, and of these, only 26% correctly identified the number of levels in the UVI (Gao et al., 2014). However, pale skin has historically been favored in China, and skin protection via sunscreen, clothing, and parasols is common (Stephens et al., 2018). In South Africa, Wright et al. (2015) and (2014) found that among a sample 7th grade students, only 29% were aware of the UVI, and among those, 19% reported seeing it on television. Public dissemination of the UVI is minimal in South Africa.

3.3. Relationship of UVI with sun exposure and protective behaviors

3.3.1. USA/Canada

Despite some awareness of the UVI in weather forecasts, there has been variable association between UVI and its use among the general public. In one study, only 38% of 448 US respondents reported that they or their family changed their sun protection behaviors (i.e., used shade, sunscreen, or hats) as a result of the UVI (Geller et al., 1997). Another study found that when controlling for temperature, the UVI was significantly and positively associated with shade use among vacationers in the US and Canada (Andersen et al., 2016).

Although exposure to the UVI has been reported to improve some sun protection behaviors, it may also worsen these behaviors. Geller et al. (1997) found that 40% of respondents who were aware of the UVI

Table 1
Characteristic of studies included in the review by outcome and country.

Outcome and country	Authors, year	Paper title	Methods	Sample size and characteristics	Strengths (+) and limitations (−)	Key findings
Awareness and understanding						
USA	Geller et al. (1997)[a]	Evaluation of the Ultraviolet Index: media reactions and public response	- Mailed survey - Observation - Random digit dialing phone survey	- Weathercasters from 169 television stations in 58 US cities - 54 newspapers with the highest circulation in each city - 700 adults	+ Random digit dialing + Relatively large sample size + Representation from every state, DC, and PR (media) + Oversampled high exposure cities - Used estimates of viewership to compute UVI exposure - Did not measure long term maintenance of behaviors	- 71% of stations broadcasted the UVI. 61% of newspapers reported the UVI. - 64% of adults indicated that they were aware of the UVI, and of these, 90% were able to describe the UVI. 54% of respondents had heard about the UVI ≥ 5 times. 15% believed that the UVI was difficult to understand. - 40% believed the UVI was useful to decide the best time to tan. - The most common sources of UVI information were television, followed by newspapers.
Australia/New Zealand	Kricker and Armstrong (1998)[a]	Dissemination, knowledge and use of UV indexes	Market research Survey	- Random sample of 504 people ages 18 and older; 70% living in metropolitan areas of New South Wales - 17 health professionals who were part of the New South Wales Sun Protection Network	+ Random sampling - Focused on only one area - Cannot be generalized to larger population outside New South Wales	- The UV forecast had been viewed or heard by 64% of the sample. Sources were TV (80%), radio (55%), and newspapers (30%). - 47% of health professionals reported using the UVI in practice. About 18% of those used the UVI ≥ 50% of the time.
Australia/New Zealand	Alberink et al. (2000)[a]	Do forecasts of UV indexes influence people's outdoor behaviour?	Mailed surveys	977 residents randomly selected from the electoral roll in Queensland	+ Random sampling + Relatively large sample + High response rate (78%) + Investigated seasonal differences - Sample has taken part in prior skin cancer studies - Lack of younger participants - Did not determine type of UVI presented or if meaning was understood	- 92% of men and 86% of women had seen or heard the UVI forecast during summer.
Australia/New Zealand	Harrison et al. (2007)	Baseline survey of sun-protection knowledge, practices and policy in early childhood settings in Queensland, Australia	Mailed survey	1383 directors and senior teachers of early childhood services	+ Random sampling + Relatively large and unique sample - Low response rate - Under representation of certain care centers	- 93% of respondents had some awareness of the UVI - Few directors understood the UVI. Pre-school teachers had lower knowledge scores than directors. - Only 20% of those who reported understanding of UVI were able to answer a UVI question correctly.
Australia/New Zealand	Mair et al. (2012)	Personalized electronic messages to improve sun protection in young adults	Online survey	141 Queensland, Australians ages 18–40 years from a pre-established panel of volunteers	+ Quota sampling - Internet panel based recruitment - Relatively small sample size	- 92% of participants had heard of the UVI. - Very few were able to clearly describe the UVI.
Australia/New Zealand	Blunden et al. (2004)[a]	Knowledge, awareness, and use of the UV index amongst the West Australian public	Phone survey	501 randomly-selected adults in Perth, Australia	+ Random sampling - Relatively small sample from one location	- 90% of respondents had heard of the UVI. - 70% were able to correctly define UVI in line with the WHO definition. 88% knew that 10 am–3 pm is when UV levels are highest. - Only 5% noticed the UVI/forecast for that particular day.

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Table 1 (*continued*)

Outcome and country	Authors, year	Paper title	Methods	Sample size and characteristics	Strengths (+) and limitations (−)	Key findings
Australia/New Zealand	Carter and Donovan (2007)	Public (Mis)understanding of the UV Index	Intercept interview	404 adults ages 16–44 years in Perth, Australia	+ Large representative sample of Australians that burn at least 1 time/year - Convenience sample - 42% refusal rate	- Mean estimations of average UVI values in summer and winter were highly exaggerated (20 and 12, respectively). - 61% did not appreciate that the UVI is independent of temperature. 55% did not know that UV peaks at noon. 23% of 22–44 year olds confused the UVI with burn time.
Australia/New Zealand	Wright et al. (2015)[a]	School students' knowledge and understanding of the Global Solar Ultraviolet Index	In-school survey	264 year eight and 214 year four students 8–13 years old.	+ Random selection of schools and classrooms - Timing of survey led to age differences - Males underrepresented - Selection bias	- 58% of year eight students answered that they had previously heard about or seen the UVI compared to 31% of year 4 students. - Among the students who had seen or heard of the UVI, 43% claimed that the UVI was easy to understand. - When asked if the sun's rays get stronger as the UVI value increases, 41% of year 8 students correctly agreed.
Australia/New Zealand	Bulliard and Reeder (2001)[a]	Getting the message across: sun protection information in media weather reports in New Zealand	Phone survey	396 adults ages 16–44 years selected via random digit dialing in New Zealand	+ Random digit dialing + Quota sampling + Generalizable to NZ population (16–44 years) - Confusing questions related to burn time - Low participation rate (52.5%)	- There was greater awareness of the burn time than the UVI (89% vs 43%). - The UVI was less often used to guide sun protection (49% vs 63%) but better understood (94% vs. 66%) and more often recalled along with sun protective messages (56% vs 32%) than burn time. - Few could describe the burn time or UVI for the past Sunday.
Europe	Morris et al. (2011)[a]	An investigation into the awareness and understanding of the ultraviolet index forecasts in the South West of England	In-person survey	466 residents and tourists ages 16 years and older from South West England	+ Quota sampling + Wide sampling strategy - Representative of population of South West England only	- 67% of participants had heard of the UVI (the predominant source being TV). - Only 40% were able to state correctly that a value of 7 would be considered to be 'high'. - The authors believe that awareness of the UVI in the UK did not increase drastically from 1998 to 2008.
Europe	Wester and Paulsson (2000)	The influence of a UV index on the attitudes of a Swedish population toward sun exposure	Phone survey	1094 Swedish adults ages 18–74 years	+ Random digit dialing + Relatively large representative sample	- 27% of Swedish adults had heard about the UVI. - Of these, 41% had become better informed about UV because of viewing or hearing about the UVI. - 57% of participants thought it would be good if newspapers presented the UVI daily.
Europe	Borner et al. (2010)[a]	The influence of the UV-index on attitudes toward sun exposure in the German population	Phone survey	1501 German residents ages 14 years and older via random digit dialing.	+ Random digit dialing + Relatively large, representative sample	- Only 27% of the respondents had heard of the UVI before. - < 10% attributed the correct meaning to the UVI. - Around 33% of men and 25% of women knew of the UVI.
Europe	Klostermann et al. (2014)[a]	Determinants of inadequate parental sun protection behaviour in their children–results of a cross-sectional study in Germany	Paper survey	Parents of 4579 Bavarian children (ages 5–6 years)	+ Total population sampling - Focused only on parents of young children	- The UVI was known to 74% of parents. - 8% of parents used the UVI to determine sun protection.

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Table 1 (*continued*)

Outcome and country	Authors, year	Paper title	Methods	Sample size and characteristics	Strengths (+) and limitations (−)	Key findings
Europe	Hault et al. (2016)	Knowledge of outdoor workers on the effects of natural UV radiation and methods of protection against exposure	Paper survey	40 outdoor workers in Germany	+ Focus on high-risk population - Convenience sample - Small sample size	- 30% had heard of the UVI. - Only 13% knew that skin should be protected when the UVI is ≥3.
Other	Wright et al. (2014)	Self-reported sun-related knowledge, attitudes and behaviors among schoolchildren attending South African primary schools	In-school paper survey	A randomly selected sample of 707 grade 7 students from 24 government, urban schools in all nine provinces of South Africa	+ Random selection of schools and classrooms - Timing of survey led to age differences - Males underrepresented - Selection bias	- Only 29% of students had seen or heard about the UVI. - 19% of those students had seen the UVI on the television. - The UVI is not commonly broadcast in South Africa
Other	Wright et al. (2015)	School students' knowledge and understanding of the Global Solar Ultraviolet Index	In-school paper survey	705 South African grade 7 students	+ Random selection of schools and classrooms - Timing of survey led to age differences - Males underrepresented - Selection bias	- 38% of students had heard of the UVI. - No significant difference in awareness between students of dark or fair skin types.
Other	Gao et al. (2014)	Knowledge, attitude and practice regarding solar ultraviolet exposure among medical university students in Northeast China	Paper survey	385 medical undergraduate students in Northeast China	+ Random sampling - Small unique sample	- 5% knew the meaning of UVI. - Only 1% gave the correct number of levels in the UVI. - Out of the 195 participants who reported use of weather forecasts, only 12% of men and 7% of women reported being 'always' or 'often' concerned about the UV forecast.
Associations with behavior						
USA/Canada	Geller et al. (1997)[a]	Evaluation of the Ultraviolet Index: media reactions and public response	Phone survey	700 adults in 58 US cities	+ Random digit dialing + Relatively large sample size + Representation from every state, DC, and PR (media) + Oversampled high exposure cities - Used estimates of viewership to compute UVI exposure - Did not measure long term maintenance of behaviors	- 38% of those who had heard of the UVI stated that they or their family changed their sun protection as a result of it. - 71% who reported a behavior change stated the alteration was "staying out of direct sunlight as much as possible".
USA/Canada	Andersen et al. (2016)	Environmental variables associated with vacationers' sun protection at warm weather resorts in North America	- Interview - Intercept survey - Observation	- Vacationers at 41 summer resorts in 17 US states and 1 Canadian province were interviewed (n = 3531) and observed (n = 4347). - Environmental information was recorded by research staff or acquired from ground stations and the weather service.	+ Large sample + Standardized observations + High interrater reliability + Focused on current not prospective or retrospective behavior - Convenience sampling	- UVI had a significant, positive relationship with shade use. - The UVI showed a weak, positive relationship with sunscreen use and reapplication.
USA/Canada	Jones et al. (2013)	Association of UV index and sunscreen use among White high school students in the United States	In-school survey (Youth Risk Behavior Survey)	Nationally representative sample of 14,041 US high school students in 2007 and 16,410 in 2009	+ Random sampling + Large nationally representative sample - survey does not distinguish seasonal differences in sun protection use - Secondary analysis of dataset - Sun protection question was not comprehensive - Utilization of proxy measure - Moderate response rate	- Among White male students only, there was a positive relationship between the mean UVI and the adjusted odds of never wearing sunscreen.

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Table 1 (*continued*)

Outcome and country	Authors, year	Paper title	Methods	Sample size and characteristics	Strengths (+) and limitations (−)	Key findings
USA/Canada	Purdue et al. (2001)	Predictors of sunburn among Canadian adults	Phone survey (1996 National Survey on Sun Exposure & Protective Behaviors)	4023 Canadian adults	+ Random sampling + Relatively large sample - Moderate response rate - Secondary analysis of dataset	- Predictors of sunburn included high awareness of the UVI, summer outdoor work, extended time in the sun (leisure), forgetfulness, sun protective practices, and seeking a tan. - Avoiding the sun during high UV periods was associated with lower odds of sunburn. Though, approximately 57% of those with high UVI awareness reported ≥1 summer sunburns.
Australia/New Zealand	Kricker and Armstrong (1998)[a]	Dissemination, knowledge and use of UV indexes	Market research survey	- Random sample of 504 adults; 70% living in metropolitan areas of New South Wales - 17 health professionals who were part of the New South Wales Sun Protection Network	+ Random sampling - Focused on only one area - Cannot be generalized to larger population outside New South Wales	- Only 13% used the UVI regularly to determine sun protection during the summer - The majority of health professionals believed that < 26% of the general population would use the UVI regularly
Australia/New Zealand	Alberink et al. (2000)[a]	Do forecasts of UV indexes influence people's outdoor behaviour?	- Mailed surveys - Surveys distributed after the end of Australian summer and winter.	977 residents randomly selected from the electoral roll in Queensland	+ Random sampling + Relatively large sample + High response rate (78%) + Investigated seasonal differences - Sample has taken part in prior skin cancer studies - Lack of younger participants - Did not determine type of UVI presented or if meaning was understood	- Of the total number of people who had seen or heard the UVI forecast during the summer, significantly fewer men (28%) than women (46%) claimed the forecast influenced their sun protective behavior. - Skin type or history of sunburn showed no relationship to utilization of UVI forecast.
Australia/New Zealand	Bulliard and Reeder (2001)[a]	Getting the message across: sun protection information in media weather reports in New Zealand	Phone survey	396 adults ages 16–44 years selected via random digit dialing	+ Random digit dialing + Quota sampling + Generalizable to NZ population (16–44 years) - Confusing questions related to burn time - Low participation rate (52.5%)	- Although the UVI was better understood by participants, only 49% of the sample used it to guide their sun protective practices compared to the 63% that used burn time.
Australia/New Zealand	Blunden et al. (2004)[a]	Knowledge, awareness, and use of the UV index among the West Australian public	Phone survey	501 randomly-selected adults in Perth	+ Random sampling - Relatively small sample from one location	- Of the 5% of respondents who noticed the UVI for the day, 83% said that knowledge did not influence their behavior.
Australia/New Zealand	Reeder et al. (2016)	Factors associated with photo-protection by body clothing coverage, particularly in non-summer months, among a New Zealand community sample	Weekly Diary for eight weeks	506 participants from New Zealand (ages 18 to 85 years)	+ Longitudinal diary + Quota sampling - Lower male representation	- On average, participants covered 82% of their body with clothing. - From the fully weather adjusted model, a higher percentage of the body was covered in non-summer months and during mid-day. - Higher temperatures were associated with lower percentage of body covered by clothing.
Europe	Diffey and Norridge (2009)	Reported sun exposure, attitudes to sun protection and perceptions of skin cancer risk: a survey of visitors to Cancer Research UK's SunSmart campaign website	Online survey	2061 participants from the UK	+ Large sample - Convenience sampling - Lower male representation - Few older adults	- Although only one-third of respondents reported using the UVI at least once to plan their sun protective practices; they were less likely to burn than those who never consulted the UVI.

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Table 1 (*continued*)

Outcome and country	Authors, year	Paper title	Methods	Sample size and characteristics	Strengths (+) and limitations (−)	Key findings
Europe	Morris et al. (2011)[a]	An investigation into the awareness and understanding of the ultraviolet index forecasts in the South West of England	In-person survey	466 participants ages 16 years and older from South West England	+ Quota sampling + Wide sampling strategy - Representative of population of South West England only	- 60% of participants who noted being aware of the UVI indicated that knowing the UVI value did not influence their sun protection behavior.
Europe	Wester and Paulsson (2000)[a]	The influence of a UV index on the attitudes of a Swedish population toward sun exposure	Phone survey	1094 Swedish adults	+ Random digit dialing + Relatively large representative sample	- Of the 295 participants who had heard about the UVI, 24% claimed that they had altered their outdoor behavior.
Europe	Borner et al. (2010)[a]	The influence of the UV-index on attitudes toward sun exposure in the German population	Phone survey	1501 German residents ages 14 to 90 years old via random digit dialing.	+ Random digit dialing + Relatively large representative sample	- About 63% of those who were aware of the UVI considered the UVI for their sun exposure and protection behavior. - Only 37% consider the UVI frequently and alter their sun behavior accordingly. - Only 6% of participants actively searched for the UVI or UVR information.
Europe	Klostermann et al. (2014)[a]	Determinants of inadequate parental sun protection behaviour in their children—results of a cross-sectional study in Germany	Paper survey	Parents of 4579 Bavarian children (ages 5–6 years)	+ Total population sampling - Focus only on parents of young children	- Most children received sun protection like clothes (80%), hat (83%), sunscreen (89%), or shade (69%). - Only 8% of parents reported that the UVI influenced their decisions regarding their children's sun protection. - Overall, participants who used sun protection less were less likely to use the UVI. However, participants who never/rarely used sunscreen were more likely to have used the UVI. - Holidays in mountainous areas were positively associated not using the UVI while trips to pools were negatively associated with disuse of the UVI.
Europe	Ezzedine et al. (2007a)	Travelers to high UV-index countries: sun-exposure behaviour in 7822 French adults	Paper survey in 1997 and 2001	7822 French non-expatriates were classified as 196 long-term travelers (defined as having experienced at least one month-long visit to a high UVI country) and 7626 non-travelers.	+ Large sample - Convenience sample - Did not seem to take advantage of two time-points	- In the last year, travelers reported more frequent sun exposure and placed greater emphasis on tanning in high UVI areas, especially among women. - Though expatriates were aware of the travel health advice of their country of stay, they tended to be less informed about risk factors related to sun exposure. - Sun protection was similar in both groups
Europe	Ezzedine et al. (2007b)	Expatriates in high-UV index and tropical countries: sun exposure and protection behavior in 9416 French adults	Paper survey in 1997 and 2001	9416 French adults: 1594 expatriates (defined as having experienced at least one stay in a high UVI country for over three consecutive months), 7822 non-expatriates.	+ Large sample - Convenience sample - Did not seem to take advantage of two time-points	- Expatriates, particularly women, report greater sunbathing or outdoor activities during their lifetime. - Expatriate men reported experiencing more intensive sun exposure than non-expatriates during their lifetime.
Interventions						
USA/Canada	Geller et al. (2002)	The Environmental Protection Agency's National SunWise School Program: sun protection education in US schools (1999–2000)	The US Environmental Protection Agency's National SunWise School Program: sun protection education in US schools	Pre-post survey after US EPA's Sunwise School Program with 1894 students between kindergarten and eighth grade.	+ Random sampling + Pre-post design - Self-selected schools - Only one control district - Lack of comprehensive measures	- Knowledge of the UVI number corresponding with the need for skin protection increased from 25% to 55%. - Students who received the program were more likely than controls to wear long-sleeves and intend to play in the shade.

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Table 1 (*continued*)

Outcome and country	Authors, year	Paper title	Methods	Sample size and characteristics	Strengths (+) and limitations (−)	Key findings
USA/Canada	Buller et al. (2015a)	Smartphone mobile application delivering personalized, real-time sun protection advice: a randomized clinical trial	A sun protection and UVI mobile app based on social cognitive theory vs. online assessment only with follow up at 10 weeks	A nationwide population-based sample of 604 adults from the US Knowledge Panel 18 years or older who owned an Android smartphone were enrolled.	+ RCT + Large randomly selected nationwide sample - Minimal differences may be associated with loss to follow up - Lack of racial and educational variability - Lack of app use - Newly validated measures used	- Individuals utilizing the app reported more shade use but less sunscreen use controls. - No significant difference in number of sunburns in the past 90 days between the groups. - Those who used the app reported spending less time in the sun and using sun protection behaviors more than individuals who did not use the app.
USA/Canada	Buller et al. (2015b)	Evaluation of immediate and 12-week effects of a smartphone sun-safety mobile application: a randomized clinical trial	A sun protection and UVI mobile app based on Social Cognitive Theory vs. online assessment only with follow up at 7 weeks	202 adults 18 years or older who owned a smartphone recruited nationwide in the US through online promotions.	+ RCT + Nationwide sample + High follow-up rate - Convenience sampling - Representative of interested sample - Racially homogenous	- 77% of intervention participants used the app at least once, which is an improvement from the previous study. - Participants in the intervention group used wide-brimmed hats more than controls.
Australia/New Zealand	Dixon et al. (2007)	Solar UV forecasts: a randomized trial assessing their impact on adults' sun-protection behavior	- RCT assigned to one of three weather forecast conditions, two of which contained the UVI. - Online survey	557 adult Australians with workplace e-mail and Internet access	+ RCT + No admitted cross contamination + Real world presentation of information - High protection awareness at baseline - Survey served as part of intervention - Convenience sampling	No significant differences in sun exposure, protection, or sunburn after any of the interventions.
Europe	Branstrom et al. (2003)	A randomized population-based intervention to examine the effects of the ultraviolet index on tanning behaviour	- RCT assigned to four groups receiving different information packages based on the Theory of Planned Behavior. - Mailed survey	A population-based random sample (n = 3200) in Sweden	+ RCT + Random sampling - Lack of generalizability outside of Sweden - Social desirability effect - Difference in difficulty between comparison brochures - Control condition not blinded	- Significant improvements in knowledge of UVR and attitudes toward sun protection. - Information about the UVI or a personal UVR intensity indicator did not decrease sunbathing and sunburn more when compared to the control information package.
Europe	Carli et al. (2008)	The use of commercially available personal UV-meters does cause less safe tanning habits: a randomized-controlled trial	RCT assignment to daily diary or daily diary plus UVI sensor.	91 medical school students from the University of Florence ages 21–23 years	+ RCT + Dermatologic examination for eligibility (representativeness) + High completion rate + Use of commercially available UVI meter (realistic) - Convenience sampling - Unbalanced geography between arms - Possible incorrect sensor functioning	- During days of sun-exposure, the intervention group noted longer exposure times and less use of sun protective measures when compared to those who just received the daily diary. - The odd ratio of sunburns was 1.60 for participants in the intervention group.
Europe	Sachse et al. (2016)	Face-to-face Sun Protection Training and Text Messages Improve Sun Protection Behaviour in Adolescent Organ Transplant Recipients: HIPPOlino Feasibility Study	- In-person sun protection training and text messages - Phone survey pre and post	26 organ transplant recipients in Austria and Germany ages 13–22	+ Pre-post design + Participants from all over Germany + Unique population - Small unblinded convenience sample - No control	- After training, 74% could answer a question correctly regarding what the term UVI. - 53% of participants reported that they increased sunscreen use, and 21% believed sun protective clothing were of increased importance.

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Table 1 (*continued*)

Outcome and country	Authors, year	Paper title	Methods	Sample size and characteristics	Strengths (+) and limitations (−)	Key findings
Other	Sanclemente and Diaz (2009)	Impact of a sun protection campaign in Medellin (Colombia)	- Educational brochure and a multimedia public sun protection campaign - Phone surveys pre and post	707 adults in Medellin, Columbia	+ Quota sampling + Large sample size + Pre-post design - Loss to follow up	- The percentage of participants who answered a question regarding the meaning of UVI increased from 2% to 9%. - Sun protective like hat and sunscreen use stayed constant. - Common communication means about the sun and its effects were TV and brochure.

[a] Listed under more than one outcome.

used this information to determine the "best" time to tan. Additionally, Jones et al. (2013) found that among white male high school students, as the average UVI increased, sunscreen use decreased, and the odds of never wearing sunscreen increased. In the US and Canada, researchers also found a weak negative association between the use of sun protective clothing and the UVI (Jones et al., 2013) and a statistically significant association between increased sunburn odds and high awareness of the UVI (Purdue et al., 2001). Thus, researchers need to help public health professionals determine how the UVI might be used to promote skin protection without unintended consequences.

3.3.2. Australia/NZ

Similarly, less than half of respondents in Australia and New Zealand who had heard of the UVI reported that the UVI influenced their sun protection. For example, Kricker and Armstrong (1998) surveyed a representative sample of 504 adults and 17 health professionals in New South Wales. Of the 64% of adults and 65% of health professionals who reported awareness of UVI, only 24% and 47%, respectively, reported that they used this information to determine personal or recommended sun protection. In a study that stratified results based on gender and time of year, 28% of men and 46% of women in the summer and 22% of men and 39% of women in the winter used the forecast to influence their sun-protective behavior (Alberink et al., 2000). In New Zealand, 80% of individuals stated that daily UVI had no influence on their sun protective behaviors (Blunden et al., 2004) and no significant association was identified between UVI levels and clothing coverage (Reeder et al., 2016). One study even found that 63% of participants perceived the burn time to be more useful than the UVI in guiding sun protection (Bulliard and Reeder, 2001). In summary, far fewer Australians or New Zealanders who are aware of the UVI use it to guide their sun exposure or protection behavior.

3.3.3. Europe

Research conducted in European countries has also found generally low levels of UVI use. Among 1094 Swedish adults, researchers found that of the 27% who had heard of the UVI, only 24% reported that they altered their sun habits as a result (Wester and Paulsson, 2000). However, the majority of participants (57%) believed that it would be good or very good if newspapers presented a daily report of the UVI (Wester and Paulsson, 2000). Morris et al. (2011) found that of 67% of UVI-aware participants in Southwest England, 60% reported that UVI did not impact their behavior. Also in the UK, Diffey and Norridge (2009) found that about one third of respondents reported that they had used the UVI at least once to plan their sun exposure. Use of the UVI did not have a significant effect on the adoption of two or more sun protection methods (i.e., shade, clothing, sunscreen). However, respondents who said they used the UVI also reported a lower incidence of recent sunburn.

In Germany, one study found that about two thirds of UVI-aware participants acknowledged that the UVI influenced their sun protective behavior (Borner et al., 2010). However, in another study, Klostermann et al. (2014) found that although most children received some form of sun protection (69–89% shade, clothes, or sunscreen), only 8% of parents reported that UVI had an impact on these behaviors. Disuse of UVI was positively associated with holidays in mountainous regions, suggesting that participants may not consider mountainous regions to have a high UVI.

Some researchers found that people who travel to high UVI locales engage in more risky sun exposure behavior than non-travelers. In France, Ezzedine et al. (2007a) and (2007b) surveyed expatriate travelers and non-expatriates and found that expatriates generally engaged in more sunbathing or outdoor activities during their lifetime, particularly women. Expatriate men reported experiencing more intensive sun exposure than non-expatriates during their lifetime. Similarly, researchers found that travelers reported more frequent sun exposure and placed greater emphasis on tanning, especially among

women. Expatriates were less informed about sun exposure risks than other health exposure risks in their country of stay. Sun protection behaviors were similar across groups. Although it is not clear whether knowledge of the UVI specifically influenced their sun-seeking behavior, it is likely that respondents had some awareness of the relatively high UVR levels in southern latitudes (Ezzedine et al., 2007b).

In summary, less than half of respondents in Europe who had heard of the UVI reported that the UVI influenced their sun exposure or protection. Awareness or use of the UVI has been associated with both lower risk (i.e., less sunburn) and higher risk (i.e., more sun exposure) behaviors.

3.4. Impact of UVI interventions

3.4.1. USA/Canada

Whereas the previous section examined the association between existing awareness and knowledge of the UVI on sun-related behaviors, this section focuses on the impact of targeted UVI-related interventions on knowledge, intentions, and behavior. Geller et al. (2002) evaluated the US EPA's SunWise School Program. Participating schools utilized UVR measurements and classroom lessons regarding the ozone, the importance of sun protection, and the provision of UVR data to schools and communities. Researchers noted that following the program, children in the intervention condition were more likely to wear long-sleeved shirts and intend to play in the shade compared to the control group. Buller and colleagues conducted two RCTs to evaluate the efficacy of the sun safety mobile application (app), Solar Cell (Buller et al., 2015a; Buller et al., 2015b), as well as an hourly UVI. In the first study, those randomized to the app reported more shade use but less sunscreen use than controls, with no significant difference in the number of sunburns. Participants may have believed that sunscreen is unnecessary when in the shade, thus cancelling out the risk and protective effects of behavior change on sunburns. Although only about 41% of participants in the treatment group used the app, app use was associated with greater sun protection (Buller et al., 2015a). In the second study, those randomized to the app reported greater use of the app than in the prior study and also reported wearing more sun protection clothing, particularly among women (Buller et al., 2015b). These findings suggest that engaging US adults in app-based interventions can modify sun protection behaviors in relation to the UVI. However, prior studies have also noted that app use can vary widely (Rathbone and Prescott, 2017).

3.4.2. Australia

Despite the fairly large number of studies that have assessed UVI awareness, understanding, and associations with behavior in Australia or New Zealand, only one randomized intervention trial was identified. Australian researchers found no significant association between weather forecasts with or without the UVI or sun protection messages and sun protection behavior or sunburn after 18 weeks (Dixon et al., 2007). However, in this study, the authors note that participants had high baseline skin protection awareness, the survey may have functioned as an intervention, and there may have been an effect of social desirability.

3.4.3. Europe

In various European countries, researchers have demonstrated mixed results regarding associations between the UVI interventions and sun protective behavior. A RCT of 1743 Swedish participants found that although knowledge increased among all intervention groups, information about the UVI, the use of a personal UVR intensity indicator, or their combination did not decrease sunbathing or sunburn any more than general written information about UVR exposure and sun protection (Branstrom et al., 2003). Researchers hypothesized that: 1) at the time, the UVI was only available on the Internet and a handful of newspapers, 2) the UVI may be more appropriate in countries with higher ambient UVR intensity, and 3) the detailed information about the UVI, UVR, sun protection, and the UVR sensor may have been too complicated for participants.

Similar results were found in a study in Italy in which medical students were randomized to a commercially available UVI sensor or a control condition. Contrary to hypotheses, the intervention group noted longer sun exposure, lower use of sun protection (i.e., sunglasses, hats), and higher frequency of sunburns. This may be due to the low-cost UVI sensors' under-reporting UVR exposure, causing participants to incorrectly believe that sun risk was low (Carli et al., 2008). In a study by Sachse et al. (2016), Austrian and German participants received in-person sun protection training as well as “traffic light”-type UVI warnings and sun protection reminder text messages for four weeks. Knowledge of the term UVI increased significantly post training. Researchers found that 58% of participants increased their sunscreen use on high UVI (over 8) days.

In summary, results of UVI-related interventions are mixed in terms of modifications in sun protection behaviors in European studies (Dixon et al., 2007; Branstrom et al., 2003). Researchers in Europe believe that such findings may be due to unfamiliarity with the UVI, especially in countries that do not normally experience intense UVR. Australian researchers suggest that the provision of UVI forecasts in relevant settings (i.e., on a sports event scoreboard when the public is already outdoors) may be more beneficial than repeated exposure to UVR forecasts in a more general and less relevant setting. Researchers also suggest that the provision of UVR forecasts could be counterproductive, providing a false sense of security or that it may encourage people to tan (Dixon et al., 2007).

3.4.4. Colombia

In Colombia, a prospective intervention study was conducted before and after a widespread sun protection campaign that utilized a brochure, radio, UVI digital displays on electronic billboards, and local television programs. Although about half of participants were lost to follow up, researchers found significant increases in knowledge about sun protection and the UVI but no significant increase in the use of sunscreen (Sanclemente and Diaz, 2009). The authors report that changes in knowledge were associated with exposures to the UVI brochure and television.

4. Overall conclusions

The strengths of this paper include the systematic review of over 20 years of international research on UVI awareness, comprehension, use, and impact on sun-related behaviors. Many of the individual studies included large sample sizes but were also typically cross-sectional and self-report in nature. Limitations of the review are the inclusion of only papers published in the peer-reviewed English literature. Gray literature was not included, but almost all of the studies from the gray literature included in Italia and Rehfuess's prior review were rated as weak in quality (World Health Organization et al., 2002). Despite including 12 additional studies published after 2010, we reached similar conclusions to Italia and Rehfuess (World Health Organization et al., 2002). Although we noted strengths and limitations of the studies reviewed, we did not conduct a formal quality assessment. Based on our overall review, the quality of the studies appeared variable, for example, with few studies being randomized controlled trials. However, we are doubtful that a formal quality assessment would significantly alter our conclusions. Additionally, for some outcomes and geographic regions, there was only one study available, so excluding consideration of a lower quality study might not be advantageous.

Although the UVI was intended to raise public awareness about the dangers of excessive UVR exposure and to improve sun protective behavior, global research findings have been mixed. In contrast to promising results regarding high levels of UVI awareness in studies conducted in the USA, Canada, Australia, and New Zealand, lower levels of UVI awareness have been found in Europe and elsewhere. Some

European researchers hypothesize that lower awareness levels may be due to the relatively lower UVI in those regions. Regardless of awareness of the UVI, comprehension and understanding of the UVI were consistently lower across regions.

This discrepancy suggests that even if individuals notice the UVI displayed in the media, many do not understand it enough to inform their sun-related behaviors. Though some individuals use the UVI to inform their skin protection behavior, many do not. It is well-known that although knowledge is often necessary in inform behavior, it is rarely sufficient (Happell et al., 2014). Moreover, some researchers in the US and France found that the UVI may even be positively associated with risky sun exposure (Geller et al., 1997; Ezzedine et al., 2007a; Ezzedine et al., 2007b). Such findings suggest that although there is some public awareness of the UVI, its promotion and use is largely inadequate. Mechanisms potentially influencing the relationship between the UVI and behavior were not well-described in the cross-sectional studies.

Fewer studies evaluated the impact of UVI-related interventions on behavior than evaluated the other two outcomes, and results have been mixed. The results of the available RCTs are inconclusive in terms of effects of UVI-specific interventions on sun safety behavior. In the US, results from interventions conducted through a school program (Geller et al., 2002) or an app for adults were found to improve some skin protection outcomes (Buller et al., 2015a, 2015b). It should be noted that the app also presented general sun protection information, not just the UVI. However, studies from several other countries demonstrated no intervention effect on behavior. A small Italian intervention study (Carli et al., 2008) even demonstrated more UVR exposure and less skin protection after intervention among medical students.

Especially given this possibility for a negative impact, better education about the UVI and how it could be used to inform sun protection would need to be provided to the public. Even among high-awareness individuals, there is a need to conduct more research to determine how best to communicate information about the UVI, improve comprehension, and increase the impact of the UVI on sun protection behavior (Allinson et al., 2012). Many people are motivated to tan for appearance enhancement, and this has not been well-addressed in the UVI literature. Indeed, the UVI has been used by some to facilitate tanning and potentially justify unprotected exposure. There is more research on successful appearance-focused (Dodd and Forshaw, 2010; Williams et al., 2013) and other types of interventions to improve sun safety (Saraiya et al., 2000, Reinau et al., 2012, Rodrigues et al., 2013) than on the use of UVI to modify behavior. One of the other barriers to sun protection is that people do not believe they need to protect themselves at certain times or in certain places, and they make decisions about their skin protection based on temperature or burning rather than UVI. Little attention was paid to the potential impact of various settings on UVI use. For example, sun protection would likely vary for outdoor versus indoor workers or at school versus at home. Similarly, the Global Solar Index Workshop determined that although the UVI is a useful tool to influence sun protection behavior, it could be improved by adapting it to fit varying countries' conditions (Gies et al., 2018).

Would a more nuanced message advising a variety of behaviors based on an imperceptible and changing UVI produce greater behavior change? One of the challenges related to the use of the UVI is that it is fairly complex with regard to behavior change. For example, it changes across hours, days, weeks, months, and years as well as geographic locales and environments within locales (e.g., near the water). At different values, individuals are advised to engage in multiple different sun safety behaviors. People are most successful at increasing and maintaining healthy behaviors (e.g., hand washing) when they become habits. Other than checking the UVI daily, most of the other recommendations related to the UVI essentially preclude habit formation since it has not necessarily been recommended to wear sunscreen during all daylight hours every day all year-round, for example.

Simplification of behavioral messages such as only differentiating between low, moderate, and high UVI, with easily-differentiated behavioral recommendations for each level could be more useful than highly-nuanced messages. More basic behavioral research is needed to inform future interventions. For example, it would be important to determine how many and what types of numbers, colors, images, messages, and behaviors people can attend to most effectively. This type of research should be conducted before future widespread public campaigns. There are extant literatures on health literacy, numeracy, and communication upon which to draw. On the other hand, simple messages such as “wear sunscreen” or “avoid intentional tanning” are sometimes ignored without awareness of the importance of these behaviors in reducing the risk for sunburn, skin cancer, and skin aging and addressing practical issues such as convenience and comfort.

There is also a need for further studies of models, mechanisms, and constructs from psychosocial theory such as self-efficacy and barriers to behavior change, which have been underutilized (Allinson et al., 2012), as well as newer promising effective means of communicating the UVI such as text messages and social media. Additionally, there are a couple of additional methodologic issues that could particularly strengthen intervention research in this area: 1) isolation of the effects of UVI-related interventions from other sun protection intervention components and 2) increasing sample size and statistical power in order to obtain more conclusive results. Regarding the former point, more randomized studies could be conducted in which participants receive sun protection interventions with or without a UVI component in order to help determine the independent effects of the UVI component. The Global Solar Index Workshop stressed that the existing research has not yet demonstrated that the UVI is an effective method of behavior change on its own and that it should be used in combination with other effective health communication campaigns at this point (Gies et al., 2018). The aforementioned research and intervention recommendations could help clarify and enhance the utility of the UVI for the public health.

Conflict of interest

The authors declare that there is no conflict of interest.

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