Research/Recherche

Ocular exposure to UV-B in sunlight: the Melbourne visual impairment project model

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Quantification of ocular exposure to ultraviolet-B radiation (UV-B) has become an important public health issue, with reports that the ozone layer is being depleted worldwide. Ocular exposure to UV-B is determined by ambient UV-B levels, the duration of outdoor exposure, the proportion of ambient UV-B that reaches the eye, and the use of ocular protection. We have developed a simplified model for quantifying lifetime ocular UV-B exposure that can be used in large epidemiological surveys. Exposure to UV-B is assessed and quantified using a model based on personal exposure over the six summer months. Data available for a population-based sample of 1150 people in the age range 40–98 years revealed a distribution in average annual lifetime ocular UV-B exposure similar to that reported in a previous study on which this model is based, and also demonstrate that people can recall lifetime personal behaviour related to ocular protection. It takes 12 minutes on average to collect these data. This model can be employed by researchers worldwide for uniform assessment of ocular UV-B exposure.

Introduction

Clinicians, public health researchers, and programme planners have recently become interested in personal exposure to sunlight and ultraviolet-B (UV-B) radiation as preventable risk factors for sunburn, melanoma, and a number of ocular disorders (*1*).[a] Epidemiological studies of the association between cataract and personal ocular UV-B exposure in different geographical locations should permit investigation of the relationship between a thinning ozone layer (and hence increased UV-B exposure) and higher prevalence of cataract and lens opacities. As a consequence of the Earth Summit in Brazil in 1992, WHO and the International Agency for Research on Cancer (IARC) proposed that a multicentre study of the effect of environmental change on solar UV-B radiation and health be set up, with one component being the measurement of the ocular effects of UV-B radiation (*3*). The information obtained could be used to develop policies and programmes for the prevention of adverse ocular effects arising from UV-B exposure.

Two large epidemiological studies of eye disease in the USA collected data on UV-B exposure and demonstrated a positive association between lens opacities and UV-B exposure (*3*, *4*). Of these, the Chesapeake Bay Waterman Study quantified UV-B exposure in "Maryland sun years" using a model that includes information on history of work activity, leisure activity, wearing of spectacles, and hat use, along with field and laboratory measurements of UV-B radiant exposure (*5*), while in the Beaver Dam Eye Study, a sunlight exposure variable was calculated based on a "Wisconsin sun year" (*3*). A simplified model for assessing ocular exposure to UV-B radiation has also been developed and evaluated (*6*). This model includes ocular UV-B exposure during the middle of the day (09:00 to 15:00) over the northern hemisphere summer months (April–September). The results correlated highly with the full model ($r = 0.98$), while predicting 62% of total ocular exposure and requiring far less participant's time. Such a model is useful for epidemiological studies if relative rather than absolute UV-B exposure is the variable of interest, and if limited resources preclude the implementation of a longer, more complete model. The aim of the present investigation was to extend this work and to develop fur-

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[a] *The effects of solar UV radiation on the eye. Report of an informal consultation, Geneva, 30 August to 3 September 1993.* Unpublished document WHO/PBL/EHG/94.1, 1994.

Reprint No. **5710**

ther a questionnaire and model for the assessment and quantification of UV-B exposure in participants in population-based epidemiological studies of eye disease. This work was undertaken specifically for the Melbourne Visual Impairment Project (Melbourne VIP). The model is based on the abbreviated model previously tested in the Chesapeake Bay Waterman study (6), but includes a measure of childhood exposure and more information about leisure-time behaviour.

Methods

Assessment tool

The model for personal ocular exposure to UV-B (see Annex) is based on a questionnaire that includes the following questions (Table 1):

- For each period of working life greater than 6 months, where did you live, what was your occupation, and how many hours between 09:00 and 17:00 (daylight savings) did you spend outdoors on weekdays and at the weekend during the warmer months, from mid-spring to mid-autumn?
- Did you work over water during that period?
- During that time spent outdoors, how often did you wear a hat, sunglasses or prescription spectacles/contact lenses on weekdays and at the weekend?

One piece of information included in the abbreviated model was not present in the Melbourne VIP questionnaire. This was the number of days worked per week, because in the majority of cases, workweeks comprise 5 days regardless of which days.

Additional information on the length of time lived at all different locations was gathered for school life-periods. Other than location in childhood, it was believed that the majority of variation in cumulative lifetime ocular UV-B exposure is due to behaviours in adulthood and that childhood exposures are likely to be generally similar among people in a given environment. Also, it is very difficult to quantify childhood behaviours with an acceptable degree of reliability and validity.

A data entry programme was developed using Paradox software (Borland International, Scotts Valley, CA, USA) for IBM-compatible microcomputers and an analytical tool was developed using Pascal (Borland International). Both were evaluated by comparing the computer-generated with the manually computed exposure variable.

Prior to being interviewed, participants were asked to complete a chronological listing of their life-periods by year, location, and occupation. They were then questioned by a trained interviewer about the protective behaviours mentioned previously during those life-periods. The questionnaire makes allowance for up to 10 school life-periods and 20 adult life-periods of at least 6 months' duration.

Quantification of exposure

The sunlight exposure questionnaire takes 3–25 min to administer (mean, 12 min), depending on the age and mobility of the participant. The data obtained were entered in duplicate into the computer by the trained interviewer. The analytical tool was then used to calculate exposure in Melbourne sun years (see Annex).

The assumptions made in adopting the original model from the Chesapeake Bay Waterman study include those shown below.

— Everyone who works does so for 5 days and has a 2-day weekend or leisure period.

— Subjects were queried about the amount of leisure time spent outdoors and the proportion of time wearing ocular protection from UV, but were not queried about their specific leisure activities. Therefore, exposure during leisure time was assumed to occur over land (with the exception of those people who lived "at sea", when leisure time was assumed to occur over water). A question about whether weekend leisure activities took place over water can easily be added to the questionnaire if researchers expect water activities to be common in their study populations.

Evaluation of the assessment instrument

The UV-B assessment instrument was evaluated on data collected from 1150 consecutive participants in the Melbourne VIP. Lifetime ocular exposure was quantified and then correlated with age. Additionally, backwards stepwise regression models were used to evaluate the independent effect of UV-B exposure and personal ocular protection behaviour on average annual lifetime ocular UV-B exposure. Finally, facial UV-B exposure was calculated by removing the terms related to use of spectacles, contact lenses, and sunglasses. Linear regression was used to compare the relationship between ocular UV-B exposure and facial UV-B exposure. All statistical analyses were performed with SAS software (Cary, NC, USA).

Results

The personal ocular UV-B exposure model was evaluated on 1150 participants (age range, 40–98

Table 1: **Simplified questionnaire for the assessment of personal ocular UV-B exposure** (SUNGLS = sunglasses; GLS/CL = glasses/contact lenses)

Yr/Age began wearing: GLASSES: ..... CONTACT LENSES: ..... SUNGLASSES normal: ..... prescription: ..... photochromatic: ..... clip-on: .....

LIFE PERIODS SINCE LEAVING SCHOOL		*DAYTIME ACTIVITIES*					*LEISURE ACTIVITIES*				
COL.1 LOCATION	COL.2 ACTIVITY	COL.3 HOURS	COL.4 HAT	COL.5 SUNGLS	COL.6 GLS/CL	COL.7 WATER	COL.8 HOURS	COL.9 HAT	COL.10 SUNGLS	COL.11 GLS/CL	COL.12 WATER
PERIOD 1											
Town:	Position										
State/ Country	Industry	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Year/Age	Tasks & Resp				.....					.....	
PERIOD 2											
Town:	Position										
State/ Country	Industry	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Year/Age	Tasks & Resp				.....					.....	
PERIOD 3											
Town:	Position										
State/ Country	Industry	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Year/Age	Tasks & Resp				.....					.....	
PERIOD 4											
Town:	Position										
State/ Country	Industry	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Year/Age	Tasks & Resp				.....					.....	
PERIOD 5											
Town:	Position										
State/ Country	Industry	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Year/Age	Tasks & Resp				.....					.....	
PERIOD 6											
Town:	Position										
State/ Country	Industry	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Year/Age	Tasks & Resp				.....					.....	
PERIOD 7											
Town:	Position										
State/ Country	Industry	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Year/Age	Tasks & Resp				.....					.....	
PERIOD 8											
Town:	Position										
State/ Country	Industry	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Year/Age	Tasks & Resp				.....					.....	
PERIOD 9											
Town:	Position										
State/ Country	Industry	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Year/Age	Tasks & Resp				.....					.....	
PERIOD 10											
Town:	Position										
State/ Country	Industry	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Year/Age	Tasks & Resp				.....					.....	

years; mean, 59.5 years) of which 500 were males (43.5%).

Lifetime ocular UV-B exposure ranged from 0.01 to 3.39 Melbourne sun years (median, 0.54) (Fig. 1). The distribution is skewed to the left, with relatively few people having extremely high exposures.

The average annual ocular UV-B exposure was significantly related to age ($r = 0.07$; $P = 0.03$) (Fig. 2). Stepwise regression modelling revealed that for this cohort the increase in average annual ocular UV-B exposure with age was due to both higher ambient UV-B exposure and lack of use of personal ocular protective devices (Table 2). The following significant factors remained in the multivariate model after backwards elimination: average number of hours that a hat was worn at work and leisure; average number of hours that sunglasses were worn at work and leisure; average number of hours that spectacles were worn at work; use of contact lenses during leisure time; average number of hours spent outdoors; and average number of hours that a hat was worn during leisure hours. All of these factors decreased with increasing age of the participant, with the exception of the average number of hours spent outdoors, which increased with age. The R^2 for this model was 0.89. The few outliers (Fig. 2) were men who had been farmers all their lives and who rarely used ocular protection.

At all ages, males had a significantly higher mean annual ocular UV-B exposure than females ($F = 168.7$; $P = 0.0001$) (Fig. 3). The relationship between age and average annual ocular UV-B exposure differed by sex. The correlation between age and average annual ocular UV-B exposure in males was 0.15 ($P = 0.0005$), while for females the correlation was not significant ($r = 0.01$, $P = 0.80$). This difference most probably arose because the women in the study cohort worked in the home, while the men worked outside the home.

The range of lifetime facial UV-B exposure was 0.01–3.40 Melbourne sun years (mean, 0.85 ± 0.48). The average annual facial UV-B exposure was

Fig. 1. **Distribution of lifetime effective ocular UV-B exposure among the study population.**

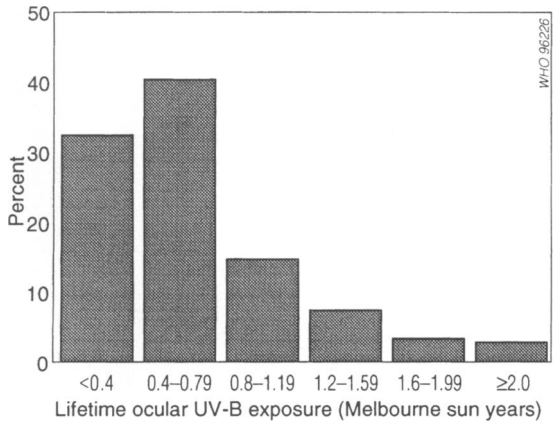

Fig. 2. **Lifetime ocular UV-B exposure, by age, among the study population.**

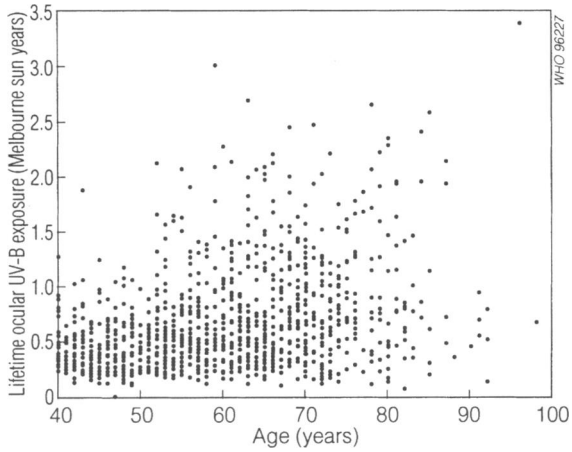

Fig. 3. **Age- and sex-specific mean (± SD) average annual ocular UV-B exposure among the study population.**

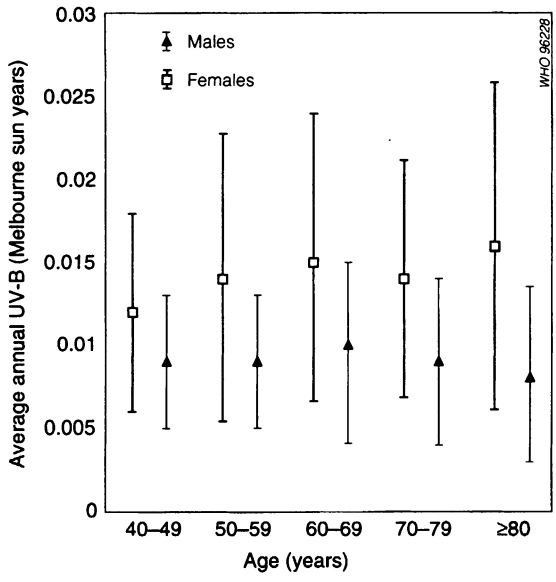

Table 2: **Multivariate relation of ocular UV-B exposure factors and age**

Model factor	Parameter	Standard error	*F*-value	*P*-value
Average work hours wearing hat	−0.001	0.00009	138.2	0.0001
Average work hours wearing sunglasses	−0.003	0.0001	426.4	0.0001
Average work hours wearing spectacles	−0.002	0.0001	187.9	0.0001
Average work hours wearing contact lenses	−0.002	0.001	12.4	0.0004
Average work hours spent outdoors	+0.003	0.0001	2763.2	0.0001
Average leisure hours wearing hat	−0.0002	0.0001	10.7	0.001
Average leisure hours wearing sunglasses	−0.001	0.0001	140.4	0.0001
Average leisure hours wearing spectacles	−0.001	0.0001	120.3	0.0001
Average leisure hours spent outdoors	0.002	0.0001	607.1	0.0001

highly correlated with the average annual ocular UV-B exposure ($r = 0.87$; $P = 0.0001$).

Discussion

Although ambient levels of UV-B radiation may vary up to fourfold with geographical region (*11*) and with occupation, ocular protection can have a ninefold impact on personal ocular exposure (*5*, *7–10*). Our findings show that lifetime personal ocular UV-B exposure can be ascertained relatively easily by questionnaire and that people can recall personal behaviour related to ocular UV-B exposure over their lifetime. Although we have no way of confirming the validity of individual recall data on personal exposure, the observed internal consistency and dose–response support the validity of the questionnaire and model.

This model for the personal assessment and quantification of ocular UV-B radiation exposure is intended for use in large-scale epidemiological surveys of eye disease where a relative measure of ocular exposure to UV-B radiation is desired that can be used to rank individuals by exposure. It is based on the results of studies that examined using objective dosimetry the ocular dose of UV-B radiation under various conditions (*5*, *6*), and requires surprisingly little time for the interviewer and subject. The questionnaire is far simpler than the original version (*5*), since it requires quantification of exposure for the daylight hours over only 6 months of the year; in temperate zones this accounts for 96% of potential exposure (*6*). Previously, we have demonstrated the high correlation between such a shortened questionnaire and a longer version (*6*). More importantly, we showed that the relative ranking of people in terms of exposure did not vary according to the version of the questionnaire. For epidemiological studies ranking individuals on an exposure continuum is of primary importance.

The computerized data entry and analysis systems are valuable cost-saving tools for epidemiological field studies and yield multiple exposure variables for use in statistical analyses.

The model we have described should prove useful for studying the ocular effects of UV-B radiation and could be employed by researchers engaged in similar studies in other countries. Standardization of assessment techniques will permit comparison of data across studies and time and help us to assess the effects of changes in the environment and UV-B exposure on the incidence, prevalence, and progression of ocular disorders, such as cataract, and facial skin disorders, such as non-melanotic skin cancer.[b]

Various proposals have been forwarded for the assessment of exposure to ultraviolet light (*13*, *14*). For example, examination of the UV-B attenuation afforded by the eyebrows and by squinting or partially closing the eyelids in bright sunlight suggests that the relative eyelid opening varies by individual, although further information is not currently available (*13*); it might not, however, be feasible or practical to measure individual attenuation of UV-B arising from such factors. Nevertheless, on a population level, if the attenuation due to these factors is found not to be related to other measured variables, such as sex or occupation, information about the attenuation of UV-B radiation would shift the distribution of ocular UV-B exposure, but not necessarily affect the ranking of individuals within the population of interest; for epidemiological studies, it is relative rather than absolute exposure that is of importance. Further research is needed to determine how the attenuation of ocular UV-B exposure from squinting varies throughout a lifetime, since the shape of the eyelids varies with an individual's age. Once additional data are collected on the effect of eyebrows or squinting on UV-B attenuation, they can easily be included in this model either as modifiers for the variables derived by Rosenthal et al. (*5*) or as new variables.

[b] Single copies of the questionnaire can be obtained upon request from Dr McCarty.

Several other methodological considerations in epidemiological studies for measurement of ocular UV radiation exposure have recently been reviewed (*14*). These include information on lifetime personal exposure, meteorological data, laboratory data on the protection factor, and biological markers of ocular UV exposure. The present model takes into account the first three of these methodological considerations. Identification of a noninvasive, objective biological marker of lifetime ocular UV exposure would clearly be of great benefit for epidemiological studies and could potentially decrease misclassification bias. Until such a biological marker becomes available, however, epidemiologists need to have access to a simple assessment tool based on laboratory data, such as the current model. As further data about the UV exposure geometry (*13*) become available, it should be easy to incorporate them into the questionnaire and model we have described here.

Acknowledgements

The Melbourne Visual Impairment Project is supported, in part, by grants from the Victorian Health Promotion Foundation and the National Health and Medical Research Council. We gratefully acknowledge the help provided by Dr C. Guest in developing the sunlight questionnaire and by Mrs S. Lee in the computer programming for analysis of the data.

Résumé

Exposition oculaire aux UVB solaires: le modèle du Melbourne Visual Impairment Project

La quantification de l'exposition oculaire au rayonnement ultraviolet B (UVB) est aujourd'hui une importante question de santé publique du fait de la réduction de la couche d'ozone partout dans le monde. L'exposition oculaire aux UVB est déterminée par plusieurs facteurs: niveau ambiant du rayonnement UVB, durée de l'exposition à l'extérieur, proportion des UVB atteignant l'œil et utilisation d'une protection oculaire. Nous avons élaboré un modèle simplifié permettant de quantifier l'exposition oculaire aux UVB sur toute la vie, utilisable dans le cadre de vastes enquêtes épidémiologiques. L'exposition aux UVB est évaluée et chiffrée au moyen d'un modèle basé sur l'exposition personnelle au cours des six mois d'été et comportant le questionnaire suivant:

• Pour chaque période de vie active ayant duré plus de six mois, où habitiez-vous, quelle était votre profession, et combien de temps passiez-vous à l'extérieur les jours de semaine et les week-ends de la mi-printemps à la mi-automne?

• Travailliez-vous sur l'eau pendant cette période?

• Pendant le temps passé à l'extérieur, combien de temps (en pourcentage) portiez-vous un chapeau, des lunettes de soleil ou des lunettes correctrices les jours de semaine et pendant les week-ends?

Des renseignements complémentaires sur la durée du séjour en différents endroits ont été recueillis pour la période de scolarité.

Dans ce modèle, l'exposition peut être exprimée en exposition oculaire aux UVB cumulée sur toute la vie, exposition oculaire annuelle moyenne aux UVB, et exposition oculaire aux UVB pour chaque année de la vie. En soustrayant les éléments concernant le port de lunettes correctrices, de lentilles de contact et de lunettes solaires, on peut calculer les paramètres équivalents pour l'exposition faciale aux UVB. Cet outil a été évalué au moyen de données recueilies sur un échantillon de 1150 personnes âgées de 40 à 98 ans. L'exposition oculaire aux UVB sur toute la vie allait de 0,01 à 3,39 années-soleil (Melbourne), avec une distribution de l'exposition oculaire annuelle moyenne analogue à celle qui était rapportée dans une étude précédente ayant servi à l'élaboration du modèle. L'exposition oculaire annuelle moyenne aux UVB était significativement liée à l'âge (r = 0,01; p = 0,03). En procédant à une régression par étapes, nous avons montré que, pour la cohorte d'étude, l'augmentation de l'exposition oculaire annuelle moyenne aux UVB avec l'âge est due à la fois à une augmentation de l'exposition aux UVB ambiants et à l'absence d'utilisation d'une protection oculaire personnelle. Ces résultats montrent qu'il est possible de se souvenir de son comportement personnel en matière de protection oculaire sur toute la vie. La collecte de ces données a pris en moyenne 12 minutes. Ce modèle peut être utilisé par les chercheurs du monde entier afin d'uniformiser l'évaluation de l'exposition oculaire aux UVB.

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Annex

Quantitative model for determining exposure to sunlight in Melbourne sun years

Shown below is the quantitative model for calculating the exposure of individuals to sunlight in Melbourne sun years.

$$
\begin{aligned}
OE_{eff} = & \sum_{s=1}^{n} years_s \times LF_s \\
& + \sum_{p=1}^{n} years_p \left\{ \left[hrsday_p \times \frac{5}{7} \times LF_p \right] \times \right. \\
& \left[watday_p \times 1.9 + \left(1 - watday_p\right) \right] \times \\
& \left[hatday_p \times 0.53 + \left(1 - hatday_p\right) \right] \times \\
& \left[sunday_p \times 0.07 + \left(1 - sunday_p\right) \right] \times \\
& \left[glsday_p \times 0.21 + \left(1 - glsday_p\right) \right] \times \\
& \left. \left[clday_p \times 0.31 + \left(1 - clday_p\right) \right] \right\} \\
& + \left\{ \left[hrsleis_p \times \frac{2}{7} \times LF_p \right] \times \right. \\
& \left[watleis_p \times 1.9 + \left(1 - watleis_p\right) \right] \times \\
& \left[hatleis_p \times 0.53 + \left(1 - hatleis_p\right) \right] \times \\
& \left[sunleis_p \times 0.07 + \left(1 - sunleis_p\right) \right] \times \\
& \left[glsleis_p \times 0.21 + \left(1 - glsleis_p\right) \right] \times \\
& \left. \left[clleis_p \times 0.31 + \left(1 - clleis_p\right) \right] \right\}
\end{aligned}
$$

where

OE_{eff} = lifetime effective ocular exposure
$years_s$ = number of school years in period s
LF_s = location factor, dependent upon where the person lived during school period s relative to Melbourne, Australia
$years_p$ = number of years in life period p
$hrsday_p$ = number of hours each weekday spent outdoors in sunlight from mid-spring through mid-autumn during period p
LF_p = location factor, dependent upon where the person lived during period p relative to Melbourne, Australia
$watday_p$ = 1 if worked over water in period p
= 0 if did not work over water in period p
$hatday_p$ = % of time that the person wore a brimmed hat on weekdays in period p
$sunday_p$ = % of time that the person wore sunglasses on weekdays in period p
$glsday_p$ = % of time that the person wore ordinary glasses on weekdays in period p
$clday_p$ = % of time that the person wore contact lenses on weekdays in period p
$watleis_p$ = 1 if spent leisure time over water in period p
= 0 if did not spend leisure time over water in period p
$hrsleis_p$ = number of hours each weekend day spent outdoors in sunlight from mid-spring through mid-autumn
$hatleis_p$ = % of time that the person wore a brimmed hat on weekend days in period p
$sunleis_p$ = % of time that the person wore sunglasses on weekend days in period p
$glsleis_p$ = % of time that the person wore ordinary glasses on weekend days in period p

$clleis_p$ = % of time that the person wore contact lenses on weekend days in period p

The factor 1.9 used in the expression reflects the nearly twofold increase in ocular exposure caused by the surface reflectivity of water (*10*), while the other factors relate to the degrees of ocular protection provided by hats (0.53), sunglasses (0.07), spectacles (0.21), and contact lenses (0.31) (*8*, *9*). These values were derived by Rosenthal et al. in studies of the ocular dose of UV radiation from sunlight exposure under various environmental conditions and with various personal behaviours related to ocular protection (*7–10*).

In this model, exposure can be expressed as cumulative lifetime ocular UV-B exposure, average annual ocular UV-B exposure, and ocular UV-B exposure for each year of life. By removing the components related to use of spectacles, contact lenses, and sunglasses from the model, the equivalent facial UV-B exposure variables can be calculated.

The location factor relative to Melbourne, Australia, was developed using information about radiant UV-B from Schulze (*11*) and Paltridge & Barton (*12*). It can be readily updated when more precise data and changes over time are documented or with data from other sites.

For the period of time that a person was in school, ocular UV-B exposure is calculated as the sum of years multiplied by the location factor times 0.046 (the exposure for a person over land) times 2/8 (assuming 2 h of exposure for everyone out of a possible 8 h), and is the first term in the model. A standard 2 h was used for everyone because it was believed that people would not be able to recall reliably how many hours they spent outdoors during their childhood and that most of the variation between individuals would be due to UV-B exposure in adulthood.