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Assessing UVB Radiation Received by School Children in Mid-Latitude Ontario, Canada

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Abstract

School children can receive too much ultraviolet B (UVB) radiation on schoolgrounds, leading to sunburn (erythema) and risking melanoma. Yet receiving too little UVB can result in vitamin D deficiency, which is needed for bone metabolism and may be linked to cancer, hypertension, and influenza. We measured the UVB received by school children using personal dosimeters (electronic instruments that measure UV exposure) during mid-winter in southern Canada. Dosimeter measurements validated a model that then estimated the amount of UVB children receive throughout the year. During summer children would receive too much UVB in unshaded schoolgrounds, but during the school year children would receive insufficient UVB. Findings provide evidence that schoolgrounds in mid-high latitudes should have strategic shading during summer but allow UVB exposure in other seasons.

Keywords: vitamin D, erythema, shade guidelines, landscape design

Ultraviolet B Radiation and Health

Skin cancer causes about 60,000 deaths per year (Lucas, 2010). One type of highly-preventable skin cancer, malignant melanoma, is caused by overexposure to solar ultraviolet B (UVB) radiation (Wright, Reeder, Bodeker, Gray, & Cox, 2007). Shade guidelines and policies have been developed in many countries in response to solar overexposure and many of these guidelines have been applied to schoolgrounds in an attempt to protect children. Providing shade for school-aged children can be effective during times of the year when solar radiation levels are high, because shade reduces transmissivity of UVB radiation.

Yet, UVB has positive health benefits through the synthesis of vitamin D in a person's skin. Vitamin D deficiency has been linked to health issues including cancer, cardiovascular disease, influenza, and multiple sclerosis (Engelsen, 2010; Grant, 2010). UVB as threat or benefit establishes a dilemma for schoolground designers: should they provide open skyviews to allow for more vitamin D synthesis, or provide more shade to block UVB and reduce melanoma risks?

UVB is diffuse radiation and is received approximately equally from all parts of the sky. Many elements in the landscape modify the amount of UVB that a person receives, including trees, shrubs, and buildings. Vegetation absorbs most of the UVB spectrum. Leaf reflectance of UVB is very low (~5%), and leaf transmittance is essentially zero regardless of plant species (Yoshimura, Zhu, Wu, & Ma, 2010). Trees can provide a canopy of overhead protection, while buildings, shrubs and hedges can also assist in intercepting diffuse radiation from other directions (Yoshimura et al., 2010).

Ameliorating UVB

Shade guidelines for schoolgrounds were originally developed in Australia in response to high incidences of skin cancer (Greenwood, Soulos, & Thomas, 1998). Canadian cities have developed shade guidelines (e.g., City of Toronto, 2007; Waterloo Region Shade Work Group, 2012), however most of Canada is in the mid- to high-latitudes (above 45ºN) while Australia is mostly a low-latitude country (15-35ºS). This means that winters in Australia are still quite sunny with high sun angles, but in Canada the amount of sunshine received in winter can be very low because of low sun angles and reduced daylight periods.

Particularly in Canadian regions in the lee of the Great Lakes where seasonal cloud cover is extensive, solar radiation is low in late fall and early winter when school is in session (from the first week of September until third week of June). Shade guidelines for outdoor spaces in a city in southern Ontario (Waterloo), for example, include design considerations such as, "shade the play equipment or frequently used activity areas," and considerations to "get shade closer to the structure" (Waterloo Region Shade Work Group, 2012, p. 5). While Canadian guidelines also reference critical exposure times (e.g., City of Toronto, 2007), the emphasis of the design guidelines is on managing sun exposure to reduce risk of sunburn, much like Australian and American guidelines.

The design of a landscape affects the amount of UVB that a person receives. A practical challenge is how to design landscapes that afford people an opportunity to receive enough daylight to synthesize sufficient vitamin D while avoiding the dangers of sunburn (referred to in this paper by its medical term, erythema). UVB exposure is particularly important in landscapes designed for children as they require vitamin D for healthy growth and development, and they are particularly sensitive to erythema. Children are often required to spend time outside in schoolgrounds during the academic year, making the design of these landscapes consequential.

This study measured and modeled UVB levels experienced by children on a schoolground in southern Ontario, Canada throughout the year. Our project (a) measured the amount of UVB received by school children in mid-winter; (b) compared the measurements with a pre-existing model to validate its use in winter conditions; (c) applied the model to other times of the year; and (d) compared the results with required amounts of UVB to produce vitamin D and the limit before erythema is expected to occur. We approached the research as a pilot study due to time and funding constraints and the practicalities of engaging school children to volunteer for the study.

Methods

The project set the sample frame as elementary schools in the Regional Municipality of Waterloo, Ontario, Canada, where school shade guidelines have been proposed (see inset, Figure 1).

The region is conveniently located adjacent to the lead researcher's university, and has 103 elementary schools with 42,000 students. Research ethics clearance permitted researchers to interact only with the school board in executing the study, not with teachers or schools.

Ultimately the number of participating schools was limited to those willing to volunteer and to inform parents and secure their permissions to participate in a matter of a few weeks, before executing the study with students. One school and teacher expressed a willingness to participate in our time frame. The limited amount of participation with a convenience sample leads us to consider this an exploratory pilot study to inform future investigation.

The participating school is Millen Woods Elementary School in Waterloo, Canada (43.5ºN, - 80.5ºW; Figure 1). A convenience sample of children was selected by the teacher to wear one of three radiation-sensing dosimeters. The participants were grade 3 and 4 students, male and female, aged 8 and 9 years. With this sample we measured then modeled the amount of UVB radiation that children received on the schoolground.

Figure 1. Plan view of Millen Woods Elementary School, Waterloo, Ontario. Landscape attributes are illustrated over aerial photograph base. Inset (lower left) shows location of Waterloo Region in southern Ontario, Canada. Inset (upper left) shows three dosimeters worn over a coat sleeve. Photographs (right side) correspond to locations on schoolground

Source of aerial photograph: Google Maps; source of inset map: Regional Municipality of Waterloo; source of dosimeter photograph: Victoria Cox; source of schoolground photographs: Laura Hilliard

Measurements

Measurements were taken using personal UV dosimeter badges: Mark II (Scienterra, New Zealand) set to record UVB wavelengths (280-320 nm). Dosimeter badges are small (36 mm diameter and 13 mm thick), lightweight (26 g) and circular, attached with a band. The UVB spectral response of the dosimeters is approximately 230-320 nm. Dosimeters were calibrated against a UVB Solarmeter (Solartech Inc.) under a range of test conditions. The results were all within 10 percent of the Solarmeter values, considered acceptable (Webb, 1998). Dosimeters are the best way to measure UV exposure received (McCarty, 2008) and have been used in a number of exposure studies (Thieden, Agren, & Wulf, 2000; Thieden, Collins, Philipsen, Murphy, & Wulf, 2005; Bodekaer, Petersen, Philipsen, Heydenreich, Thieden, & Wulf, 2015; Thieden, Philipsen, Sandby-Møller, Heydenreich, & Wulf, 2004; Køster et al., 2016; Vanos, McKercher, Naughton, & Lochbaum, 2017).

Dosimeters were attached the upper arm of the participants over their winter jackets (see inset, Figure 1). Data were gathered with three participants during 15 collection events over three days in February 2013 with varying weather conditions (see Table 1) ranging from fully overcast to full sun. Participants were outdoors from 10:50-11:10 am and 1:30-1:50 pm on each day. The entire school site is 2.28 hectares (ha) and has an open yard facing west (see Figure 1). The schoolground has a building that occupies 16 percent (3,700 m^2) of the area, and pavement on 21 percent (4,700 m^2) of the site. The open area (turf and shrub or tree cover) is 63 percent or 1.44 ha of the schoolground. Several deciduous trees are around the perimeter of an asphalt play area with north and western exposures where the students' play is generally concentrated in the winter months. The existing trees are young and small and offer minimal shade for those playing on the asphalt, yet all vegetation and structures affect the UVB received. The ground surface was covered with fresh snow during data collection and the participants were dressed for cold weather with only their faces exposed.

At the end of each test day, the data were downloaded from the dosimeters. Data were recorded for each minute of each test period (totaling ~600 dosimeter readings), and these values were summed daily to determine the total amount of UVB that each subject received.

Models

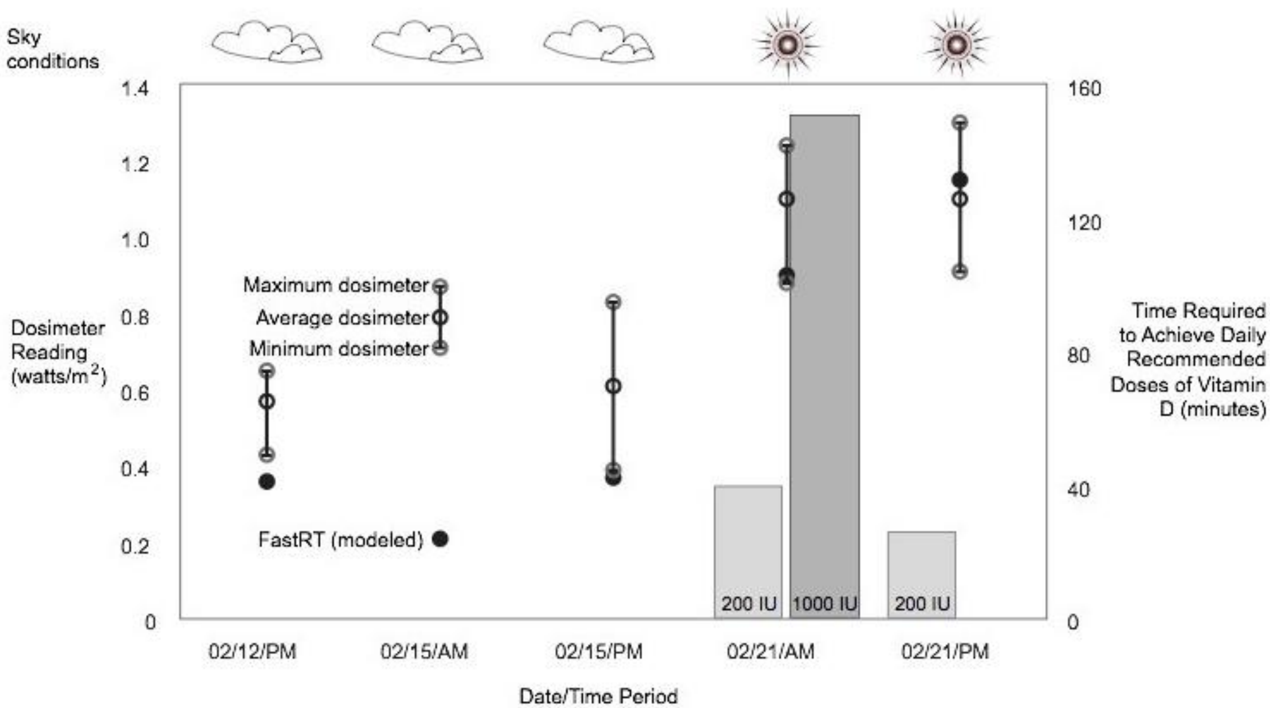
Few models exist for assessing UV radiation and vitamin D effects; the existing modeling is considered incomplete (Engelsen, 2010). Measurements were compared with a pre-existing model called FastRT (https://fastrt.nilu.no/) (Webb & Engelsen, 2006). FastRT inputs include the date, latitude and longitude, cloud conditions, total column ozone, and surface altitude, albedo (reflectance), and type (e.g., soil texture, vegetation, or paving). The model was used to simulate the amount of UVB school children would be expected to receive at other times of the year.

A second model, VitD_quartMED (https://fastrt.nilu.no/VitD_quartMED.html) (Webb & Engelsen, 2006), estimates how much vitamin D a person could be expected to synthesize under different conditions and the researchers applied this to the same time periods as the first model. VitD_quartMED inputs included date, latitude and longitude, skin type, timing of exposure, percent of body exposed, desired dietary equivalent dose of vitamin D in international units (I.U.), cloud conditions, total column ozone, and surface altitude, albedo, and type. The models have been validated against measurements and other models, although under overcast conditions the accuracy level is uncertain and may be imprecise due to the lack of information on the cloud properties (Engelsen, Brustad, Aksnes, & Lund, 2005; Engelsen & Kylling, 2005; Webb & Engelsen, 2006).

Results

The participants wearing the dosimeters were encouraged to be consistent in their normal outdoor behaviors. This resulted in a range of measurements as some participants reported spending the whole time in the open areas while others spent their recess time near the school building. Individual observation was not permitted by ethics clearance, so locations of students with dosimeters was limited to self-reporting. The location of a student (variable) and time of day (consistent across participants) affects dosimeter readings. Range and mean values for each test period are shown in Figure 2. Comparing our measurements to FastRT, the model estimates were lower than the range of UVB received during overcast conditions (possibly because experienced cloud conditions differed from the model, for example, in density or thickness), but within the range during sunny conditions. Sunny days are of the most importance in terms of both erythema and vitamin D production, so we considered FastRT results valid in sunny conditions and used FastRT to estimate for sunny conditions throughout the year—the only conditions consequential for the two dependent variables.

Figure 2. UVB received by the test participants on each of the test days (range and average values) and sky conditions. Values estimated by FastRT are indicated with a filled circle. Bars show time to achieve vitamin D synthesis.



Note: under clear-sky conditions FastRT estimates were within measured ranges.

Dosimeter data were used to calculate how long a subject would have to spend in the test condition to receive 200 and 1,000 I.U. of vitamin D daily. The values of 200 I.U. and 1,000 I.U. were selected because research suggests that 1,000 I.U. is an appropriate daily intake of vitamin D to achieve vitamin D sufficiency (Schwalfenberg, Genuis, & Hiltz, 2010) and that 200 I.U. is the minimum amount that children and adolescents should receive (Gartner & Greer 2003). While vitamin D sufficiency can also be achieved via diet and supplements, we considered only the UVB synthesis portion as a consequence of children's schoolground environments.

Under overcast conditions participants could spend the whole day during the February research period outdoors and not receive 200 I.U. of vitamin D. On the sunny day with fresh snow on the ground, participants received sufficient UVB to get 200 I.U. of vitamin D after spending 40 minutes outdoors in the morning (that is, twice the morning recess duration) or 26 minutes in the afternoon (six minutes more than the afternoon recess duration).

VitD_quartMED estimated that in mid-spring with 25 percent skin exposure (e.g., face, hands, forearms) it would take seven minutes for a person with light skin to obtain 1,000 I.U. of vitamin D under clear skies and 48 minutes under overcast conditions. Mid-autumn with 10 percent skin exposure (e.g, faces and hands), it would take nearly two hours under clear skies to provide 1,000 I.U of vitamin D, and no amount of time would provide 1,000 I.U. under overcast conditions.

In mid-spring, it would take someone with dark skin tones 17 minutes with 25 percent body exposure to obtain 1,000 I.U. of vitamin D under clear skies and more than 1.75 hours if conditions were overcast. In mid-summer with 50 percent skin exposure (e.g., face, hands, forearms, legs) it would take eight minutes under clear skies and 57 minutes under overcast conditions, while in mid-autumn with 10 percent body exposure it would not be possible to obtain 1,000 I.U. of vitamin D (Table 1).

Table 1. Modeled results (VitD_quartMED) of time (minutes) to achieve natural vitamin D production targets for different skin types, sky conditions, and skin exposures for three school seasons in Waterloo, Canada

	Mid-spring 25% body exposure	Mid-summer 50% body exposure	Mid-autumn 10% body exposure
Clear sky, time to 1000 I.U. Light Skin	7	3	110
Clear sky, time to 1000 I.U. Dark Skin	17	8	†
Overcast sky, time to 1000 I.U. Light Skin	48	25	†
Overcast sky, time to 1000 I.U. Dark Skin	107	57	†

† not possible to obtain 1000 I.U. in these conditions

Minimum erythemal dose (MED) values were calculated and the amount of time required to receive sufficient daily vitamin D ranged from 17 to 30 percent of the time required to experience erythema throughout the year.

Discussion

The academic year in mid- to high latitudes typically is from late summer (first week of September) to the summer solstice (third week of June) and students are often required to spend time outdoors daily during recess. In our study these recesses summed to 40 minutes per day. Our results based on this small sample at one location suggest that during most of the academic year it might be more important to provide students in southern Ontario (or other mid- to high-latitude locations) UVB exposure than it is to shade them from it. This should be examined in larger cohort studies like that of Køster et al. (2016) and more schoolground locations. From late spring to late summer UVB exposure can lead to erythema, but for the majority of the academic year a lack of UVB will limit vitamin D synthesis.

Deciduous trees and shrubs can be strategically placed to absorb UVB before it reaches the ground in locations where students play during periods of likely elevated UVB exposure (e.g., late spring to late summer). Tree species have variable physical characteristics that can be used to affect UVB exposure. Species transmissivity values, leafing periods, and other characteristics all affect how much UVB will pass through tree canopies at different times of the year (see Brown & Gillespie, 1995). Ideal species would have late leaf emergence in the spring, an open canopy structure, and senesce early in the autumn (e.g., *Gymnocladus dioicus*—Kentucky coffeetree—for southern Ontario) to allow UVB to pass.

UVB arrives approximately equally from all parts of the sky, so even though a person is under the shade of a tree they can still experience erythema. Shrubs, walls, and retractable or movable shade structures (e.g., awnings, extended eaves) can effectively reduce UVB received from all parts of the sky during mid-summer, while opening up the area to UVB access during winter.

Results from our pilot study and literature review reinforce two key concepts for designing for optimal levels of UVB for outdoor spaces that people use in mid- to high latitudes to maximize UVB exposure in winter and minimize UVB in summer.

1. If a person can see the sky, they are receiving UVB radiation. UVB radiation is mostly diffuse and comes relatively evenly from all parts of the sky (not just the direction of the sun). UVB can lead to erythema even when a person is in a shadow.
2. Strategically located deciduous trees and shrubs can effectively intercept UVB during the growing season while allowing the UVB to pass through when the trees have shed their leaves. Varying the UVB in this way can help to protect against erythema while promoting vitamin D synthesis.

The primary purpose of schoolground shade guidelines is to reduce the threat of erythema which can lead to skin cancer. Yet vitamin D deficiency in Canada is a common issue causing significant health complications (Schwalfenberg, Genuis, & Hiltz, 2010). The results of this exploratory study suggest that existing schoolground shade guidelines should be further studied to learn if they are suitable for students using mid- and high-latitude schoolgrounds during the academic year. It might be advisable to modify guidelines to include information regarding the importance of sunlight and vitamin D in the academic year and to promote more access to sunny, outdoor spaces.

A landscape architecture approach to modification would focus on elements such as trees, shrubs, buildings, or furnishings that intercept UVB. Deciduous trees and shrubs are valuable components in the design of schoolgrounds (Samborski, 2010) that can flexibly optimize levels of UVB received by children. Designed for the appropriate location and sun angle, leafy canopies seasonally block and absorb UVB or allow UVB to pass through. Building overhangs and site furnishings can be used to block UVB during times when erythema is a threat, but allow solar exposure during school sessions. Shade guidelines that do not explicitly address the need for vitamin D synthesis miss an important opportunity to promote healthy schoolgrounds in all seasons.

Conclusion

The results of this small-sample pilot study indicated that in almost every case, students at a school in Waterloo, Ontario would not receive recommended levels of vitamin D by playing on a typical schoolground in February. Nor would the students be exposed to enough UVB to cause erythema on the schoolground during most of the academic year. With evidence-based landscape architecture (Brown & Corry, 2010) schoolgrounds can be designed so that students have a low probability of receiving dangerous levels of UVB, but can receive adequate amounts of vitamin D even in midwinter in mid- to high latitudes .

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