Quantification of ultraviolet (UV) radiation in the shade and in direct sunlight

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Abstract

Ultraviolet (UV) radiation is associated with negative health effects, including sun damage and skin cancer. The purpose of this study is to compare the protective effects of the shade provided by a sun umbrella versus that provided by a tree. Sun sensors that register the level and dose of UV radiation were placed in the shade and in direct sunlight. Measurements were recorded every half hour between the hours of 12:30 p.m. and 3:00 p.m. in Sacramento, California. The results suggest that the level of UV radiation in the shade is not zero. The sensors located in tree shade indicated that over 5% of UV radiation was detected in the shade. The sensors located in sun-umbrella shade showed that greater than 17% of UV radiation reached the shade. The sun sensors used in our study collected UV radiation data relevant to UV index; however, they did not differentiate between UVA, UVB, visible, and infrared light. The amount of UV radiation detected in the shade is not zero, thus regular sunscreen use and other sun protective practices should be followed to reduce the risk of sun damage and skin cancer.

Keywords: ultraviolet, UV, radiation, skin cancer, sunlight, shade

Introduction

Exposure to ultraviolet (UV) radiation may result in sunburn, skin damage, skin cancer, premature aging, damage to the eyes, and immunosuppression [1]. Long-term exposure to UV radiation is a major factor leading to the development of non-melanoma skin cancer. Malignant melanoma, although not as common as non-melanoma skin cancer, is the major cause of skin cancer related death [1]. In the United States, since the 1970s, the incidence of melanoma has increased by 4% every year and many studies suggest that exposure to UV radiation is correlated with the risk of developing this type of cancer [1]. In order to reduce the risk of skin cancer, individuals should minimize their exposure to UV radiation [2]. When outdoors, the appropriate sun protective measures should be taken, including wearing sun protective clothing, applying sunscreen, wearing sunglasses, and staying in the shade when possible.

There are two forms of radiation caused by sunlight: direct radiation and diffuse radiation. Tree shade and hats, for example, may protect the skin from direct radiation by blocking sunlight from reaching the skin. However, diffuse radiation may come from all directions and protective measures may not be as effective. For example, in tree shade there may be less direct radiation compared to that in direct sunlight, because trees are able to filter the direct component. A larger proportion of UV dose in the shade comes from diffuse radiation.

Even though diffuse radiation can be detected in the shade, utilization of shade is believed to be one important strategy to minimize UV exposure and protect the skin from UV damage [2]. A study of 50 trees in Australia showed that the erythemal UV in the shade depended on the tree canopy density and the height of the start of canopy above the ground, with no significant dependence on canopy width or tree height [3]. Additionally, Parisi et al. showed that on a summer afternoon, 61% of erythemal UV radiation in tree shade was related to diffuse component of UV [4]. Moreover, about 56% of ultraviolet radiation type A (UVA) radiation is due to a diffuse component [4]. These values are similar to the percentage of diffuse UV radiation detected in full sun on a winter afternoon (diffuse erythemal UV, 46%; diffuse UVA, 28%). The higher diffuse UV radiation in the summer tree shade may result in high UV exposure of skin and other parts of the body, including the eyes. Moreover, hats may provide more protection from direct radiation than from diffuse radiation [4].

Quantitative measurements of UV radiation in various environments are needed for developing optimal sun protection strategies. Although there have been numerous studies on quantifying UV radiation in tree shade, few studies quantify UV exposure in the shade near a swimming pool, a potentially reflective surface. In this study, our primary objective was to quantify the UV exposure in direct sunlight by a swimming pool compared to the UV exposure in the shade by a swimming pool (shade provided by sun-umbrella).

Methods

Measurement of UV level and dose

UV measurements were conducted with a SunSense Coin®, which were kindly donated from SunSense company (Norway). The sun sensors register erythema-weighted ultraviolet (UV) radiation according to the international UV index (UVI). From the time the coin is turned on, it displays the accumulated UV dose according to the formula: *Dose = UVI × time (hours)*. The sun sensors also provide a measurement of the UV level, which is an approximate measure of the theoretical UVI. **Table 1** shows how the theoretical UVI is related to the UV level measured by the sun sensors.

The level display changes quickly depending on direct sunlight exposure, whereas the dose reflects the cumulative UV exposure. The sun sensors were used to measure UV dose and level in the shade and in direct sunlight. To further assess the role of shade, measurements were recorded under tree shade and sun umbrella shade.

UV level and dose next to swimming pool

Two swimming pools, one located in Davis, California (latitude 38.5) and the other in Sacramento, California (latitude 38.6) were used for data collection. The measurements of UV dose and level occurred at 30-minute intervals at the following times (Pacific Standard Time): 12:30 p.m., 1:00 p.m., 1:30 p.m., 2:00 p.m., 2:30 p.m., and 3:00 p.m. The measurements were done on a horizontal plane at ground level in the shade that was provided by a sun-umbrella, as well as in direct sunlight (**Figure 1**). The distance between coin dosimeters in the shade and those in direct sunlight was approximately 12 meters. The measurements were recorded on the same days at both locations. The theoretical UVI and the ambient temperature were the same at the two locations, thus both locations were combined for the purposes of data analysis. At each time point, there were ten sensors in the shade (provided by the sun-umbrellas) and ten in direct sunlight, next to the pool. The coin dosimeters used for data collection in direct sunlight were placed at a distance of one meter from the pool. All data were recorded on three sunny days in September 2016.

Table 1. *UV Level Displays in Sun Sensor.*

Number of "Level" bars displayed on sun sensor	Intensity of sunlight	Corresponding theoretical UV Index
1	Low	1-2
2	Moderate	3-5
3	Strong	6-7
4	Very strong	8-10
5	Extreme	11+

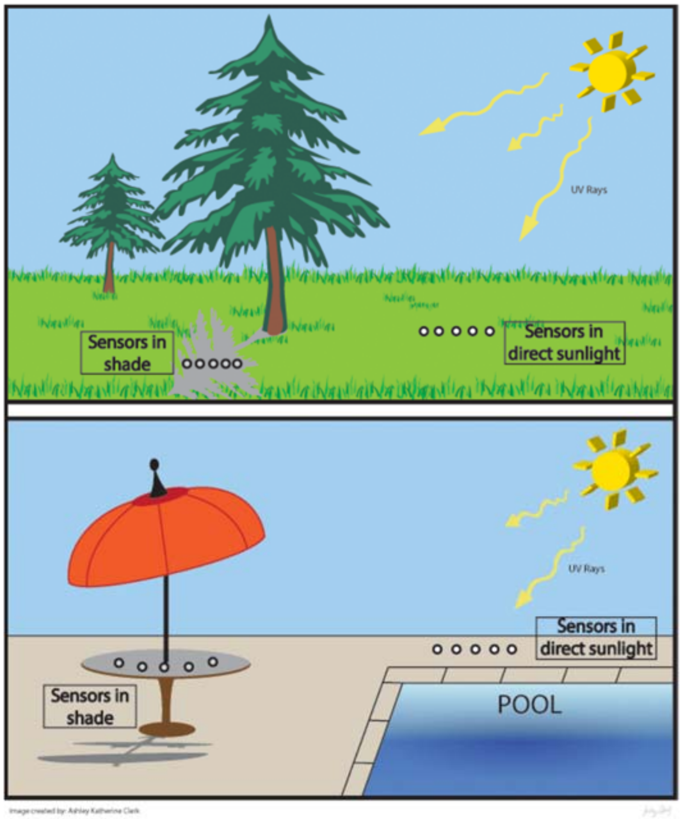


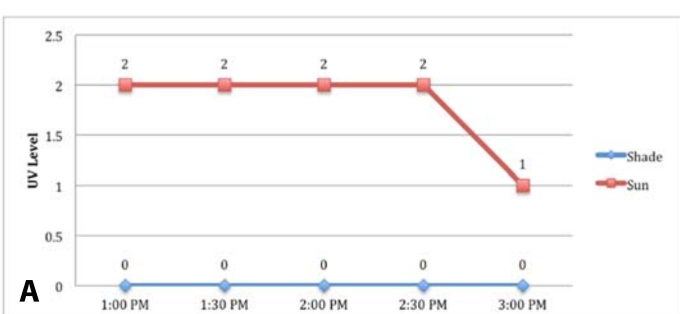
Figure 1. *The overall experimental setup, showing sun sensors in tree shade (top panel) and sun umbrella shade (bottom panel).*

UV level and dose next to tree

In Sacramento, California (latitude 38.6), two trees (pine tree and chestnut oak tree) isolated from other trees and structures by at least five meters, were used in the study. The two trees were in different locations, but at the same latitude. The solar UV level and dose in both tree shade and full sunlight were measured. The measurements occurred at 30-minute intervals at the following times (Pacific Standard Time): 12:30 p.m., 1:00 p.m., 1:30 p.m., 2:00 p.m., 2:30 p.m., and 3:00 p.m. The UV irradiation level and dose were measured on a horizontal plane at ground level in the tree shade and adjacent full sunlight using the sun sensors. The coins were moved throughout the day to maintain exposure to the sun, but they remained at an approximately equal distance from the tree trunk at all times (approximately 15 meters). The dosimeters that were recording data in the shade remained next to the tree trunk at all times. For each of the two trees, five coin dosimeters were collecting data in direct sunlight while five were in the shade, next to the tree trunk. Thus, at each time point, there were collectively ten measurements in the sun and ten in the shade. The data from the two trees were combined for the purposes of analysis as data collections were done on the same days, at the same times, at the same latitude. All data were recorded on three sunny days in September and October 2016.

Statistical methods

Since the UV dose is a continuous outcome variable, a linear mix-effects model was used to fit the repeated measures UV dose data over time (12:30 p.m. to 3:00 p.m.) to estimate the change rate in the UV dose for each of the two locations, direct sunlight and shade, and compare their change rate in the UV dose over time. For the UV level that is a 3-level ordinal categorical outcome variable, a random-effects proportional odds model was used to fit the repeated measures UV level data over time (12:30 p.m. to 3:00 p.m.) to estimate the change rate in the UV level for each of the two locations, direct sunlight and shade, and to compare their change rate in the UV level over time. A P-value <0.05 was considered statistically significant. All analyses were performed with SAS v9.4 (SAS Institute Inc., Cary, NC, USA).



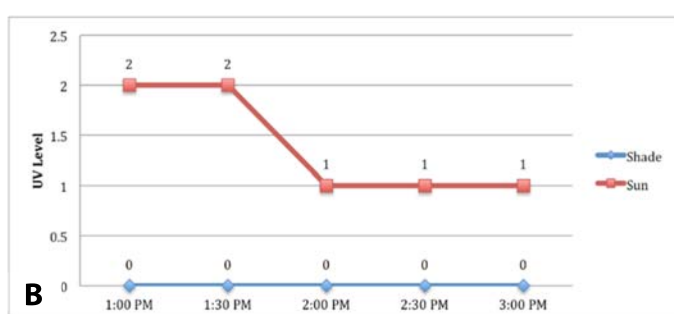


Figure 2. *Shade UV Level. Median UV level at each time point by sensor location in comparison to shade in* ***A)*** *sun umbrella shade and* ***B)*** *tree shade.*

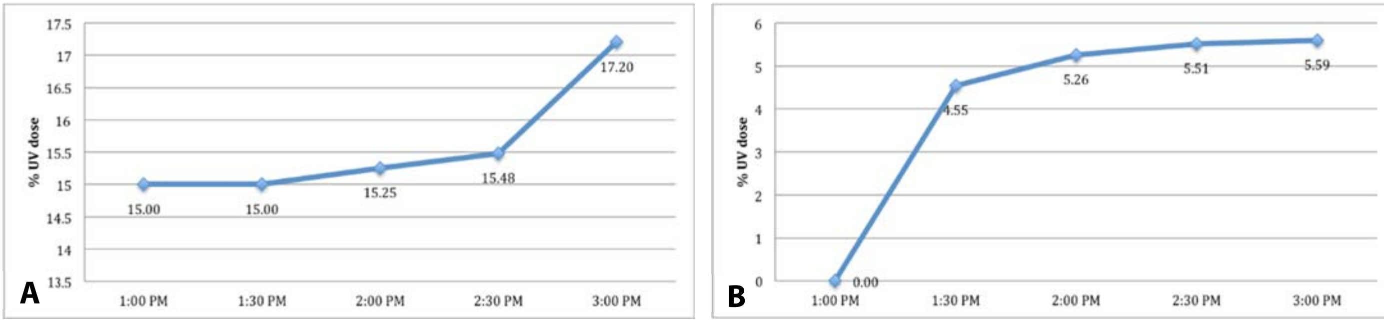


Figure 3. *Shade UV dose. UV Dose as a percent of dose received in direct sunlight in* ***A)*** *sun umbrella shade and* ***B)*** *tree shade.*

Results

UV level (shade versus direct sunlight)

The change in the UV level over time was not statistically significant in the sun umbrella shade group (**Figure 2A)**. Similarly, the change in the UV level over time was not statistically significant in the direct sunlight group by the pool. The difference in the change rate in the UV level between the two location groups (sun umbrella shade versus direct sunlight) was not statistically significant (P=0.373).

The change in the UV level over time was not statistically significant in the tree shade group (**Figure 2B)**. However, the change in the UV level over time was statistically significant in the direct sunlight group (P=0.024). The difference in the change rate in the UV level between the two location groups (tree shade versus direct sunlight) was not statistically significant (P=0.9996).

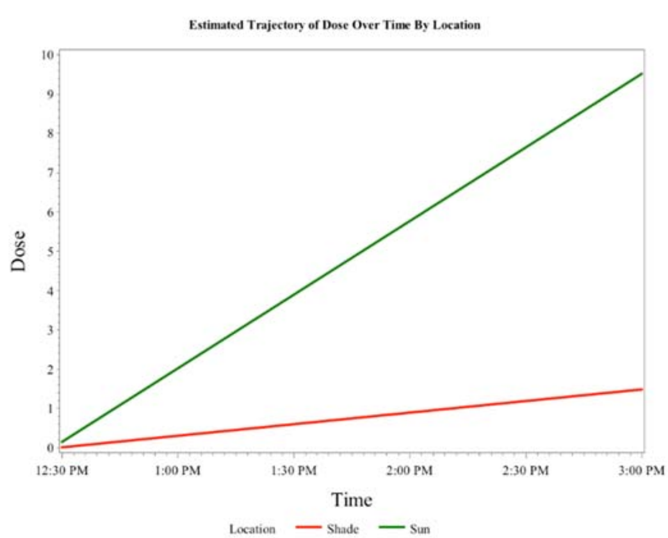


Figure 4. *Estimated trajectory of UV dose over time when comparing direct sunlight to poolside sun umbrella shade*

UV dose (shade versus direct sunlight)

The UV dose detected in the shade was not zero. The UV dose detected in sun umbrella shade increased exponentially from 15% at baseline to 17.2% at 3:00p.m. (**Figure 3A)**. The percent UV dose detected in the tree shade was 0% at baseline and increased to 5.6% at 3:00p.m. (**Figure 3B)**.

The difference in the change rate in the UV dose between the two location groups (sun umbrella shade versus direct sunlight) was statistically significant (P<0.0001) (**Figure 4**). Similarly, the difference in the change rate in the UV dose between the two location groups (tree shade versus direct sunlight) was statistically significant (P<0.0001) (**Figure 5**).

Discussion

Our work demonstrates that shade is an effective mode of reducing UV radiation. However, it does not reduce UV radiation exposure to zero. In our study, we used a practical approach to our measurements. We utilized an umbrella near a pool, as this is how people typically seek shade when participating in activity near water and the area under a tree, since shade-seeking is a common approach used by people when outdoors. The sun sensor provides a reliable and reproducible measure of the UV dose received over time in the area where the coin was placed. It is important to note that the sun sensor readings may not match the meteorological (or theoretical) readings over time due to local conditions, such as buildings and trees (up to 50% of UV radiation can be diffused), reflections, and orientation of the sensor in relation to the sun.

UV Reflectivity

In our study, UV exposure in the shade provided by an umbrella near a pool is greater than that found under a tree. This finding suggests that the type of shade matters (near a water source under an umbrella versus not near water) owing to reflectivity of UV rays. The amount of UV radiation reaching earth's surface varies widely. Several factors such as cloud cover, the ozone, elevation, water depth and earth's surface all account for the variation.

At sea level, UVA comprises approximately 95% of the UV energy reaching the earth's surface, whereas ultraviolet light type B (UVB) comprises the remaining 5% [5]. Water, such as the ocean's surface, can reflect about 5-8 percent of the UV radiation reaching its surface with greater reflection in water that is clearer [6]. Land can typically reflects 2-4 percent of UV radiation [6]. Therefore, the large body of water provided by a pool may reflect a large amount of UV radiation contributing to the increased dose of UV exposure under an umbrella next to a pool.

Additionally, we found tree shade to be an effective mode of sun protection. Similar to our findings, other studies have concluded trees with large dense foliage are best at protecting from UV rays [7]. However, as seen in our study, shade provided by a tree does not eliminate all UV exposure and there is still risk of exposure. Therefore, it is important to use

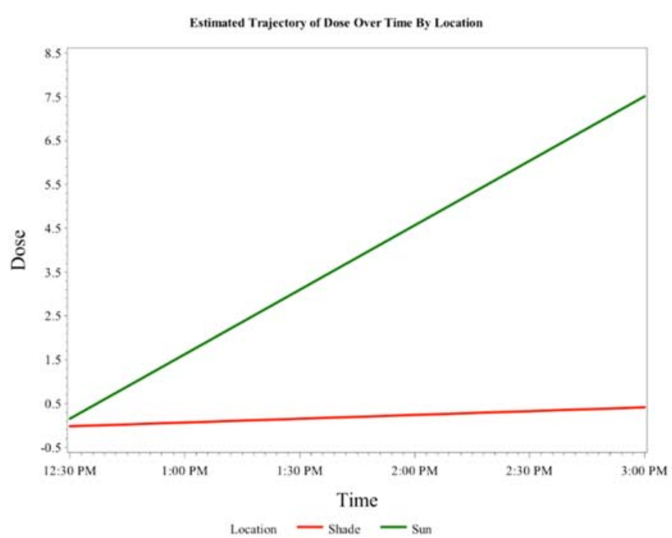


Figure 5. *Estimated trajectory of UV dose over time when comparing direct sunlight to poolside tree shade.*

sun protective measures such as sunscreen, sun protective clothing, and hats, even while spending time under a tree or umbrella.

The role of sunscreen in the shade

In addition to sunscreens and protective clothing, it is advised to seek shade for additional UV protection. People may assume spending time in the shade will completely protect them from the sun. However, an individual will still receive UV radiation indirectly. Umbrellas provide partial UV protection. Their Sun Protection Factor (SPF) can range from 3-106 and their Ultraviolet Protection Factor (UPF) up to 50+. Some studies have suggested that the amount of UV radiation that reaches beneath an umbrella can be up to 84% of that in the sun [8]. However, our study demonstrated only 15-17% of the UV rays reached beneath the umbrella. There are multiple factors that may attribute to these differences. For example, our study design included a large beach umbrella instead of a hand-held umbrella. Furthermore, our umbrella was near a water source that scatters UV rays in a different manner than concrete, grass, or sand [9].

The importance of broad-spectrum sunscreen use is highlighted in our study. A greater proportion of UVA rays reach the earth's surface in comparison to UVB and UVA rays tend to scatter more than visible light. Therefore, the UV index obtained by our sun sensors in the shade may reflect greater UVA exposure in the shade. Although the sensors used in this study do not differentiate between UVA and UVB, our findings warrant the development of future sensors that can differentiate UVA and UVB exposure.

Limitations

We were not able to eliminate all surrounding buildings from our collections. However, we utilized a direct sunlight control at each location to control for variations in exposures related to surrounding structures. Our study was limited to the Sacramento area and the UV exposures may be different in different geographic areas. Nevertheless, we utilized a control measurement for each shade measurement and report the exposure in terms of percent of direct sunlight to normalize the data.

Our study is limited to collection of UV light relevant to the UV index. This represents how current public health messages are developed and represents true UV exposure as a mix of UVA and UVB. The sensors were not able to differentially capture UVA, UVB, visible light, and infrared light. As future sensors are refined to subcategorize the radiation, future studies will be able to differentiate and quantify the subgroups of radiation that are represented in the shade.

Conclusion

Although tree shade and sun-umbrella shade provide protection from the damaging UV radiation, the amount of UV radiation detected in the shade is not zero. Our study shows that the percentage of UV radiation detected in tree shade was greater than 5%. Similarly, the percentage of UV radiation detected in the shade under a sun-umbrella next to a swimming pool was greater than 17%. The public should be aware that shade provides UV protection. However, individuals may still be at risk of skin damage related to UV exposure in the shade. Individuals should follow sun protective measures, such as regular sunscreen application and sun protective clothing use, even in the shade, to reduce their exposure to ultraviolet radiation.

Potential conflicts of interest

RKS serves as a scientific advisor to LearnHealth and a consultant to Burt's Bees, Dermala, and Tomorrow's Leaf. The other authors have no conflicts of interest to declare.

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