UV-B Exposure to the Eye Depending on Solar Altitude

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Purpose: To assess the validity of the solar ultraviolet index (UVI) as a determiner of eye risk under different conditions of facial profiles and orientation, and reflected light.

Methods: Ocular UV radiation (UVR) exposure was measured as a function of the time of the day (solar altitude) using a two-dummy–type mannequin dosimetry system with embedded UVR (260–310 nm) sensors, in September and November in Kanazawa, Japan, on a motorized sun-tracking mount with one dummy face directed toward the sun and the other away from the sun.

Results: A bimodal distribution of UV-B exposure was found in September for the face directed toward the sun, which differed dramatically from the pattern of ambient UVR exposure and measurements taken on the top of the head and those for the eye taken later in the year. Although the overall level was lower, a higher solar altitude is associated with higher UVR exposure in the condition facing away from the sun.

Conclusions: The UVI is based on ambient solar radiation on an unobstructed horizontal plane similar to our measures taken on the top of the head, which differed so much from our measures of ocular exposure that UVI as a determiner of eye risk is deemed invalid. The use of the UVI as an indicator for the need for eye protection can be seriously misleading. Doctors should caution patients with regard to this problem, and eye protection may be warranted throughout the year.

Key Words: Ultraviolet radiation—Sunlight—Cataract—Pterygium.

(*Eye & Contact Lens* 2011;37: 191–195)

It seems simple enough to determine ultraviolet radiation (UVR) exposure in humans, but in fact, this can be complicated as a result of the many factors that influence exposure measurement conditions. Even given constant measurement positions, solar UVR levels can vary widely depending on factors such as geographical latitude, season of the year, time of the day,[1] and changes in airborne chemicals from clean versus polluted air conditions.[2] In general, however, solar UVR levels are greater at low latitudes,[3,4] in the summer season, and from 10 AM to 2 PM everyday.[1] On recognizing the difficulties in measuring and reporting UVR exposure levels, and in an attempt to better communicate the levels of ambient UVR to consumers, a UV index (UVI)[5] was developed by the World Health Organization in collaboration with the United Nations Environment Programme, the World Meteorological Organization (WMO), the International Commission on Non-Ionizing Radiation Protection, and the German Federal Office for Radiation Protection. This UVI consists of 11 to 13 increments based on the intensity of UVR present under standardized measurement conditions and is reported for cities in dozens of countries worldwide throughout the year. The index is intended to alert people about the need to adopt protective measures appropriate to the level of UVR exposure in their local area and has been moderately effective in informing the public about ambient levels of UVR when used consistently. However, this index is based on skin erythema dose and does not take into account some unique features of the eyes that account for important differences in exposure risks. Photoconjunctivitis and photokeratitis such as snow blindness and arc-eye or welder's flash are well known to be caused by UVR exposure.[6] Chronic UVR exposure to the eyes is one of the main factors in the development of pterygium[7] and cataract, especially cortical cataract.[8–10]

In the 2010 report of the WMO,[11] it is mentioned that there is clear evidence of a decrease in the atmospheric burden of ozone-depleting substances and some early signs of stratospheric ozone recovery. According to the National Aeronautics and Space Administration Earth Observatory accessed on January 31, 2011,[12] the deepest hole ever recorded was on September 30, 1994, whereas the broadest hole occurred on September 29, 2000, when the ozone-depleted area stretched 29.9 million km^2. Although the mean area of the ozone hole was 22.2 million km^2 in 2010 having decreased a little, the decrease of UVR dose reaching the surface of Earth is uncertain. On the contrary, the Ministry of the Environment, Government of Japan, reported that UVR doses in Japan have increased in the long term since 1990 and that its main cause is believed to be the decrease of cloud amount and reduction in aerosol quantity[13]; and the American Cancer Society sounded the alarm that melanoma incidence rates have been increasing for at least 30 years.[14] It is critical that people begin focusing their attention not only on the UV exposure on the skin but also on the eyes. As with skin, there are many factors that influence ocular UVR exposure levels, including ambient UVR level, altitude, and direction of the sun, reflection from surrounding surfaces, individual factors (shape and color of the face, eyelashes, eye lid), and UVR protection measures taken. In this study, the correlation was investigated between solar altitude and the ocular UV-B exposure using a sensor equipped mannequin (dummy) system.

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The authors have no funding or conflicts of interest to disclose.

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Accepted April 14, 2011.

DOI: 10.1097/ICL.0b013e31821fbf29

FIG. 1. Observational dummies with built-in UV-B sensors.

METHODS

Ultraviolet radiation exposure was measured with a two-dummy–type mannequin system incorporating oriental female face forms, each embedded with 12 tiny UV-B sensors (G5842-01, 4×4×1.5 mm, Hamamatsu Photonics, sensitivity from 260 to 310 nm). Of the 12 sensors, three were placed in each eye (nasal, center, and temporal); one in each cheek; and one each on top of the head and on the forehead, chin, and neck of the dummy (Fig. 1). The top of the heads of the dummies was set to correspond to the head position of a 170-cm-height adult (Fig. 2). The dummy heads were mounted on an equatorial telescope to simultaneously measure UVR exposure in two conditions: one dummy facing the sun to enable us to record the maximum UVR exposure and the other dummy placed away from the sun to enable us to record the minimum UVR exposure. The heads were mounted with the faces looking in the direction of 15 degrees below the horizontal line to simulate the natural line of sight while walking (Fig. 3).[15] The mounted heads were moved every hour from sunrise to sunset to position the faces directly toward and away from the sun every hour, and UVR exposure doses were measured once every second. The UV exposure levels in the eyes and on the top of the head were compared. The data from the center of the right eye were used as the ocular exposure level. Solar orientation was recorded from the website of the National Astronomical Observatory of Japan for the days and locations of the measurements.

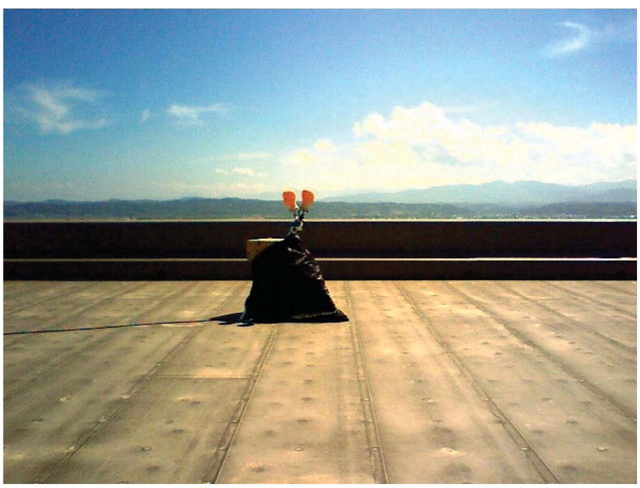

FIG. 2. Installation site: Roof of the clinical research building of the Kanazawa Medical University (LAT 36.567 degrees north, LNG 136.650 degrees east).

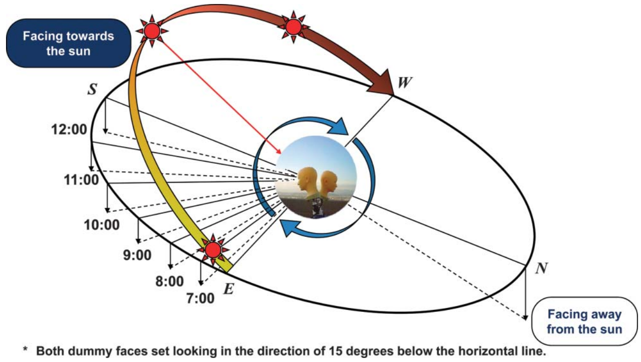

FIG. 3. Visual lines of observational dummies for measurement. *Both dummy faces set looking in the direction of 15 degrees below the horizontal line.

The measurements took place on the roof of the clinical research building at the Kanazawa Medical University, Kanazawa, Japan, located at a latitude of 36.567 degrees north and a longitude of 136.650 degrees east, on September 21 and November 21, 2006 (Fig. 2). The weather on each of the two days was sunny, and the solar culmination altitudes were 54.2 and 33.6 degrees, respectively (Table 1). The apparatus was placed on a surface of gray urethane-coated concrete, with a UVR reflectance of approximately 10%.

RESULTS

The sun reached its zenith between 10 AM and 2 PM. in both September and November. Figure 4 shows that the hourly average of UV-B intensity measured on top of the dummy head facing the sun was proportional to solar altitude for both measurement dates. However, Figure 5 shows a bimodal curve for the central right eye of the dummy facing the sun for the September date, with maximum intensities observed at approximately 9 AM and between 2 and 3 PM, whereas the November 21 data are again proportional to solar altitude, with the maximum UV-B intensity recorded at approximately noon. In the case of the central right eye of the dummy facing away from the sun, the maximum UV-B intensity was again measured at approximately noon on both days, displaying a pattern similar to that seen for the intensity on the dummy head. Although the overall level was lower, the result shows that a higher solar altitude is associated with a higher UV-B intensity in the condition facing away from the sun.

TABLE 1. *Survey Conditions*

Date	Weather	Maximum temperature (°C)	Sunlight hours	Culmination altitude (degrees)
September 21, 2006	Sunny	27.1	10.9	54.2
November 21, 2006	Sunny	17.7	9.0	33.6

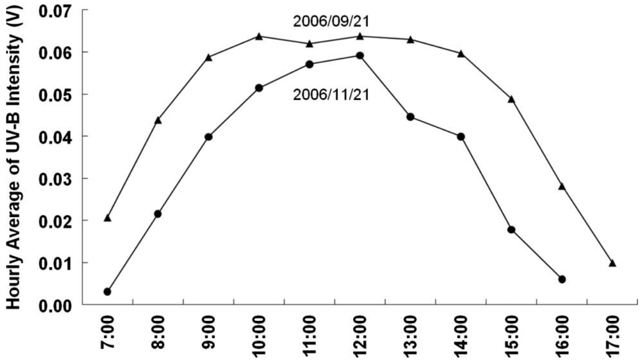

FIG. 4. Hourly average of UV-B intensity on the top of the head when facing towards the sun. *The unit is ''volts.''

Figure 6 shows the total UV-B exposure dose for the eye and the top of the head facing the sun from 8 AM to 4 PM on each day. There is a marked decrease (29% reduction over the period) in the UV-B exposure dose on the dummy head from fall to winter, which corresponds to decreasing solar altitude. However, there was a little difference (~8%) in the UV-B exposure dose in the eye of the dummy facing the sun, although the overall UV-B radiation decreases in the winter months.

Interestingly, as shown in Figure 7, the eye facing away from the sun experienced a similar difference in the levels of total UV-B exposure on the 2 days as did the top of the head. The reduction from fall to winter for facing away was approximately 28%, whereas this value was only approximately 8% for facing the sun.

Further, as shown in Figure 8, although the total daytime exposure changed little with the season, the time of peak exposure was markedly different. In the fall season, when the solar angle is higher, the highest exposure occurs in midmorning and mid-afternoon, creating the bimodal distribution of intensity seen in Figure 5. In winter, when the sun maintains a lower trajectory in the sky throughout the day, the pattern of exposure corresponds to that of the solar angle, that is, highest exposure at noon.

DISCUSSION

Perhaps the most important information gained from this study was the bimodal distribution of UV-B intensity seen for the center of eye measurements taken in September, which differed dramatically from the pattern of ambient UVR exposure and the measurements taken on the top of the head and those for the eye taken later in the year. These differences can be attributed to the unique anatomy of the ocular region. Ambient solar radiation is usually measured on an unobstructed horizontal plane, and our reference measurements

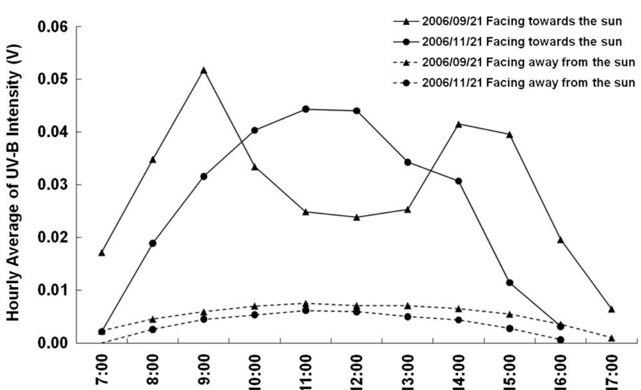

FIG. 5. Hourly average of UV-B intensity in the central eye when facing towards and away from the sun. *The unit is ''volts.''

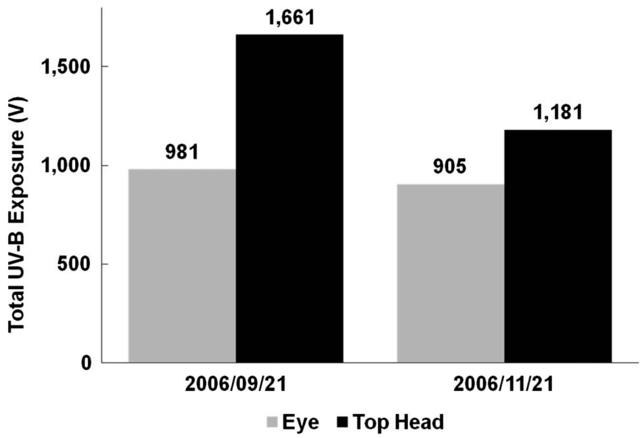

FIG. 6. Total UV-B exposure dose to the eye and the top of the head when facing towards the sun from 8 AM to 4 PM. *The unit is ''volts.''

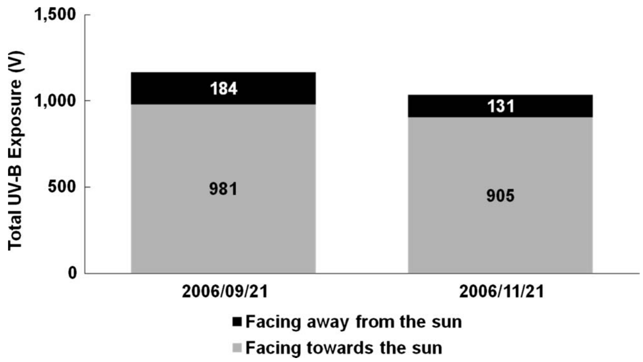

FIG. 7. Total UV-B exposure dose to the eye when facing towards and away from the sun from 8 AM to 4 PM on different days. *The unit is ''volts.''

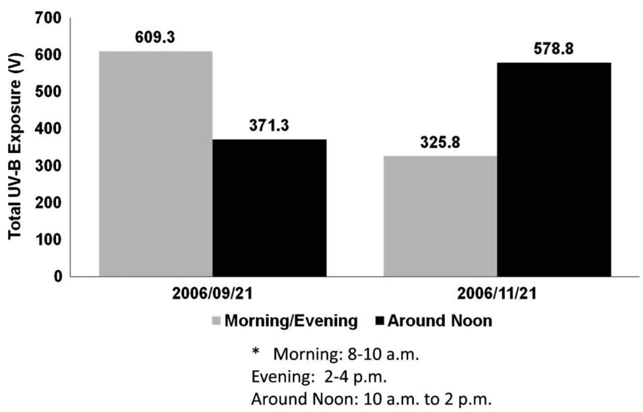

FIG. 8. Comparison of the total UV-B exposure dose to the eye when facing towards the sun between morning/evening and approximately noon. *Morning: 8 to 10 AM, evening: 2 to 4 PM, approximately noon: 10 AM to 2 PM. *The unit is ''volts.''

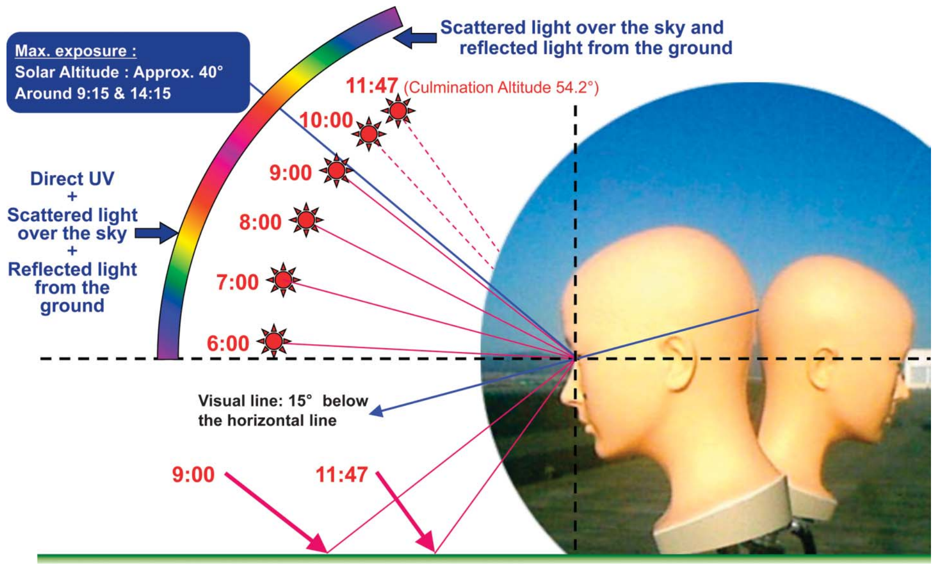

FIG. 9. Solar altitude, UVR exposure to the eye and causative light (autumnal equinox: September 21, 2006, in Kanazawa, Japan).

recorded at the top of the head closely approximated this. The eye, however, is oriented in a predominantly vertical plane and is also shaded from above by the brow ridge and upper lid, from below by the cheeks, and from the nasal side by the bridge of the nose. Only from the temporal side can light enter during most light conditions. Other authors have written extensively on the fact that these anatomical considerations make the eye unusually susceptible to UVR exposure from the temporal side by the peripheral light focusing (PLF) effect.[16–18] The PLF effect occurs when light incident on the temporal cornea is focused by the peripheral anterior eye to the nasal limbus, the usual site of pterygium formation. This study was concerned only with light reaching the corneal plane of the eye and did not consider any additional optical effects of the cornea. With the head in the position tested in this study, depending on the solar altitude, the corneal plane can receive direct, scattered and reflected light (Fig. 9). When facing the sun with the sun low in the sky, the eye receives direct UVR in proportion to ambient solar intensity and some light reflected from the ground or that scattered by the atmosphere, although the cheeks may block some of the reflected light. As the sun rises in the sky, the amount of direct exposure increases with solar angle until the sun reaches a point where the brow ridge (and even the upper lid) begins to cast a shadow over the cornea, at which time the eye receives only reflected and scattered UVR. When the eyes are facing away from the sun, the exposure is primarily from reflected and scattered light. The level of such exposure remains somewhat constant and seems to be similar to that impinging on the eyes when facing the sun during times of the year when the sun is almost directly above. According to the data in this study, direct exposure for the eye falls quickly once the sun has passed a solar altitude of approximately 40 degrees, at least for an Asian facial form similar to that used in this study. One might expect this effect to be more pronounced in Caucasians, particularly in men, because of the more prominent brow ridge and more deeply set eyes.[19]

What this potentially means is that the awareness of the need for skin protection based on the traditional UVI may not only be insufficient for ocular protection but may actually be misleading. As illustrated in Figure 10, using the latitude of Kanazawa, Japan, which

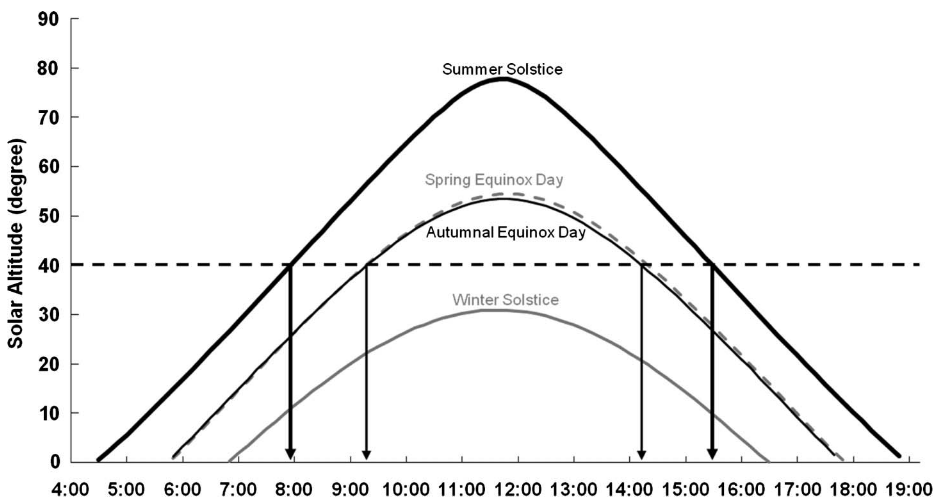

FIG. 10. The maximum UVR exposure time in the eye by season: solar altitude in Kanazawa, Japan (located at LAN 36.567 degrees north, LNG 136.650 degrees east).

is similar to the American south; the Middle East; northern Africa; and south central China and populated cities in Australia, Argentina, and Chile, peak exposure times for the eyes are NOT between 10 AM and 2 PM as has been believed for skin except during the winter months but between 8 and 10 AM and 2 and 4 PM for most of the year because of the angle of the sun in relation to the eye at those times. These results are consistent with a report that a greater portion of UVR reaches the eye from scattered sunlight from clouds and light reflected from the ground than direct sunlight,[20] although the reasons given include human behavior such as squinting and head movements that are not simulated in mannequin measurements.

The results of this study illustrate the significant influence of not only direct sunlight in ocular UVR exposure but also the impact of reflected and scattered light in contributing to the total exposure levels of the eye as it relates to solar angle. Additionally, the impact was shown of the anatomy of the face and orbit in providing natural protection for the eye during times of high solar altitude when other surfaces such as the head and shoulders are more exposed. Because solar altitude varies with latitude, the particular times of greatest risks during the day and throughout the year will vary with distance from the equator. The local environment and means of protection attempted will also affect the total ocular exposure to UVR. These factors are the subjects of further study by these investigators. Unfortunately, all the factors cited here mean that the public may be relatively poorly informed as to when ocular protection is particularly important and the measures that are appropriate to take. A different index of exposure or a correction factor would be required to provide a meaningful measure for ocular risk to UVR.

In conclusion, the results of this study indicate the need for a new method of educating both patients and doctors about the difference in patterns for ocular UVR exposure compared with that of skin exposure and the need for full-time UVR protection for the eyes. Based on this research, doctors should caution patients that unlike the skin, ocular exposure to UVR will be maximum at times when sun protection is perhaps not used, such as in the midmorning; midafternoon; and in the fall, winter, and spring. Thus, eye protection full time throughout the day and year may be in order and bears further investigation.

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