The Effect of Prescription Eyewear on Ocular Exposure to Ultraviolet Radiation

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Abstract: Several studies have suggested that ultraviolet radiation in sunlight may cause cataracts and other eye disease. We evaluated the effect of prescription eyewear in attenuating ocular exposure to ultraviolet radiation (UVR) in the sunlight portions of the ultraviolet spectrum (295–350 nm). Using natural sunlight as the source, the attenuation was measured with two ultraviolet detectors, one sensitive to only UVB (295–315 nm) and one sensitive to both UVA and UVB (295–350 nm).

A random sample of spectacles, spectacle lenses, and contact lenses was examined. The average transmission, as measured with either detector, was highest for soft contact lenses, followed by glass spectacle lenses, untinted hard contact lenses, and plastic spectacle lenses.

Measurements performed with mannikins wearing spectacles showed that an average of 6.6 per cent of incident radiation reached the eye even when the lenses were covered with black opaque tape. The amount of exposure was increased substantially when the spectacles were moved 0.6 cm away from the forehead. The results show that the protection against ultraviolet exposure provided by prescription eyewear is highly variable and depends largely on its composition, size, and wearing position. (*Am J Public Health* 1986; 76:1216–1220.)

Introduction

Epidemiological studies[1–3] and experimental animal studies[4,5] have suggested that ultraviolet radiation (UVR) from sunlight may cause cataracts and possibly retinal disease.[1] One factor influencing exposure to UVR is the use of prescription eyewear (spectacles and contact lenses). Spectacle lenses provide an attenuation of UVR which may vary greatly with the composition, size, and shape of the lens as well as the part of the ultraviolet spectrum that is being considered. UVR covers a range of wavelengths from 100 to 400 nm which is often broken down into three regions: UVA (315–400 nm), UVB (280–315 nm), and UVC (100–280 nm). Both UVA and UVB are found in sunlight and have been implicated as potential hazards to the eye. UVC emitted by the sun is completely absorbed by ozone in the upper atmosphere and does not reach the earth's surface.

In this study we examined the UVA and UVB attenuation of a sample of spectacles and contact lenses in use, and investigated the dependence of this attenuation on various factors.

Methods and Materials

Sample of Spectacles

A sample of 43 spectacles or spectacle lenses and 39 contact lenses was provided by an optician in Baltimore, Maryland. These materials had been left at the optician's office for disposal by previous users and were collected over approximately a one-year period between 1981 and 1982; they were all in good condition without visible scratches. Bifocals and tinted lenses were excluded from the sample.

UV Attenuation Measurements

Previous studies have measured UV absorption of spectacle lenses using spectrophotometers.[6–8] Although this method gives the maximum amount of information about lens properties, it has several disadvantages:

- It may be difficult to correct for the effects of light refraction on the measured absorbance;
- Depending on the beam size, only a relatively small part of the spectacle lens may be irradiated;
- The information is presented in the form of attenuation vs wavelength, whereas the biologically significant radiation is a weighted integral over a range of wavelengths. (While in principle the absorption spectrum, together with the spectral distribution of sunlight, permits calculation of attenuation with respect to any given action spectrum, this procedure is quite tedious and is ultimately limited by uncertainties in the spectral distribution of sunlight.

An alternative approach, used in this study, is to measure incident and transmitted radiation with a radiometer, sensitive to a range of wavelengths, whose overall response is a weighted average over the spectrum of the incident radiation. This response is described by a "response spectrum" which is the function of detection efficiency vs wavelength. The overall response of the detector is defined as the "effective irradiance" of the incident radiation. Ideally, the detector response spectrum should correspond exactly to the biological action spectrum of the effect considered. However, only a few studies have examined the action spectrum for ocular damage from ultraviolet radiation. For corneal damage the effective wavelengths are thought to lie between 295 and 310 nm with the action spectrum similar to that for erythema.[9] For lens damage the action spectrum is believed to start at approximately 300 nm and extend into the UVA region although there is controversy about how far.[10]

In this study, detectors with two different response spectra were used (see Figure 1). The first, an International Light ACTS 270, responds only to UVB and is designed to approximate the action spectra for erythema and photokeratitis. The second detector, an International Light SCS280, responds to longer wavelengths including a portion of the UVA region (315–350 nm). Figure 1 shows the response spectra of both detectors compared to the action spectrum for lens damage observed in the rabbit eye.[4] Because the response spectra of the two detectors "bracket" most hypothesized action spectra for either corneal and lens damage, the attenuations measured with them can be assumed as limits on the attenuation of biologically effective energy which is damaging to these structures.

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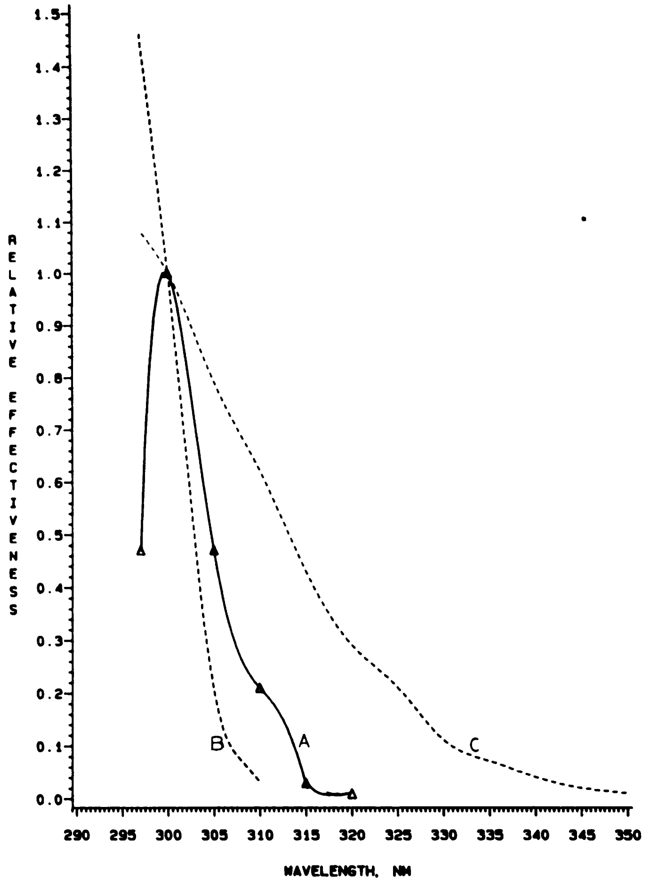

FIGURE 1—(A) Action spectrum for damage to the rabbit lens constructed from data of Pitts, *et al*, 1977. (B) Spectral response of detector ACTS 270. (C) Spectral response of detector SCS 280.

Both detectors were used in conjunction with an International Light IL700 Research Radiometer. Because of the size of the detectors (1 cm2), and the fact that they can be placed directly posterior to the spectacle lens, problems with refraction of light were minimized.

Measurement Configuration

Two geometries were used for measuring the attenuation of ultraviolet radiation:

In the first case, the detector was placed in a horizontal plane, under an open sky and measurements were taken with and without the spectacle lens placed directly above it. (For contact lenses, a mask was used so that only light passing through the lens would reach the detector.) *Per cent transmission* was defined as the ratio (× 100) of the effective irradiance measured with the lens covering the detector to the effective irradiance measured without the lens covering the detector.

In the second case, the detector was mounted in the eye socket of a mannikin headform with realistic facial features, but without eyelids. The UVR incident on the "eye" was measured with the headform exposed to sunlight under an open sky, with and without the headform "wearing" the spectacles. *Per cent ocular exposure* was defined as the ratio (× 100) of the effective irradiance measured with the mannikin "wearing" the spectacles to the effective irradiance measured with the mannikin not wearing the spectacles. The mannikin set-up has been described previously.[11] Unless otherwise stated, all measurements were made with the mannikin in a stationary position facing toward the sun; spectacles were placed as close to the forehead as possible.

TABLE 1—Reflectance of the Surface upon Which Mannikin Measurements Were Performed

Radiometer	Response Spectrum (above 295 nm)	Reflectance (%)
International Light IL 700 with ACTS 270 detector	UVB (295–310 nm)	7
International Light IL 700 with SCS 280 detector	UVB (295–350 nm)	13
United Detector Technology UDT 40X	visible (400–800 nm)	28

Exposure Conditions

All measurements were performed on a unobstructed asphalt/gravel rooftop in Baltimore, Maryland (latitude = 39.5°). Measurements were made during March and April 1985 between 12 noon and 2:00 pm under clear sky conditions. The eyes of the mannikins were at a height of four feet above the roof. The reflectance of the roof surface measured with detectors with three different response spectra is shown in Table 1.

Results

The results of the measurement of per cent transmission and per cent ocular exposure are presented in Table 2. In the case of glass lenses, there was little or no difference between per cent transmission and per cent ocular exposure. However, with the plastic lenses the per cent ocular exposure was substantially higher than the per cent transmission with either detector.

To measure the amount of UVR reaching the eyes from pathways other than through the spectacle lenses ("non-lens pathways"), lenses on a sample of spectacles were covered with black tape. In this series, measurements were performed with the mannikin both facing the sun and away from the sun (Table 3). The mean (± S.D.) of all measurements of per cent ocular exposure with covered lenses was 6.6 ± 4.8 per cent. This is an estimate of the contribution of non-lens pathways in determining ocular exposure.

The relationship of per cent ocular exposure to the lens surface area for plastic lenses is shown in Figure 2. This Figure suggests that the per cent ocular exposure is a function of lens size for plastic lenses (below 20 cm2). Data for glass lenses failed to show any relationship between these two variables. The relationship of per cent transmission to lens thickness for glass and plastic lenses is shown in Figure 3. Table 4 indicates the effect of distance between the spectacles and the forehead on per cent ocular exposure.

The per cent transmission through contact lenses (hard and soft) is shown in Table 5. Soft contact lenses exhibited the highest percentage of UV transmission, followed by blue hard contact lens.

Scans of wavelength vs transmission were performed for three lenses of each of the following types: glass, plastic, hard contact. Qualitatively, the scans were similar within each category. A typical scan for each type is shown in Figure 4.

TABLE 2—Transmission of UVR through Spectacle Lenses and Per Cent Ocular Exposure for Mannikins Wearing Spectacles

		Per Cent Transmission[a]	Per Cent Ocular Exposure[a]	Difference (95% Confidence Limits)
Measurements with 270 Detector				
Lens Type	N			
Plastic	27	0.6 ± 0.8	6.7 ± 3.5	6.1(4.7,7.5)
Glass	16	15.6 ± 10.0	20.5 ± 10.4	4.9(−2.3,12.1)
Measurements with 280 Detector				
Lens Type	N			
Plastic	27	1.1 ± 0.4	7.8 ± 7.9	6.7(3.7,9.7)
Glass	16	47.2 ± 11.6	46.4 ± 12.8	−0.8(−10.4,8.8)

[a]Mean ± S.D.

TABLE 3—Per Cent Ocular Exposure to Mannikins Wearing Spectacles, with and without Covering the Lenses with Opaque Tape (Mean ± S.D.)

		% Ocular Exposure*	
Lenses	N	Facing Sun	Away from Sun
Plastic	10	14.9 ± 9.5	10.3 ± 8.3
Plastic—covered	10	7.1 ± 4.5	3.4 ± 1.9
Glass	8	48.6 ± 6.3	43.8 ± 6.0
Glass—covered	8	11.6 ± 8.3	5.1 ± 5.4

*Measurement made with SCS 280 detector.

Discussion

There is clearly a high degree of variability in both UVR transmission of eyewear and per cent ocular exposure when eyewear is worn. For example, in the transmission measurements with the ACTS 270 detector, the coefficients of variation were 1.33 for plastic lenses and 0.64 for the glass lenses. In the per cent ocular exposure measurement, the coefficients of variation were somewhat reduced, probably due to the equalizing effect of "non-lens" transmission of light (c.v. = 0.46 for plastic lenses and 0.51 for glass lenses).

Despite this high variability, definite trends in the relationship of both transmission and per cent ocular exposure to various factors were seen. In general, plastic lenses transmitted substantially less radiation, as measured by either detector, compared to glass lenses. Similarly the per cent ocular exposure was substantially less for mannikins wearing spectacles with plastic lenses compared to mannikins wearing spectacles with glass lenses. Lens thickness was an important factor in determining transmission for glass but not for plastic lenses. The near zero transmission of plastic lenses suggests that the plastic used in these lenses includes a strong absorber of ultraviolet radiation of the wavelengths for which the detectors respond.

In the mannikin measurements, spectacles with plastic lenses showed a definite correlation between lens size and per cent ocular exposure. This may be explained as follows: since the plastic lenses absorbed most of the incident UVR, overall exposure was dominated by the contribution from "non-lens" pathways. These pathways are blocked to a greater extent with larger lenses. The contribution of non-lens

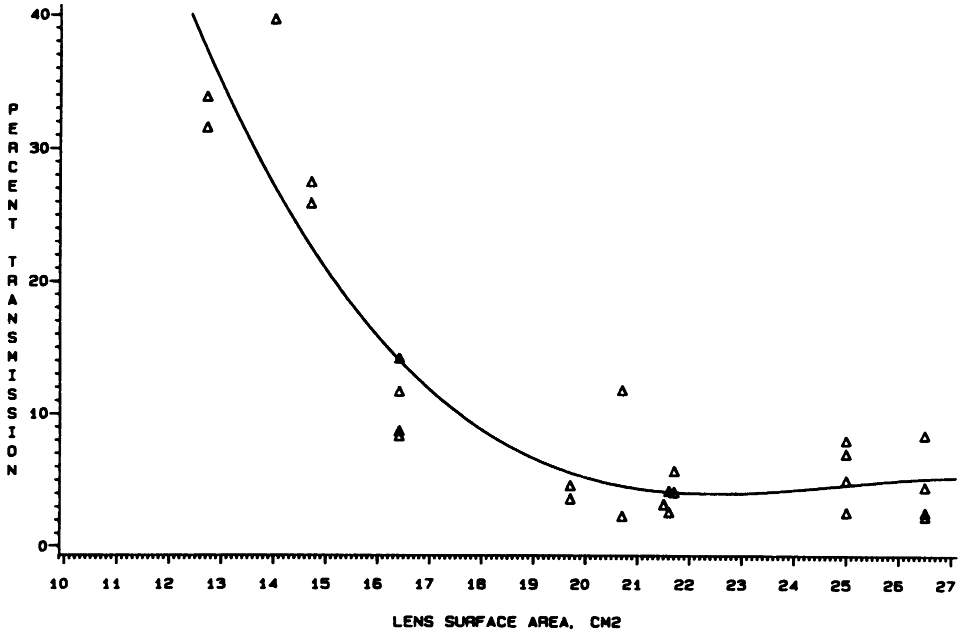

FIGURE 2—Per cent ocular exposure vs lens surface area, measured in a mannikin system, for spectacles with plastic lenses. Measurements performed with SCS 280 detector.

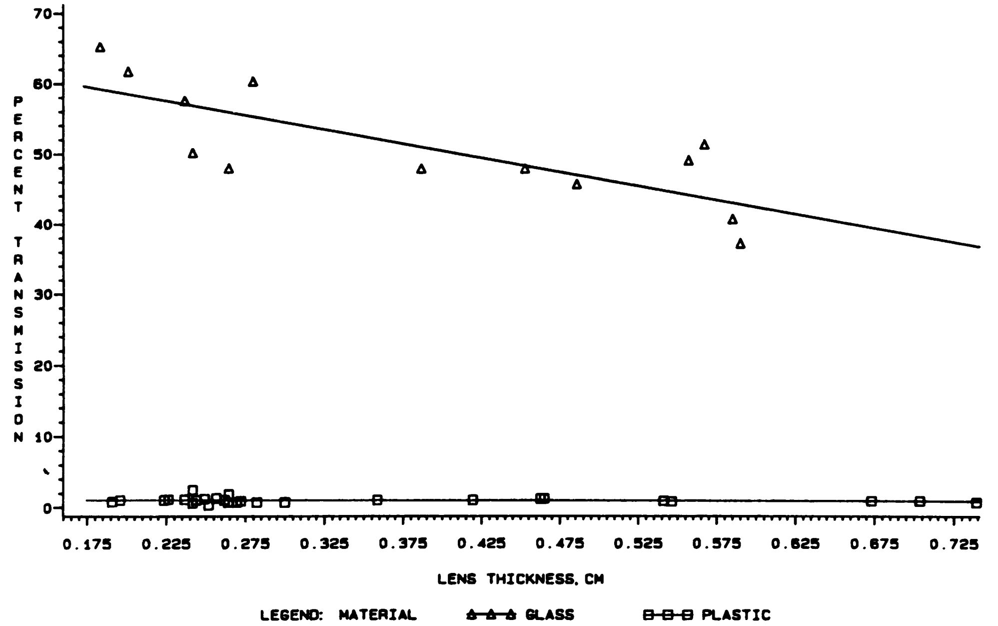

FIGURE 3—Per cent transmission vs lens thickness for glass and plastic lenses. Measurements performed with SCS 280 detector.

TABLE 4—Effect of Spectacle Position with Respect to Forehead on Per Cent Ocular Exposure (All Measurements Made with Detector SCS 280 Placed in Mannikin's "Eye")

		Per Cent Exposure with Spectacles at Given Distance from Forehead		
Lens[a]	Frame Material	0.0 cm	0.6 cm	1.2 cm
A	Metal	4.6	63.0	91.5
B	Metal	3.2	44.7	76.8
C	Metal	8.1	41.2	71.6
D	Plastic	3.6	26.5	56.5
E	Plastic	3.7	10.4	55.4
F	Plastic	27.7	62.2	88.7
G	Plastic	43.4	46.6	80.0

[a] Lens G is made of glass; all others are plastic.

pathways was confirmed by the measurements with the lenses covered with opaque material (Table 3). The data in Table 3 also suggest (although with limited statistical confidence) that the contribution of non-lens pathways is greater when facing the sun. This is most likely due to the reflection of direct sunlight, which has greatest intensity in the forward direction. From the same Table, it can be noted that the amount of UVR passing *through* spectacle lenses is approximately the same whether facing the sun or away from it.

TABLE 5—Transmission of UVR through Contact Lenses (Mean ± S.D.)

			% Transmission	
Lens Type	Lens Color	N	SCS 280 Detector	ACTS 270 Detector
Hard	Grey	8	21.7 ± 10.2	19.8 ± 10.2
	Green	4	33.8 ± 7.7	30.6 ± 7.1
	Clear	16	37.4 ± 14.6	31.4 ± 16.2
	Blue	5	49.2 ± 16.9	49.5 ± 15.5
Soft	Clear	6	71.8 ± 3.9	58.0 ± 8.0

The effect of non-lens transmission is also seen in the strong effect of spectacle position on per cent ocular exposure (Table 4). For plastic lenses, the spacing of ¼ inch away from the forehead made up to a 14-fold difference in per cent ocular exposure. However, this result must be interpreted with caution since under real life conditions the eyelids may block some of light incident from above the eye. For spectacles with glass lenses, the effect of spectacle position was much less apparent because the lenses themselves transmitted large amounts of UVR.

The transmission through contact lenses was on average higher than plastic spectacle lenses and in general closer to the transmission of glass spectacle lenses. This may be due to both the thinness of these lenses, as well as compositional differences between the plastic used in contacts as compared to spectacle lenses. The transmission of UVR through contact lenses was related to the type of lens. Soft contact lenses transmitted substantially greater amounts of UVR than hard contacts. Among the hard contact lenses, blue-tinted lenses transmitted the greatest amount of UVR, while grey-tinted lenses transmitted the least.

The dependence of transmission on spectral response of the detector can be understood clearly in terms of the exposure spectrum of sunlight and the absorption spectrum of the lenses. Measurements with the 280 detector showed greater transmission than those with the 270 detector, since the 270 emphasizes those wavelengths where absorption is the greatest. This effect is intensified because the spectral intensity of sunlight increases rapidly with wavelength. Thus eyewear is less protective if an action spectrum with a long wavelength "tail" is assumed. As might be expected, the choice of detector had little effect on the per cent ocular exposure seen with plastic lenses, since in this case most of the detected light passed around rather than through the lenses. The choice of detector had almost no effect on

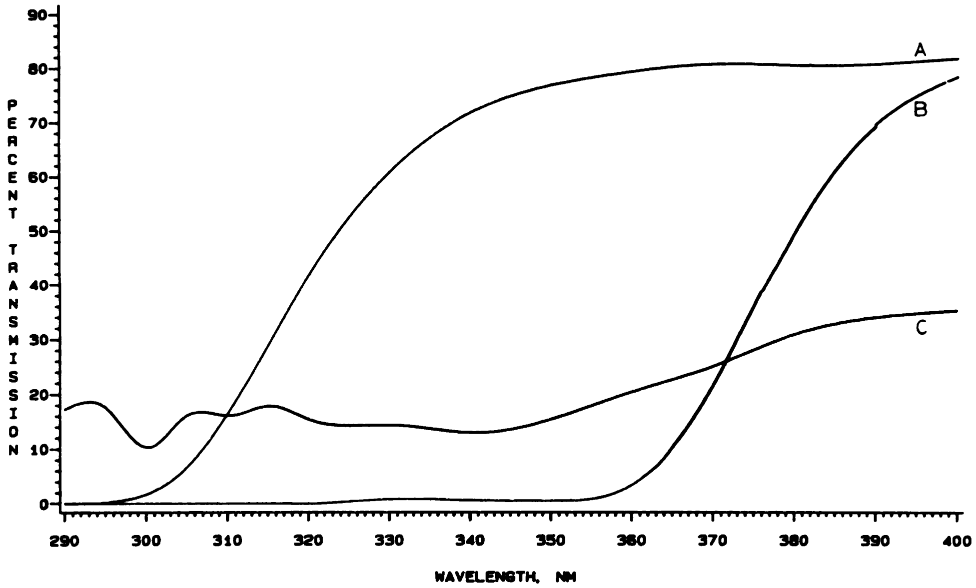

FIGURE 4—Typical spectral transmission curves for spectacle lenses of glass (A) and plastic (B), and for grey contact lenses (C).

transmission through contact lenses because of the relatively flat absorption spectrum of these lenses (Figure 4).

Because of the uncertainties in the action spectra for ocular damage, it is not possible to specify which detector measures the most biologically relevant transmission or exposures. However, since the two detector action spectra "bracket" most hypothesized biological action spectra for ocular damage, the most appropriate values of transmission and per cent ocular exposure may be considered to lie between those values given for the 270 and 280 detectors. The 270 response spectrum does have the best agreement with the action spectrum for rabbit lens damage of Pitts and Cullen;[4] however, the relevance of their data to human exposure is unknown. On the other hand, the 280 detector gives results which take account of the possible effects of longer wavelength radiation.

The sample of spectacles and lenses used in this study was obtained from one optician's office and was not characterized as to manufacturer or point of origin. It may thus not be representative of all products currently in use. In particular, the attenuation of plastic lenses, which probably depends greatly on lens composition, may vary between samples of lenses. To further investigate this issue, it is recommended that the measurements be repeated with lenses obtained from other locations.

The exposure to UVR for individuals wearing prescription eyewear depends both on properties of the lenses and the existence of non-lens pathways. Due to these pathways, ocular exposure may depend on the size and shape of the frames and lenses as well as the wearing position of spectacles. These factors can be expected to dominate for spectacles with highly absorptive lenses.

Because of light passing through non-lens pathways, there is a practical limit to the degree of UVA or UVB attenuation that can be provided to wearers of conventional spectacles. It is possible that this attenuation might be increased by the use of eyewear with sideshields or oversized lenses.

Although the purpose of prescription eyewear is not protection against UVR, it may also provide benefits in this area. This benefit may be optimized by careful consideration of the composition and design of spectacles and contact lenes.

The sizable attenuation of UVR due to prescription eyewear should be considered in the design of epidemiological studies to assess ocular effects of sunlight exposure.

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