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EVALUATION OF THE LEVEL OF TRANSMISSION OF SOLAR RADIATION BY EYEGLASSES (SPECTACLES) AND ITS EFFECTS ON THE HUMAN EYE

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ABSTRACT

Global atmospheric changes such as depletion of Ozone in the stratosphere and global warming contribute to the average increase of ultraviolet radiation on earth. Protective eyeglasses are normally recommended to safeguard the eyes from the harmful effects of solar radiation. In this paper, twenty (20) pairs of eyeglasses were selected based on systematic random sampling to determine the amount of optical radiation transmission and level of attenuation by eyeglasses, in the wavelength range of 200nm to 900nm using 6405 UV/VIS spectrophotometer. All the eyeglasses were found to transmit a substantial amount of ultraviolet radiation. The transmission of visible light depends on the lens colours. It was discovered that the eyeglasses do not provide complete protection from UV radiation. This shows that the glasses can still pose great danger to human eyes.

Keywords: Global warming, Depletion of Ozone, Solar radiation, Optical radiation, Attenuation, Eyeglasses, Human eye, Percentage transmittance (%T), Spectrophotometer.

Contribution/ Originality

There is virtually little or no study in this regard conducted in the study area. As such this study documents the first results that show the implication of using the eye glasses produce/traded in the area.

1. INTRODUCTION

According to well-established measurements, the average power density of solar radiation just outside the atmosphere of the earth is 1366W/m^2 [1]. Not all the sunlight is received directly from the sun because it is attenuated by at least 30% during its passage through the earth's atmosphere

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[1]. This means that all radiation with a wavelength below 290nm is filtered out before it reaches the earth’s surface. Solar energy comes to the surface of the earth in the form of radiation, or light, with spectral components, mostly in the visible, near infrared, and near ultraviolet. Global atmospheric changes such as stratospheric Ozone depletion may increase the level of UV radiation on earth. This would contribute to enhanced chronic exposure of the eye and skin tissue of humans to UV light [2, 3]. Little absorption of Radiation takes place in the visible region. Absorption in the ultraviolet region is due primarily to electronic transition of molecular and atomic oxygen, nitrogen and ozone in the upper atmosphere. This absorption usually prevents wavelengths shorter than 0.3μm from reaching the surface of the earth [1].

Absorption in the infrared region of the spectrum is chiefly due to vibration and rotation of polyatomic molecules such as H_2O and CO_2. Scattering in the atmosphere also substantially modifies the energy reaching the earth’s surface [1].

Even with the atmospheric attenuation of solar radiation, a substantial amount of optical radiation reaches the surface of the earth. Exposure to intense sunlight can have undesirable effect to the eyes and shielding glasses are commonly recommended to protect the eyes from the harmful effects of solar radiation [4]. The level of effect of radiation on human eye depends on its level of penetration, which in turn depends on its wavelength, duration of exposure, and frequency [5, 6]. Since this work is concerned with potential hazards of solar radiation on the human eye, the discussion will be limited to the situations where a hazard is expected.

Unlike the skin, the principal natural defence mechanism for the eye is the eye socket and partial closing of the eyelids in response to visible light level [7]. Radiation protection is necessary to restrictor minimize the level of radiation absorption by the body. Methods employed include covering, filtering and shading [7]. Shading could be a better means of protecting the eyes from harmful radiation and could be achieved by using the correct type of eyeglasses which will block 100% UV radiation. Although in general sunglasses substantially attenuate the amount of ultraviolet radiation reaching the eye, this attenuation is far from complete and there is great variability [8]. Moreover, for outdoor use in the bright sunlight, sunglasses that absorb 99 – 100% of the full UV spectrum to 400nm are recommended [9]. Using the wrong type of eyeglasses may cause more harm to the eyes than not wearing glasses at all. This because in bright light the pupil is constricted and in dim lights it is dilated. A dim light as a result of eyeglass will make the pupil remain dilated and expose the eye to harmful radiation which could be minimize by reflex action of the eye. A number of works have shown problems with UV transmission of sunglasses that are worn for protection. These problems are not yet eliminated. Ultraviolet radiation is a type of non-ionizing radiation with wavelengths ranging from 100 to 400nm [10]. It does not provide useful vision, instead it harm the retina in acute intense exposure [11]. Alteration of lens protein is another biochemical mechanism that has been proposed following UV radiation exposure [2]. These biochemical changes can occur through a direct effect of UV light. Using a theoretical model, it was [12] concluded that under certain circumstances the use of sunglasses may actually increase ocular UVR exposure, by causing pupil dilation. Similar results were reported [2, 13].

Ultraviolet radiation can be categorized into spectral bands; the UV-A region exhibit wavelengths between 315-400nm, UV-B in the region of 280-315nm and UV-C wavelengths between 100-280nm [6, 9, 14, 15]. Of these three bands, UV-C is more dangerous and UV-A cause the least harm to human eye.

The part of the electromagnetic spectrum with wavelengths from about 400 to 780nm (visible light) is the most sensitive to human vision [16]. Visible light is categorized into short (blue), medium (green) and long (red) wavelength radiations. Beside UV light, the blue light (within the visible region) can cause damage to the eye [11]. The high energy of photons in the spectrum of blue light and adjacent UV-A radiation has the power to damage the cellular function and structures of photoreceptors [14]. Prolonged exposure to blue light may reduce the colour sensitivity of the retina [17]. The region of visible radiation just beyond the red end is referred to as infrared. The infrared region is often subdivided into IR-A (0.78µm-1.4µm), IR-B (1.4-3µm) and IR-C (3µm-1mm). International Commission on Non-ionizing Radiation Protection statement on far infrared radiation exposure considers that all of the IR energy from IR-A and IR-B (780-3,000nm) poses a risk to the human eye, whereas the contribution from IR-C in a white light source could be small, or at least more or less equivalent for different sources [18]. In this paper the level of transmission of optical radiation by commercial eyeglasses used by the community around Zaria and environs was determined; which allowed for the prediction of its effect on the human eyes. In this area of study, sunlight is prevalent and often members of the community report cases of vision impairment that could be linked to occupational UV radiation exposure and blue light.

2. THEORY

When light passed through any transparent media, it is subjected to beam attenuation associated with light reflection, absorption, refraction, or scattering depending on the density of the media and other characteristics.Linear attenuation coefficient is the percentage reduction of incident light per unit thickness of absorber. This implies that for each unit thickness (such as millimetre) of absorbing material placed in the path of the beam there is set percentage of reduction in the intensity of the radiation. The attenuation coefficient μ is determined experimentally using the narrow beam geometry technique that employs collimated source of mono-energetic photons and a narrowly collimated detector as illustrated in figure 1a [19].

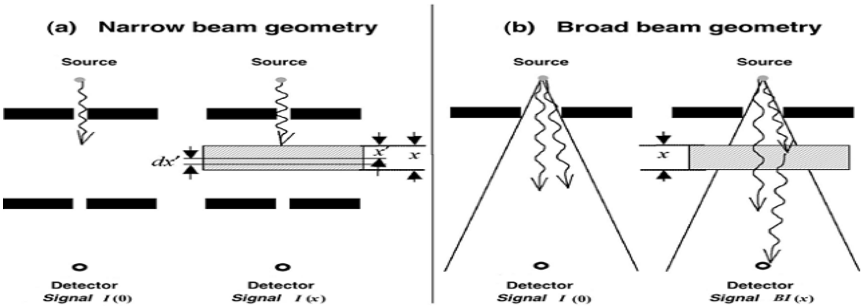

Figure-1. Measurement of photon attenuation in absorbing material. Part (a) is for narrow beam geometry; part (b) is for broad beam geometry [19].

As shown in the figure, a slab of absorber material of thickness *x* is placed between the source and detector. The absorber decreases the detector signal (intensity) from *I(0)* that is measured without the absorber in place to *I(x)* that is measured with absorber thickness *x* in the beam path.

A layer of elemental thickness dx' within the absorber reduces the beam intensity by small intensity dI and the fractional reduction in intensity, $-\frac{dI}{I}$, is proportional to

- Attenuation coefficient μ
- Layer of elemental thickness dx'

The relationship between μ, dx' and $-\frac{dI}{I}$ is given by:

$$-\frac{dI}{I} = \mu dx' \qquad (1)$$

And integrating (1) over the entire thickness x, we have

$$I(x) = I(0)e^{-\int_0^x \mu dx'} \qquad (2)$$

For a homogeneous medium μ = constant and (2) reduces to the standard exponential relationship valid for monoenergetic photon beams

$$I = I_o e^{-\mu x} \qquad (3)$$

Where I_o is the initial intensity and I is the intensity after passing through thickness *x*. μ is a property of the material and is known as the linear attenuation coefficient. If *x* is measured in *mm*, μ has unit mm^{-1}.

Absorbance is related logarithmically to transmission by

$$A = 2 - \log \%T \qquad (4)$$

The amount of light transmitted through a sample is referred to as transmittance *(T).* The transmittance is defined as the ratio of the light energy *(I)* transmitted through the sample to the energy transmitted through the reference blank *(* I_o*).*

$$T = \frac{I}{I_0} \qquad (5)$$

This is multiplied by 100 to determine the percentage transmittance *(%T),* the percentage of light transmitted by the substance relative to the reference blank.

$$\%T = \frac{I}{I_0} \times 100 \qquad (6)$$

From equation 3 and 5 we have

$$\frac{I}{I_0} = e^{-\mu x} = T \qquad (7)$$

For percentage transmittance we therefore have

$$\%T = 100e^{-\mu x} \qquad (8)$$

Finally we generate the equation of linear attenuation coefficient as

$$\mu = \frac{\ln 100 - \ln \%T}{x} = \frac{\ln\left(\frac{100}{\%T}\right)}{x} \qquad (9)$$

When light passes from one medium to another, some of the rays are reflected by the second medium. The ratio of the total amount of radiation reflected by a surface to the total amount of radiation incident on the surface is the reflectance. This can be calculated from

$$R = 1 - A - T \quad (10)$$

Where $\boldsymbol{A}$ and $\boldsymbol{T}$ are absorbance and transmittance respectively.

3. MATERIALS AND METHOD

This research was carried out in the Multi-user Science Research Laboratory, Ahmadu Bello University Zaria using 6405 UV/VIS spectrophotometer [20]. Measurements were carried out on 20 commercial eyeglasses of different colours (colourless, brown, blue, gray, Purple, darkcolours) which were purchased within Zaria markets, Nigeria. All samples were cut to a standard size of 1cm by 4cm in order to properly fit into the chamber of the spectrophotometer. The thickness of each glass is 1.02±0.05 mm. Data (%transmittance) was collected from the spectrophotometer in the following Settings:

Measure mode:	%Transmittance
Start wavelength:	200.0nm
End wavelength:	900.0nm
Scan interval:	5.0nm

Keeping the same settings, the values of the wavelengths and the corresponding percentage transmittance of each of the eyeglasses were read and recorded from the output (screen) of the spectrophotometer.

The linear attenuation coefficient μ of each sample was calculated using equation 9.Thickness of the eyeglass lenses was measured with micrometre screw gauge. The absorbance of each sample was calculated using equation 4.

The average %transmittance was calculated for each region of the optical radiation and for each sample using the relations

$$\frac{\sum_{200}^{400}(\%T_{200}+\%T_{205}+\cdots+\%T_{400})}{\sum_{200}^{900}(\%T_{200}+\%T_{205}+\cdots+\%T_{900})} \times 100 \text{For UVR} \quad (11)$$

$$\frac{\sum_{400}^{780}(\%T_{400}+\%T_{405}+\ldots+\%T_{780})}{\sum_{200}^{900}(\%T_{200}+\%T_{205}+\ldots+\%T_{900})} \times 100 \text{For VR} \quad (12)$$

$$\frac{\sum_{780}^{900}(\%T_{780}+\%T_{785}+\cdots+\%T_{900})}{\sum_{200}^{900}(\%T_{200}+\%T_{205}+\cdots+\%T_{900})} \times 100 \text{For IRR} \quad (13)$$

4. RESULTS AND DISCUSSIONS

The average value of transmittance, absorbance, reflectance and linear attenuation coefficient for all the samples are summarised in table 1.

Table-1. Transmittance, absorbance, reflectance and linear attenuation coefficient

Sample	transmittance	absorbance	reflectance	Linear Attenuation coefficient
1	0.165474453	0.863401079	-0.073308486	1.656712045
2	0.163276596	0.856869327	-0.070035994	1.644178782
3	0.37506383	0.652647447	0.75978933	1.252313568
4	0.417787234	0.601279328	-0.061498078	1.153747347
5	0.160914894	0.818424941	-0.028508274	1.570410891
6	0.089780142	1.152226508	-0.269439471	2.210916317
7	0.684588652	0.15866424	0.043591958	0.304448262
8	0.275021277	0.599787025	0.065919871	1.150883886
9	0.322836879	0.553179457	0.061057831	1.06145231
10	0.221368794	0.710992726	-1.99E-06	1.36426771
11	0.352411348	0.632895076	-0.036878816	1.214412306
12	0.365113475	0.631561997	-0.03375731	1.211854367
13	0.321794326	0.809995041	-0.230115412	1.554235423
14	0.395283688	0.518700708	0.028169211	0.995293764
15	0.277234043	0.59423719	0.068780051	1.140234747
16	0.444411348	0.362998661	0.062120605	0.696529421
17	0.431269504	0.505293404	0.019636283	0.96956755
18	0.446134752	0.553602013	-0.065024777	1.062263119
19	0.314368794	0.539451941	0.07843599	1.035111664
20	0.561695035	0.235109058	0.031566868	0.451132177

Source: Original data obtained in our laboratory

The wavelength, 200nm to 900nm was grouped into three: 200nm to 400nm for UV Radiation, 400nm to 780nm for visible light and 780nm to 900nm for IR radiation. The average %transmittance for each group is summarised in table 2.

From table 2, it can be observed that some of the eyeglasses under study (samples 1, 2, 5, 6, 10, 13 and 20) indicate lower transmission of UV radiation. With the exception of sample 20, the rest transmit below 35% of the total radiation the worst being samples 6, 5, 2 and 1 with 9%, 16.1%, 16.3% and 16.5% respectively. These eyeglasses indicate some benefits as well as harms to the human eye. The benefit is in the ability of the eyeglasses to minimize the transmission of UV radiation to almost 0%.

However, the harm lies in the visible region; the eye primarily functions as a receiver and transducer of light from the environment [11]. The human eye contains photosensitive cells in the retina, which are stimulated by sunlight radiation [4]. The optical quality of the retinal image is the result of light passing through the ocular structures of the eye [21]. Also, the pupil response is most sensitive to visible light; eyeglasses may allow pupil dilation in proportion to the darkness of the eyeglasses increased intraocular insolation [22]. These eyeglasses may lead to light deficiency to the eye, which as a result may enhance eye defects caused by light deficiency. Moreover, with these eyeglasses, visibility will be greatly affected.

Sample 20 provides the highest percentage transmittance at visible range and very low percentage transmittance at UV range; it could minimize UV transmission and allow sufficient transmission of visible light for the stimulation of photosensitive cells in the retina.

Table-2. Showing average percentage Transmittance

				Average %Transmittance (%T) of		
Sample	**Lens Colour**	**Lens Material**	**Average %Transmittance**	**UVR (200-400nm)**	**VR (400-780nm)**	**IRR (780-900nm)**
1	Dark	Plastic	16.5474453	0.158800176	57.30921923	44.23908249
2	Dark	Plastic	16.3276596	0.61680132	52.75388759	48.63608722
3	Slate gray	Plastic	37.506383	3.698661221	56.76386052	41.78579533
4	Light brown	Plastic	41.7787234	5.639301962	59.42147077	36.63509201
5	Gray	Plastic	16.0914894	0.709594958	57.18630173	43.98607255
6	Dark	Plastic	8.9780142	0.197487953	52.78458014	48.83482108
7	Colourless	Glass	68.4588652	12.10334932	68.90403721	20.74445492
8	Brown	Glass	27.5021277	7.860126876	59.43576255	35.00954149
9	Dark	Glass	32.2836879	17.19024605	49.81107206	35.77768014
10	Dark	Plastic	22.1368794	0.144170698	60.73751322	40.68176721
11	Gray	Plastic	35.2411348	6.138055947	54.85208291	41.23968605
12	Brown	Plastic	36.5113475	7.105534081	52.94380451	42.10291175
13	Dark brown	Plastic	32.1794326	0.614903136	50.60498534	50.92015075
14	Gray	Plastic	39.5283688	5.3610837	57.84695434	38.98627433
15	Brown	Glass	27.72340426	8.068559734	59.43207982	34.82220517
16	Blue	Plastic	44.4411348	3.603459832	64.0914749	34.79780409
17	Light Gray	Plastic	43.1269504	7.584403624	57.89439063	36.64753573
18	Light brown	Plastic	44.6134752	3.228678165	62.87099595	35.69509578
19	Dark	Glass	31.4368794	14.76334431	50.89563687	37.18585029
20	Purple	Plastic	56.1695035	0.236114092	71.8304524	29.18471193

Source: Original data obtained in our laboratory

Furthermore, some of the eyeglasses (samples 7, 9, 12, 16, 19) show significant transmission of UV radiation in addition to substantial transmission of visible light. These eyeglasses could be harmful to the eye because, they moderate glare from direct visible light and may increase the level of exposure to UV radiation. Therefore, these type of eyeglasses may enhance eye defects resulting from prolonged exposure to UV radiation.Potential adverse health effects associated with exposure of the eye to UV radiation can manifest as *photokeratitis*, *photoconjunctivitist*, retinal burns, cancer and *cateracts* [23]. The conjunctiva is easily damaged by UV radiation, which activates a complex series of oxidative reactions and distinct pathways of cell death [15]. However, individual ocular exposure to UV radiation can be considered to result from environmental and physiological factors [24].

Considering transmission in the infrared region, all the eyeglasses show a significant transmission of infrared radiation. This is observable in table 2. Although the range of the infrared radiation was cut-off at 900nm for this research (due to equipment limitation), there is tendency of continuity of transmission of infrared radiation by the eyeglasses beyond 900nm. Visible and infrared radiations can easily be detected by human senses and normal reflex action can reduce the hazards [25].

Observing and comparing the properties of the samples from table 2, it shows that dark eyeglasses with plastic material block more of the UV radiation than eyeglasses with glass material. This shows that the type of lens material determines the level of optical radiation transmission by the eyeglasses.

It was established that the level of attenuation of ocular exposure to UV radiation by sunglasses is highly variable among different samples [8]. However, they are with the opinion that the variation based on glass material (i.e. between plastic and glass for example) is negligible.

Additionally, it can be observed from the two tables presented, darker coloured eyeglasses do not assure sufficient blocking of low wavelength light. These types of eyeglasses reduce the intensity of visible light reaching the eyes. Consequently, the pupils remain dilated, resulting to more UV-A and some portions of UV-B rays reaching the lens and retina. This may not occur with naked eyes as the eyes control the amount of light in high intensity and in darkness.

In addition, samples with plastic material show no transmittance of UV-B and UV-C.

Solar radiation varies from one geographical location to another. Thus, radiation transmission by eyeglasses could vary from one location to another. It may also be necessary to review the cut-off wavelength for UV radiation spectrum. Further research which could determine and take into consideration, the chemical composition of the lens material could give more insight on the interaction of radiation with eyeglasses as well as its attenuation, absorbance and transmittance.

5. CONCLUSION

All the eyeglasses under study transmit portion(s) of the UV radiation with varying degrees of intensities. The lens'colour and material type significantly contribute in the transmission and absorption of optical radiation. Dark coloured eyeglasses do not allow high transmission of light and this will greatly affect proper vision and consequently damage the lens and retina. However, if dark eyeglasses must be used in high intensity sun, dark eyeglasses with plastic lenses would be better (less damaging) to the eye than dark eyeglasses with glass lens materials.

The claim by the manufacturers of these eyeglasses was a bit of concern; since none of the glasses could block100% UV radiation with 400nm cut off. This shows that some of the eyeglasses could pose a great danger to the human eyes as a result of exposure to UV radiation or blue light.

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