

GOT THE BLUES, WITH MACULAR DEGENERATION

by

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GOT THE BLUES, WITH MACULAR DEGENERATION

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## ABSTRACT

*Background:* Oxidative stress induced by low-wavelength visible light is a known risk factor for developing age-related macular degeneration (AMD). Exposure to sources emitting light from the blue region of the visible spectrum could negatively affect the state of AMD. While low vision patients with AMD benefit visually from illuminated magnifying devices, it should be considered that some may emit and transmit wavelengths that cause harm to the retinal tissue of the eye.

*Methods:* The visible spectra of light both emitted and transmitted were measured for commonly used illuminated handheld magnifiers, including the Eschenbach 3X/12D Mobilux LED magnifiers, the Optelec PowerMag+ 4X/12D LED magnifier, and the Eschenbach 3.5X/10D incandescent magnifier. These spectra were obtained using the Sekonic C-700 Spectromaster spectrometer. Additionally, the transmittance of UV and visible light through each handheld magnifier was measured using the Beckman DU6408 spectrophotometer.

*Results:* Data collected indicate that the illuminated low vision devices examined in this study emit short-wavelength visible light. These data also reveal that these devices transmit over 90% of this light through the magnifying lenses themselves.

*Conclusions:* The illuminated low vision devices evaluated in this study were not determined to produce harmful levels of radiation based on current studies involving phototoxic damage to retinal anatomy.

*Key words:* age-related macular degeneration (AMD), oxidative stress, spectral irradiance

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## CHAPTER 1

### INTRODUCTION

The high energy (blue and violet) region of the visible light spectrum has gained significant importance with the increasing exposure to blue light emitting devices throughout the population and their daily lives. The use of light emitting diodes (LEDs) has increased for workplace and household ambient lighting, televisions, smart phones, computer screens and low vision devices. It is well known that ultraviolet (UV) and short wavelength visible light pose threats to the viability and function of the neural retina and retinal pigment epithelium (RPE)<sup>1,2</sup>. Aging results in physiological changes to the human retina and the functionality of retinal photoreceptors and RPE. Damage is considered an alteration in the tissue that results in temporary or permanent visible change to the retina and/or deteriorated visual function<sup>3</sup>. Ocular cell damage from light exposure may be the result of either photooxidative reactions or an inflammatory response. Long term exposure to low intensity radiation causes a photooxidative reaction. With this prolonged light exposure, oxidative stress ensues, resulting in a cascade of changes ultimately inducing cellular apoptosis and the development of degenerative disease. Age-related macular degeneration (AMD) initially involves the degeneration of the RPE. Lipofuscin, a component of the RPE, is considered a photosensitizer which enables photochemical changes at a cellular level. This begins when a certain type of fluorophore within RPE lipofuscin known as A2E (*N*-retinylidene-*N*-retinylethanolamine) becomes excited by

short wavelengths (with peak absorbance at 338-447 nm). The absorption and excitation of A2E causes a release of various forms of reactive oxygen species (ROS) and eventually initiates cell death<sup>4</sup>.

With age and increasing disease state, lipofuscin collects in the RPE, thereby increasing the concentration of A2E in the RPE. Eventual drusen formation occurs, potentially impacting the retinal photoreceptors. A lifetime of exposure to oxidative factors such as cigarette smoke, genetic predisposition to elevated cholesterol, and a diet lacking in anti-oxidative nutrients can all lead to increased retinal oxidation and potential vision loss<sup>5</sup>. Age-related macular degeneration is becoming more common as the aging population escalates. The projected number of people with AMD worldwide has been proposed by Wong et al. for the years 2020 and 2040 to be 196 million and 288 million, respectively. According to the American Optometric Association, it is the leading cause of blindness in people over the age of 50 and the prevalence increases rapidly in persons greater than 75 years old. While it predominately affects those of European decent, it is predicted that Asia will see the largest number of people with the condition given its population size<sup>6</sup>. Up to 90% of AMD cases are the non-exudative (dry) form in which the RPE and photoreceptor outer segments slowly break down. The remaining 10% of cases are the more devastating exudative (wet) form which causes neovascularization, subretinal fluid buildup, and, in 90% of cases, legal blindness<sup>7</sup>. Low vision as established by the World Health Organization is defined as best corrected vision of Snellen acuity 20/70 or worse. In the U.S., legal blindness is defined as best-corrected vision of 20/200 or worse and/or visual field of less than 20 degrees. Macular degeneration affects central visual acuity more than visual field size regarding these definitions. As low vision and legal blindness



greatly affect the quality of life and activities that patients suffering from these conditions can perform, dedicated optical devices and special lighting are significant tools for aiding in their daily lives. The process of aging and degeneration involves a complexity of multiple pathways, both genetic and photochemical. Therefore, it is important to understand among patients suffering from these conditions what further deterioration may result from blue light exposure due to regular use of the optical devices.

According to reports from Morgan et al, ANSI standards established a maximum permissible exposure (MPE) of  $560 \text{ J/cm}^2$ , yet the study by Morgan et al measured damage occurring to the RPE well below these standard levels at  $>79 \text{ J/cm}^2$  of exposure to 488 nm light<sup>8</sup>. While their findings raise notable concern, it must be considered that the ocular anatomy provides inherent protection to the retina from spectral irradiance. This includes corneal absorption, the pupil diameter, and transmission of light through the cornea and lens. Pokorny et al determined the lens transmits light greater than 660 nm, the cornea absorbs almost all light less than 300 nm, and a lens or UV-absorbing IOL (intraocular lens) will transmit less than 1% of light below 390 nm<sup>9</sup>. The spectral irradiance that reaches the retina is also reduced due to these structures as noted by Meyers et al. The study calculated that while sunlight at 500 nm reflecting off the ground has a spectral irradiance of  $1 \text{ mW/cm}^2/10\text{nm}$ , the retinal irradiance would likely be only a few microwatts/cm<sup>2</sup>/10nm<sup>10</sup>. This is useful information when considering potential damage from illuminated magnifiers low vision patients use. Despite the protection provided by the cornea and crystalline lens, there are still risks for increased retinal damage. LED sources notoriously emit light in the shorter wavelength (blue) portion of the visible spectrum, thus one must consider that an aged, diseased retina with pseudophakia (lacking

natural lenticular protection) has an increased risk of exacerbating disease. Due to the multifactorial pathology, it is difficult to predict how or when further damage will develop from one individual to another.

This study focuses on the concern of spectral illumination, particularly regarding emittance from handheld low vision devices and its impact on patients who suffer from degenerative retinal diseases such as age-related macular degeneration.

## CHAPTER 2

### METHODS

The Sekonic C-700 SpectroMaster spectrophotometer was utilized to measure the spectral energy distribution associated with three commonly used handheld illuminated magnifiers. Additionally, the Beckman spectrophotometer DU 640B was used to perform wavelength scans in order to measure transmittance of light through the magnifier lenses. The handheld magnifiers that were tested in this experiment were the Optelec PowerMag+ Bright White LED 4X/12D magnifier (Optelec Inc.), the Eschenbach 1511-2 Mobilux 3X/12D LED magnifier, and the Eschenbach 1510-3 incandescent illuminated 3.5X/10D magnifier (Eschenbach Optik). The spectral energy distribution measurements were collected by the Sekonic SpectroMaster for each magnifier at working distances of 2.5, 10, and 25 centimeters using a white sheet of paper as a viewing target. The viewing target distance for each measurement was subjectively determined by one examiner placing the

eye at the appropriate working distance. At each working distance for each magnifier, measurements were taken in ambient room light without magnifier illumination, in ambient room light with magnifier illumination on, and without ambient light with the magnifier illumination on. The irradiance of the light incident on the spectrometer in  $\text{mW}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$  was measured for a range of wavelengths spanning from 380 to 780 nm. The Sekonic spectrophotometer program was used to display data collected in the form of a spectral energy distribution curve. Irradiance data at peak wavelengths were extrapolated from the resulting plots.

The Beckman DU 640B spectrophotometer measured the transmittance of wavelengths between 200 and 800 nm through each of three handheld magnifier lenses. The illumination capability of each magnifier was turned off during each scan.

## CHAPTER 3

### RESULTS

The spectral irradiance data collected for the three measured devices are summarized in Tables 1-3. Measurements below are the spectral irradiances measured on the three devices for a wavelength range of 370-780 nm. Though almost all had peaks in the green and red portion of the visible light spectrum, this study did not aim to focus on these irradiances.

Table 1. Spectral Irradiance Peaks of the Optelec Power Mag+ 4X/12D LED Magnifier

	Ambient light ON Illuminator OFF ( $mW \cdot m^{-2} \cdot nm^{-1}$ )	Ambient light ON Illuminator ON ( $mW \cdot m^{-2} \cdot nm^{-1}$ )	Ambient light OFF Illuminator ON ( $mW \cdot m^{-2} \cdot nm^{-1}$ )
2.5 cm			
435 nm	7.84	8.08	8.85
544 nm	20.4	20.8	22.9
612 nm	19.8	20.0	21.9
10 cm			
435 nm	5.88	5.33	6.28
544 nm	15.1	14.0	15.8
612 nm	14.2	13.4	15.3
25 cm			
435 nm	5.96	6.20	6.04
544 nm	15.9	16.3	15.4
612 nm	15.4	15.9	14.9

Table 2. Spectral Irradiance Peaks of the Eschenbach 3.5X/10D Incandescent Magnifier

	Ambient light ON Illuminator OFF ( $mW \cdot m^{-2} \cdot nm^{-1}$ )	Ambient light ON Illuminator ON ( $mW \cdot m^{-2} \cdot nm^{-1}$ )	Ambient light OFF Illuminator ON ( $mW \cdot m^{-2} \cdot nm^{-1}$ )
2.5 cm			
435 nm	10.8	8.04	8.08
544 nm	24.6	20.8	21.2
612 nm	22.7	20.4	20.0
10 cm			
435 nm	5.15	4.31	0.0471
544 nm	13.4	10.8	0.267
612 nm	12.8	10.1	0.508*
25 cm			
435 nm	5.57	4.94	0.118
544 nm	15.0	13.2	0.824
612 nm	14.5	12.7	0.157**

\*: Highest irradiance on the measured spectrum was  $1.55 mW \cdot m^{-2} \cdot nm^{-1}$  at 780 nm

\*\* : Highest irradiance on the measured spectrum was  $0.514 mW \cdot m^{-2} \cdot nm^{-1}$  at 780 nm

Table 3. Spectral Irradiance Peaks of the Eschenbach Mobilux 3X/12D LED Magnifier

	Ambient light ON Illuminator OFF ( $mW \cdot m^{-2} \cdot nm^{-1}$ )	Ambient light ON Illuminator ON ( $mW \cdot m^{-2} \cdot nm^{-1}$ )	Ambient OFF, Illuminator ON ( $mW \cdot m^{-2} \cdot nm^{-1}$ )
2.5 cm			
435 nm	8.24	8.27	8.46
544 nm	22.6	21.5	21.9
612 nm	21.2	20.8	20.8
10 cm			
435 nm	4.94	8.00*	4.55**
544 nm	12.6	19.3	11.7
612 nm	11.8	17.3	10.5
25 cm			
435 nm	5.57	6.35	5.41
544 nm	14.7	16.8	13.7
612 nm	14.4	16.1	13.1

\*: Highest blue peak measured spectrum was  $15.5 mW \cdot m^{-2} \cdot nm^{-1}$  at 458 nm

\*\* : Highest blue peak on the measured spectrum was  $9.23 mW \cdot m^{-2} \cdot nm^{-1}$  at 458 nm

With the exception of four results, all three devices showed peak spectral irradiance values at 435 nm (blue), 544 nm (green), and 612 nm (orange/red) in all lighting conditions and at all working distances.

The first device assessed was the Optelec PowerMag+ Bright White LED 4X/12D magnifier. With ambient light on and the device's illuminator off, the greatest irradiances for each of the blue, green, and red peaks were measured at a working distance of 2.5 cm. The lowest magnitudes of irradiance at each of the three peak wavelengths were measured at a 10 cm working distance. The irradiances at 25 cm were only slightly higher than those recorded at 10 cm. For the data collected with ambient light on/illuminator on and ambient light off/illuminator on, the irradiances follow a similar pattern. The greatest peak irradiances were noted at a 2.5 cm working distance, the least were found at 10 cm, and values relatively higher than the minimum were recorded at 25 cm. The highest peak irradiances were found to occur with ambient light off/illuminator on at working distances of 2.5 and 10 cm and with ambient light on/illuminator on at a 25 cm working distance.

The second device assessed was the Eschenbach 1510-3 incandescent illuminated 3.5X/10D magnifier. Much like the first device, the irradiance is highest at 2.5 cm, lowest at 10 cm, and slightly higher than the lowest values at 25 cm for each set of environmental conditions. The highest irradiances for the established reference peaks of 435, 544, and 612 nm were found with ambient light on/illuminator off for all three working distances. The lowest peak irradiances were recorded with ambient light off/illuminator on. Two of the exceptions to the 435, 544, and 612 nm peak irradiances were measurements for this incandescent illumination device: measurements taken with ambient light off/illuminator on at working distances of 10 and 25 cm. The spectral distribution curves in these two

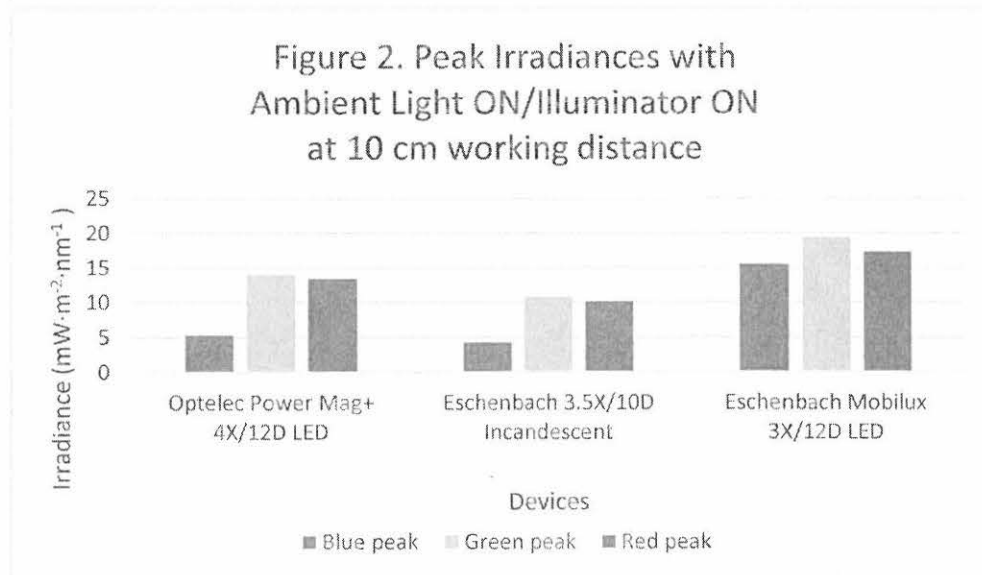
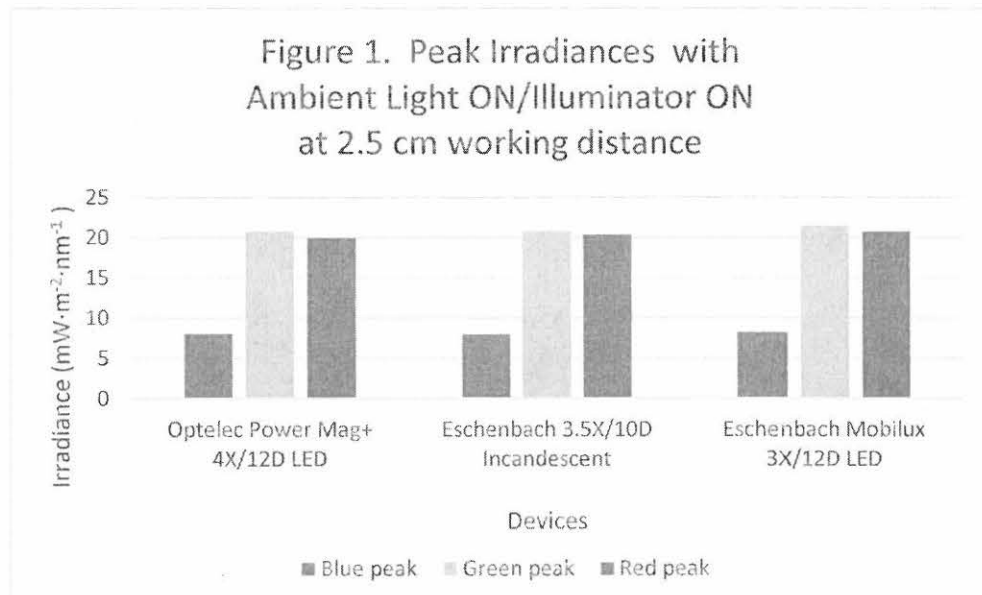
instances differ dramatically from those of the other devices under the same experimental conditions. The majority of the spectrum is concentrated at longer wavelengths with the overall peak irradiance occurring at 780 nm, the upper limit of the measured wavelengths in this study. These data suggest that the incandescent illumination system of the Eschenbach 3.5X/10D magnifier is a lesser source of high-energy blue light than the other two magnifiers examined in this study. Additionally, based on this trend, it is likely that infrared light is also produced by this illumination system, though the infrared portion of the electromagnetic spectrum was not included in the scope of this study.

The third and final device assessed using the Sekonic C-700 spectrometer was the Eschenbach Mobilux 3X/12D LED magnifier. The data once again follow the same hierarchy of greatest irradiance at a 2.5 cm working distance and the least at 10 cm under the same lighting conditions. The highest magnitudes of irradiance at each established peak wavelength were observed with ambient light off/illuminator on for 2.5 and 10 cm working distances and ambient light on/illuminator on for a 25 cm working distance. The final two exceptions to the established peak irradiances of 435, 544, and 612 pertain to this device. The data revealed primary blue peak irradiances at 458 nm rather than 435 nm at a 10 cm working distance with both ambient light on/illumination on and ambient light off/illumination on. The spectral distributions under both conditions also included secondary blue peaks at 435 nm. The irradiance at 435 nm at a 10 cm working distance with ambient light on/illumination off was  $8.00 \text{ mW}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$ , which is relatively higher than that measured for the PowerMag+ LED magnifier at 10 cm under the same lighting conditions ( $5.33 \text{ mW}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$ ). However, the blue peak irradiance for the Mobilux magnifier examined at 458 nm was found to be  $15.5 \text{ mW}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$ , which is much higher

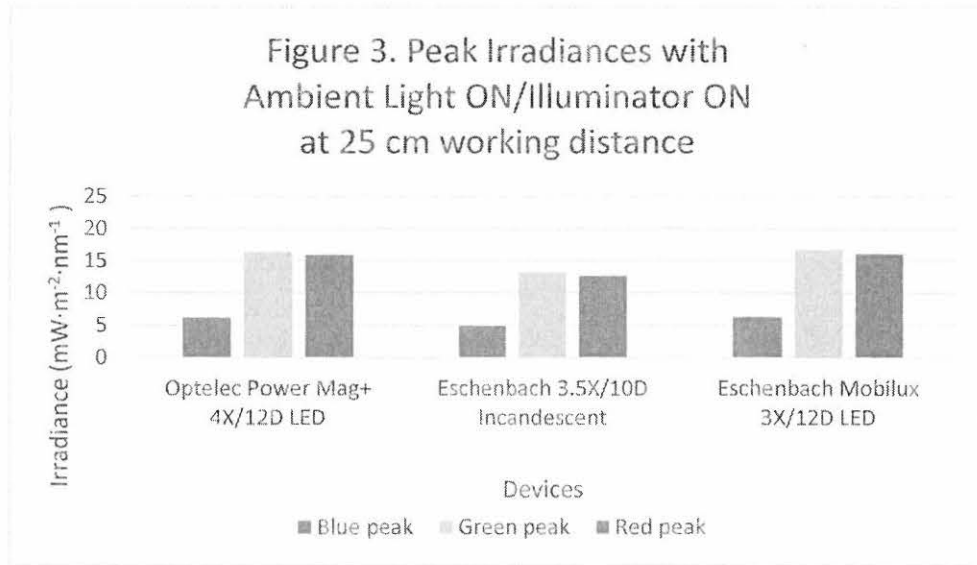
than that recorded for the PowerMag+ LED magnifier. Similarly, the irradiance at the blue peak of 458 nm for the Mobilux device at 10 cm with ambient light off/illumination on was  $9.23 \text{ mW}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$ , which is higher than the PowerMag+ device's peak blue irradiance of  $6.28 \text{ mW}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$  under the same conditions. Interestingly, at a 10 cm working distance with ambient lights off/illuminator on, the spectral irradiance of the Mobilux illuminator at 435 nm was  $4.55 \text{ mW}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$ , which is lower than that of the PowerMag+ illuminator under the same conditions. These results suggest that at a 10 cm working distance, the Eschenbach 1511-2 Mobilux 3X/12D LED illuminated magnifier may produce a higher amount of irradiance within the blue spectrum than the Optelec PowerMag+ Bright White LED 4X/12D illuminated magnifier in the absence of ambient light.

While a more definitive understanding of the relationship between visible light and retinal tissue damage must be explored, the results of this study may still be applied clinically when prescribing devices. For example, it should be considered that handheld illuminated magnifiers are typically used with ambient light present and the illuminator on. Working distances determined by patients' acuity and visual demands are also considered when prescribing. Comparisons of peak irradiances for each magnifier under the condition of ambient light on/illuminator on at the three different working distances were put into graphical format to evaluate the amount of blue light emittance from the devices. Though blue light was emitted by all devices, it was always lower than the peak green and red waves emitted by the devices. Under such conditions, our study showed the Eschenbach Mobilux 3X/12D LED magnifier showed the highest irradiances at the blue, green, and red peaks when compared to the Optelec LED and Eschenbach incandescent magnifiers at a

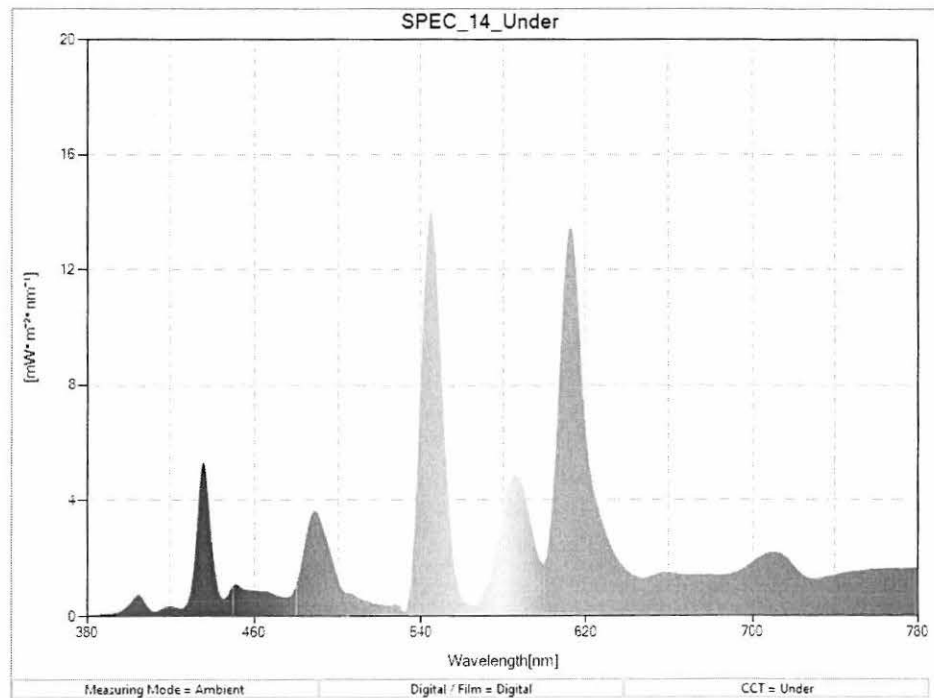
10 cm working distance. Below the comparisons between devices and working distances are shown in Figures 1, 2 and 3.







The working distance of 10 cm with ambient light on/illuminator on proved to have the highest irradiance peaks. Figures 4, 5, and 6 are presented below.



**Figure 4. Optelec PowerMag+4X/12D LED Magnifier, with Ambient Light ON/Illuminator ON at a 10 cm**

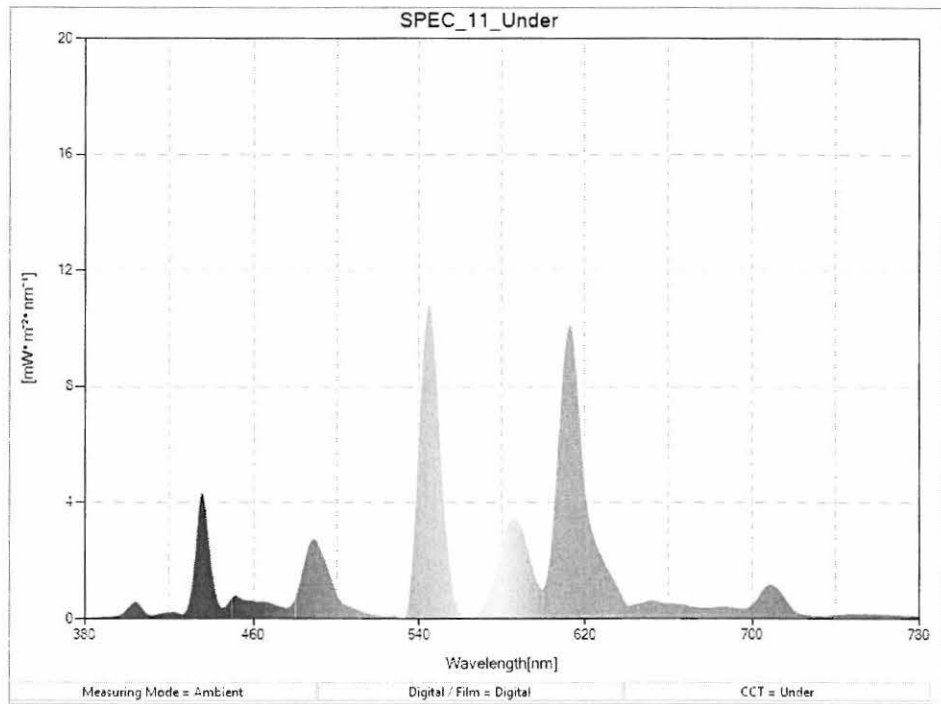


Figure 5. Eschenbach 3.5X/10D Incandescent Magnifier with Ambient Light ON/Illuminator ON at a 10 cm

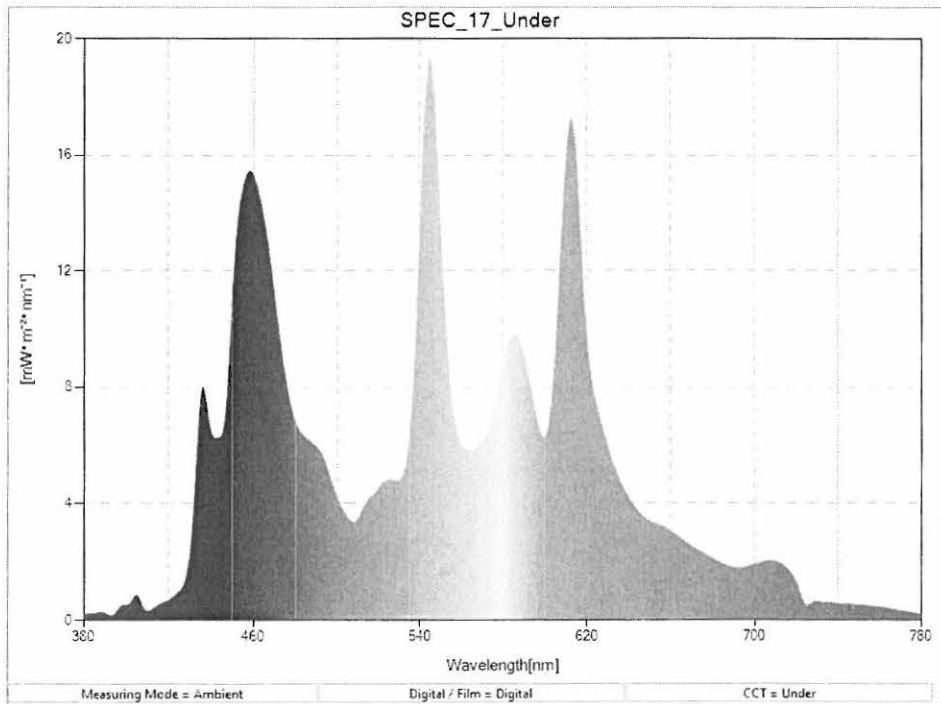


Figure 6. Eschenbach Mobilux 3X/12D LED Magnifier with Ambient Light ON/Illuminator ON at a 10 cm

The data collected utilizing the Beckman DU 640B spectrophotometer revealed approximate information regarding transmission of light between 200 and 800 nm through the lens of each handheld magnifier. The Optelec PowerMag+ LED magnifier allowed transmission of almost 0% of light below and approximately 92% of light above 380 nm. The Eschenbach incandescent magnifier allowed transmission of almost 0% of light below and approximately 92% of light above 320 nm. The Eschenbach Mobilux LED magnifier allowed transmission of nearly 0% of light below and approximately 90% of light above 320 nm. These data suggest that all three of the devices tested permit the transmission of some ultraviolet wavelengths, as well as equally transmitting most visible light.

## CHAPTER 4

### DISCUSSION

While degenerative retinal diseases such as age-related macular degeneration have been demonstrated to be multifactorial in etiology with strong genetic correlation, it is important to take environmental factors into account. Exposure to ultraviolet and low wavelength visible light is a significant factor for developing retinal disease states<sup>11</sup>. While intensity of the incident light is significant, so is the factor of exposure time.

## *Prevention*

A variety of viewpoints concerning prevention of progressive retinal disease exist, specifically with regard to macular degeneration. From a systemic vantage, smoking cessation is the initial factor to eliminate to prevent further oxidative damage to ocular cells. It has also been determined that increased dietary anti-oxidants such as lutein, zeaxanthin, vitamin C and E, among other supplements have shown to support ocular health in staving off oxidative stress<sup>12,13</sup>. Avoiding UV light exposure is yet another preventative measure that can be taken, as seen by the Chesapeake Bay study on fishermen. In that study those who had significantly higher exposure to blue and/or visible light over the preceding 20 years were more likely to have advanced age-related macular degeneration when compared to age-matched controls<sup>14</sup>. Another preventative measure taken by practitioners when considering retinal damage is the implantation of a blue-light and UV absorbing intraocular lens in cataract surgery. Gaillard et al determined conventional IOLs allow for blue light absorption by A2E to be increased by fivefold, thereby contributing to RPE damage<sup>15</sup>. Blue absorbing filtered sunglasses and/or lenses may also be utilized especially in pseudophakic eyes to reduce the intensity of retinal irradiance.

According to studies by Schutt et al., degeneration of A2E-laden RPE cells occurred at illuminations between 390 and 550 nm with irradiance of 2.8 mW/cm<sup>2</sup>.<sup>16</sup> Studies by Arnault et al. show that an increased intensity of illumination and shortened exposure duration still proved toxic when compared to lower-intensity, longer-duration light exposure<sup>17</sup>. Multiple studies have found blue light exposure proves to be more toxic than green light exposure despite blue light being exposed at lower irradiances than green<sup>18</sup>.

Kuse et al found LED light-induced cell damage was wavelength dependent rather than energy-dependent with regard to damage of photoreceptor cells<sup>19</sup>.

Given the findings of our study, irradiances for each of the devices assessed were not found to be significant enough to cause potential damage to retinal tissue under any of the circumstances tested. Acute retinal damage does not occur below a certain threshold irradiance level<sup>20</sup>. The highest irradiance values recorded with the illuminators on were those associated with the Eschenbach incandescent magnifier with ambient light on/illumination off, and this value excludes light emitted by the illumination system itself as it was turned off. The single highest value collected was at the 2.5 cm green peak (544 nm) and was  $24.6 \text{ mW} \cdot \text{m}^{-2} \cdot \text{nm}^{-1}$ , or  $0.00246 \text{ mW}/\text{cm}^2 \cdot \text{nm}^{-1}$ . Given that we know green light has less impact on retinal damage than blue light, this peak finding is less concerning when prescribing optical devices. The value of  $0.00246 \text{ mW}/\text{cm}^2$  is only 0.088% of the irradiance shown by Schutt et al. to cause degeneration of A2E-laden retinal pigment epithelial cells. Therefore, the three devices examined in this study are not expected to cause damage to retinal cells. To consider for prescribing purposes, the Mobilux 3X/12D LED magnifier showed the highest green and red peak irradiances when measured at 2.5 cm. The highest blue peak measured among all the devices proved yet again to come from the Mobilux3x/12D LED magnifier at the 10 cm working distance.

Based on the findings from our study as well as the several studies discussed previously, it is important that there be more education on light safety for both practitioners and patients. Increased awareness should be directed toward devices that emit visible blue light, as well as understanding standards of maximum exposure durations to such light sources.

### *Further Research*

Because this study focused on the amount of light exposure rather than the length of time exposed to such light, longitudinal factors may be important to further investigate when gauging the risks for developing retinal disease states such as AMD. This study aimed to assess the energy distribution across the visible spectrum produced by the light sources of three handheld, illuminated magnifying devices, as well as the transmittance of light through the magnifying lenses. As patients with degenerative retinal disease often employ multiple tools to improve their quality of life, it would be important to also explore the spectral irradiance of visible blue light from other devices such as LED screens or lamps and other lighting devices. To provide sufficient education to our patients on devices and light safety, further studies aimed at determining thresholds of visible light damage should be conducted. As Wu et al suggests, chronic exposure to ambient light levels should be included in future studies, as long-term chronic exposures may show differing outcomes from acute exposure due to different underlying mechanisms<sup>20</sup>. The factors determining photo-toxicity such as intensity and duration of the light source with varying exposures and timelines should also be examined. More studies on the mechanisms pertaining to tissue/light interaction will contribute to a deeper understanding of retinal cell damage. With a more unified understanding of ocular physiology, toxicity of light sources, and spectral irradiance of commonly used devices, both low vision and otherwise, it is becoming increasingly possible to manage risk factors for degenerative retinal damage.

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