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With an aging aviation population, the use of intraocular lenses (IOLs) has become common place throughout the world for correcting vision acuity, cataracts and eye injuries. The material which comprises an IOL will cause a change in spectral sensitivity seen by the recipient. This is most notable in color variations while viewing Advance Aviation Displays. The results reported here are for one specific composition of IOL given to us by the manufacturer, and are assumed to be or have been in wide use. Cost limitations required that we used color correction filters to simulate colorized IOLs (not actual colorized lenses), but we attempted to use filters with colors simulating the tints of IOLs in production. Additional information has been gathered on contrast variations that should be followed up with additional testing at a later time.

Keywords: intraocular lens, advance aviation displays, colorimeter

Background

Intraocular Lens Implants. Intraocular implants today are used to correct many different medical conditions such as cataracts and physical injuries to the eyes. These implants are now manufactured in both mono-vision (single diopter) and multifocal (multiple diopter) lenses to reduce the use of corrective lenses (glasses) after surgery. The surgery only takes about ten minutes to remove the organic lens and replace it with an IOL.

IOL implants are highly recommended over external corrective lenses today, because of “Fractional Distortion” (Smith & Atchison, 1996, p.108), which is described as either positive (pincushion) or negative (barrel effect) distortion. These aberrations seen at the edges of standard eyeglasses and can cause misreading of dials or displays when glancing at them. Several types of eye-glass frames used today have exacerbated this problem since they allow the complete lower edge and sides of the lens to remain uncovered, which can further distort the image seen by the eye.

However, IOL implants do cause some types of visual distortion. For example, one effect of lens replacement is seeing a “Star pattern” around bring lights observed at night. This star pattern is usually formed by two lines crossing each other (four pointed star) and is variable in luminosity and length, and can exacerbate the problem of identifying distant points of light that are in close proximity to each other. Normally, a person will see a “Halo effect” around bright lights, which does not disrupt the vision as much. A secondary effect of an IOL implant is that a color change can be seen by glancing through the edge of the eye. This secondary effect occurs when light passes through the thin curved edge of the lens.

Another – arguably more significant – type of visual distortion is contrast variations (a darkening of the viewed object; artifacts of sight correction that affect wearers of both corrective lenses and intraocular lenses). This effect is based on the material used to construct the lens and is a direct function of the material’s refractive index: as when the index increases, the amount of contrast increases. The refractive index of a Polymethylmethacrylate (PMMA) IOL is 1.49 (Olmos & Roy, 1981), which had been a widely used material for IOLs in the United States and Canada. For comparison, standard reading glasses with polycarbonate lens has a refractive index of 1.586, while a flint glass lens refractive index is 1.700 (Schwartz, 2002).

Changes seen by Intraocular Implant Recipients. Some people who had recent single eye lens replacement notice a change while viewing images on a monitor in that what used to look like a true green now looks blue-green or teal. The reason is that IOL’s have specific light absorption characteristics which depend on the material(s) used. As light enters the eye a specific portion of the color spectrum is absorbed by the IOL, causing a shift in observed color.

This noticeable color shift caused by the IOL is a form of limited spectral blindness that is not recognized yet by the Federal Aviation Administration (FAA) (as of May 2007). It has eluded recognition because studies to date have only noted a change in the blue-green spectra, while the aviation medical community only tests for red-green and blue-yellow color blindness (or deficiency). However, this "blindness" is important when looking at a monitor with readouts that rely on subtle changes in color.

The introduction of colorized IOLs has brought new factors to the spectral-absorption issue. These colorized IOLs come in a variety of colors from cyan to yellow to magenta. The choice of what color lens to have implanted depends upon the application and age of the recipient but, obviously, all choices affect the colors perceived by the recipient of the implant. In this manner colorized IOL's are being analogous to slightly-colored sun-glasses which never can be removed.

Legibility of Advance Avionics Displays. At the same time that IOL's are becoming more popular, detecting color variations are becoming more important for cockpit safety. With the introduction of Advance Aviation Displays, flight control information can be displayed in a more realistic setting (graphical realism) by adding color as well as shape. These (primarily) LCD displays, weigh less than previous cathode-ray tubes (CRTs) and associated components, reduce power and space requirements (Helfrick, 1995), reduce manufacturing costs and enhance display characteristics. Moreover, associated software often allows the pilot to select which information is displayed in front of him/her during different times of the flight. This allows the pilot to concentrate on the task at hand and reduces the chances for confusion in the cockpit, assuming that the display is legible.

Many of these advanced avionics displays have the ability to adjust color composition for the user by software selections. However specific colors have become standard in the industry, some of which are problematic for pilots with IOLs. The uses of pure colors such as green or red are easy to set by software, but can be affected by spectral shift for someone who has IOL replacements to the point where a natural green can become teal or red can become brown. When this happens, pilots may overlook important data, especially when a wide variety of information is displayed at one time.

Experimental

Background. The IOLs used this investigation were selected and provided *by the manufacturer*. The claim is that they had represented IOL types manufactured throughout the world and were representative of popular natural lens replacements. The name of the manufacturer has been withheld by prior agreement.

A noticeable difference between the hue and saturation was seen when viewing through the IOL (Garo, 1999). This is caused by the absorption of the lens material at specific wavelengths seen through the IOL (Figure 1), which is a function of its chemical composition. The chemical compositions of the two IOLs types used in this report are Polymethylmethacrylate (PMMA) or poly (methyl 2-methylpropenoate). These are both synthetic polymers of methyl methracrylate, and have a reflectance similar to that of polycarbonate. The haptic [mounting] section of the IOL has a fluorine base, but does not influence the color absorption or excitation pattern of the lens (McCormack & Protheroe Jr., 2008).

Experimentation was done by passing light through an IOL and measuring light received by two different spectrometry systems: (1) a colorimeter (photo-spectrometer) and (2) a wavelength spectrometry system. We modified the colorimeter assembly to "see" light with and without an IOL through a mount assembly. The colorimeter observes a color on the screen and breaks it down into a spectrum. The spectrum is then quantified using a permutation of three light-bands of red, green and blue and the quantity of color observed is displayed on the screen. This instrument has the advantage of being transportable to actual aircraft cockpits.

We use a SPYDER II® colorimeter manufactured by the datacolor Corporation, which is a spectrophotometer used to quantify colors from a luminous source by converting it into a numerical spectrum. It is irrelevant to this spectrometer if the source is a cathode-ray tube (CRT) or a liquid crystal display (LCD), as long as there is sufficient luminescence. This device collects light through a central aperture and then determines its spectrum using a light sensitive integrated circuit package.

The author manufactured an add-on Intraocular Lens (IOL) Colorimeter Mount for aligning the IOLs with the center of the colorimeter (Figure 2). This mount required that the center baffle be removable from the SPYDER II® so that the IOLs could be tested. Additional software from Home-Cinema France (HCFR®) was used to determine the spectral absorption of the IOLs.

A laboratory-sized wavelength spectrometry system measures the spectral wavelength of each color emitted from a screen for user defined acquisition measurements between 350nm and 920nm and downloaded the information to a data file.

The computer and display used for both data acquisition and data reduction were parts of a Hewlett Packard Pavilion dv9000® series laptop computer with a LCD – TFT screen. The power source was from the wall outlet which enabled full backlit capabilities of the monitor throughout the entire test performed within this study. The display was previously calibrated using the datacolor's SPYDER II® Pro version 2.2 software to set a baseline for the examination of the different assemblies tested. Additional tests were done using a MAG® 19" TFT – LCD display to verify TFT response.

Testing Setup. Once the colorimeter was assembled (Figure 2) and calibrated, a color was selected on the screen using the CIE RGB value. The baffle is removed from the colorimeter and replaced by the IOL Colorimeter Mount (see IOL assembly Figure 2). This assembly is placed on the screen to read the color displayed on the monitor. A reading was taken of the color viewed through the IOL to see what spectral shifts occurred. This information is fed back to the computer via the software and displayed in multiple formats.

Results

After insuring that the colorimeter could acquire a complete series of data with different fixtures and configurations, a full series of measurements was done. Different configurations with and without the pre-filter were used to collect data on the changes that occur in the color that is viewed through an IOL. Relative variations in colors caused by IOL's are plotted as Delta-E in Figure 3. [Shifts were most noticeable in the blue and red luminance values.]

"Color-blindness" in even small portions of the spectrum can cause confusion; so we wanted to determine what it would take to alter colors to correct for IOL color loss. Accordingly, data from these tests were graphed to determine if a color correction filter could equalize the color through the IOL and match it with close-to-normal vision. Using the standard configuration set as a baseline (Figure 3), an examination of each graph was done to see if there was a close match within the 90% to 100% luminescence values using the mounted IOL and filter combination. As a result, adding a magenta filter (Charles Beseler Company in Vineland, NJ; part # 8932; value 2.5 – filter factor 1.1) to the mounted IOL adjusted the color response closest to the standard configuration (Figure 3) of all other configurations.

Additionally, using the wavelength spectrometer to view specific colors on the LCD monitor through the IOL, showed a slight increase in specific wavelengths over direct observation. The highest level of contrast differences were up to 27% when testing the color blue (Color value: R,G,B-0,0,255) from 410nm to 560nm. This increase in color quantity and contrast need to be explored further.

Conclusion

With the advent of flying with IOLs in this era of advance avionics displays, we must be assured that confusion in the cockpit does not occur. It will not take much for major changes to occur if there are flight incidents with pilots having IOL implants. Since the colors for the advance avionics displays are software selectable, simple and inexpensive changes can be introduced into the cockpit. Knowing which colors can affect pilots is problematic, but can be determined given the known materials used on the market.

There are more than one hundred manufactures and many chemical variations used in the manufacturing process of IOLs around the world. However, it would not be technically difficult for each manufacturer to test for spectral absorption of each IOL and relay that information into an FAA database. This database will help manufactures to set up software commands to adjust the color displays so that the best contrasting colors are used for all personnel in the cockpit. Another solution would be to approve "Aviation IOLs" that have a specific color absorption pattern; however, current wearers of non-standard IOLs would need to be grandfathered in to keep their flight status. In any case, color displays in cockpits need to be monitored closely to insure that there is no color drift that would be a problem for users of IOLs and other vision correction devices. As we can see, the problem is addressable and the solution can be easy.

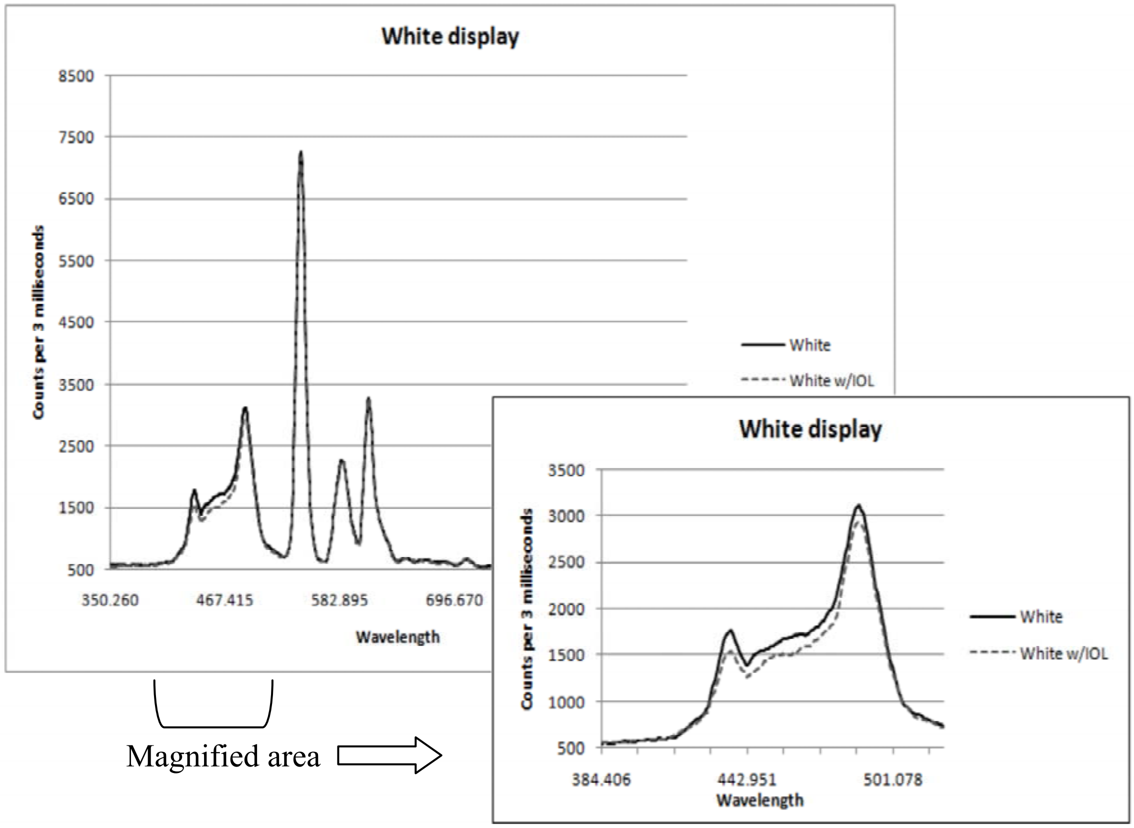

Figure 1. Spectrometer readings from the monitor with a white signal displayed; wavelength spectrometer direct reading (White) and through an IOL (White w/IOL). This shows a variable decrease in the blue to cyan spectrum when viewing the white signal from the LCD monitor through the IOL.

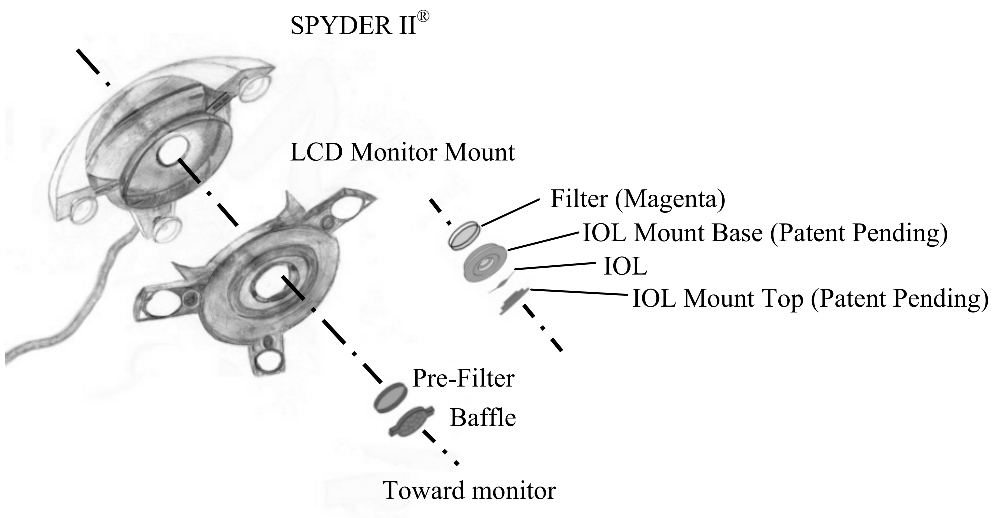

Figure 2. Colorimeter assembly (Sullivan, J. & Protheroe Jr., W. J., 2008). The standard configuration is a combination of the Spyder II®, LCD Monitor Mount, Pre-Filter and Baffle. The test configurations are combinations of the Spyder II®, LCD Monitor Mount, Pre-Filter [with and without], Filter [with and without] (Cyan, Yellow and Magenta filters), IOL Mount Base, IOL [with and without] and the IOL Mount Top.

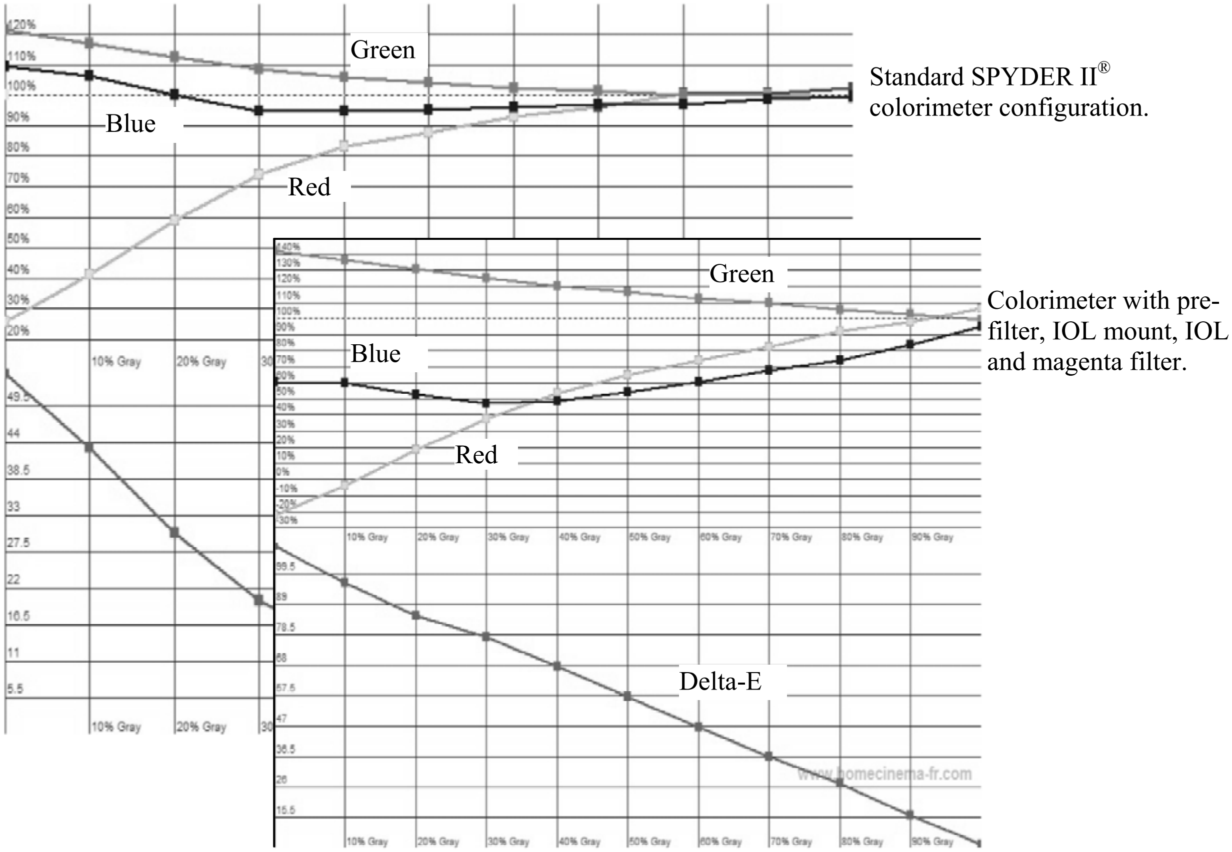

Figure 3. Colorimeter Graphs. RGB and Delta-E plot using HCFR colorimeter software. There is a slight variation in green luminance in the IOL configuration and a much greater variation in the blue and red luminance relative to the standard. None of the other test using the IOL with or without filters showed a tighter grouping seen at the higher percentage of luminance than with the magenta filter. This grouping correlates closer to a more natural vision that is seen in the standard colorimeter configuration.

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