Is it really possible to compensate for color blindness with a filter?

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Abstract

In the last two decades, there has been a resurgence of the idea that passive aids such as color filters can be an effective solution to compensate color vision deficiency (CVD) or improve color vision for CVD subjects. We examine briefly the scientific evidence that so far has been gathered to study the reliability of these aids. In the light of our experience working in this field, we reflect on several related issues: why this question has not been elucidated before, how a filter would have to be designed for a specific task, and the importance of developing a personalized color space for CVD subjects to gain some insight on the effect of aids.

1. Introduction

Congenital color vision deficiency (CVD) affects 8% of the Caucasian male population and 0.5% of the female [1]. CVD subjects do have a limited color gamut depending on their color deficiency and its severity [2]. A significant portion of them would welcome a solution to “correct”, “compensate” or “alleviate” their deficiencies because most of them face difficulties with daily tasks and are disqualified from particular professions [3]. However, currently there is no effective treatment for curing CVD in humans, although gene therapy has been tested on primates [4].

So far, two types of solutions have been used, which can be classified as active and passive aids. In active aids the CVD is addressed using image processing, with images captured by a camera and subsequently displayed to the CVD subject [5]. Passive aids are based on filters incorporated into tinted glasses or contact lenses, nowadays even with their corresponding optometric prescription.

Since Maxwell [6], many filters have been used as passive aids for CVD, used either in only one eye, like X-Chrom and Chromagen, in both eyes with different filters [6], and recently in both eyes with the same filter, like Enchroma, VINO, Colorlite, Colormax, and ColorView. The solutions, consisting of filtering just one eye or each eye with a different filter have been discarded as obsolete, since they lead to a reduced visual acuity, changes in apparent velocity perception, visual distortions (such as the Pulfrich effect), and an impairment of depth perception [7-9], which may be compromising for many activities, such as driving and piloting aircraft at low light levels.

Many of these filters have been tested and analyzed [7-22]. Considering the large variety of analyses, psychophysical experiments, simulations, number of subjects, etc., used in these papers, researchers have reached the following common conclusions:

1) Any colored filter placed in front of the eye will reduce the energy reaching the retina in some spectral bands.

2) Colored filters can alter both luminance and chromatic contrast, which can be used to distinguish colors that some CVD subjects could confuse, but only to the detriment of confusing other colors that they could previously discriminate.

3) A better score can be achieved in certain color vision tests, mainly in recognition tests based on pseudoisochromatic plates.

4) Performance was degraded on tests which required fine color discrimination, such as FM-100 (Farnsworth-Munsell 100 Hue) or CAD (Color Assessment and Diagnosis).

5) Filters do not expand the color gamut of CVD individuals, so they will not provide an improved color perception for CVD observers.

2. Why is it an open question?

There are several reasons that could explain why the possibility of using a color filter to improve the color vision of CVD subjects has not been ruled out yet.

The first is that there is still not a universally accepted demonstration about the impossibility of a color filter improving color vision for these subjects. A thorough approach to prove this proposition could be to use simulations for all kinds of CVD subjects and all possible spectral transmittances with values between 0 and 1. This has not been carried out yet, although there is a study which analyses a wide set of filters [21]. Another possible approach could be to use Information Theory [23] to prove that if the spectral responsivity of one of the three cone photoreceptors is shifted with respect to its normal peak position, this then makes it impossible to achieve an improvement in color vision by introducing changes in the signals that the photoreceptors respond to.

The second reason is that quantifying color vision improvements is still a challenging issue. Computations using simulated CVD vision modeling have been carried out with the following metrics: number of discernible colors (NODC, interpreted as a measure for gamut expansion [21]); color differences for a given set of color stimuli with or without the filter added, [18, 20]; and color differences for CVD subjects with or without the filter added, taking the color perceived by a normal subject as reference [22].

When there are psychophysical experiments available, the possible improvement obtained with the filter has been measured by: studying color discrimination thresholds (CAD test, [24]); recognition tests such as Ishihara; sorting tests such as Farnsworth D-15 or FM-100 (also used in simulations in [21]); color naming [25, 26]; or a subjective evaluation by the subjects [27]. Amongst these tests, it has been proposed that sorting tests such as FM-100 are more appropriate for evaluating possible improvements than recognition tests such as Ishihara [21]. In addition, there are issues related to the way the tests are carried out; if they are displayed on a screen the use of the filters could significantly alter the perceived color, because of the narrowness of the spectral primaries of the displays. This could also be problematic for other devices such as anomaloscopes.

To sum up, we can state that there is no standard protocol regarding the type of tests and the number and classification of CVD observers that should be used to analyse color vision improvements derived from the use of passive aids. So, further research needs to be carried out to find an effective way of measuring this possible improvement, either issuing recommendations to include some standard test (like FM100 or CAD) in the battery of tests, or else by performing discrimination experiments which include real scenes and real stimuli, or that recreate situations commonly found in daily life. It is noteworthy that considering only partial results may lead to confusion, such as the fact that the Ishihara test can be passed using a given filter which could be interpreted as a proof that the CVD is compensated by the filter.

Finally, a third reason is that the question of preference also needs to be considered. In certain situations, a subject could find a given complex natural scene more appealing when viewed through a filter, but this does not mean that the filter helps to improve the color vision of the subject. The subject’s preference could be based sometimes on a better discrimination ability for certain stimuli present in the scene, but in others purely on aesthetical or cognitive factors or even the inability of the subject to realize that he is not “seeing new colors”.

Summarizing, some open questions are the lacking of a satisfactory demonstration for the filters' effectiveness, the difficulty in quantifying color vision improvements, and how to consider the influence of the subject's preference.

3. A personalized colorimetry for CVD subjects

Many results are based on simulations of different CVD conditions, in which some modifications over the standard observer are implemented, usually after a transformation to the fundamental cone space. The assumption that standard colorimetry, developed for non-CVD subjects, could be valid for CVD observers is made. This seems particularly critical for luminance matchings as CVD observers not only have a different chromatic perception but also a different luminance perception.

Some authors have used other non-standard colorimetry strategies to study CVD subjects, such as Moreland et al. [28], or Richer et al. [12]. In the case of Moreland et al., cone responses were simulated using average cone fundamentals proposed by DeMarco et al. [29] When the authors applied this model to study the effect of filters, they concluded that no filter could improve color vision for CVD observers in terms of becoming closer to normal color vision observers.

Standard colorimetry may be adequate just as a tool for assessing the effect of filters but it is not adequate for characterizing CVD subjects' perception. Therefore, a customized colorimetry based on the perception of CVD people needs to be developed [30]. We would like to underline the term customized because there is a huge variability between observers, especially in the case of anomalous trichromats, as is evidenced by tests such as the FM-100, anomaloscope, and others [31]. To obtain this customized colorimetry system, the first necessary step is the measurement of the color matching functions (CMF) of different CVD subjects. After measuring the CMF, the next steps would be the computation of the perceptual attributes (Lightness, Brightness, Chroma, Saturation, Colorfulness, and Hue), testing the predictions of the developed models with psychophysical experiments. Finally, it would be possible to propose and adjust specifically defined color difference formulas.

This development would not only be useful for modeling the vision of CVD observers, but also to quantify more realistically the effect of different filters. It would also greatly add to the existing knowledge about the vision of CVD subjects.

4. The ultimate filter solution? What the perfect filter should do.

We attempt here to provide an answer by highlighting some evidence. A CVD observer has a reduced gamut that is included within the color gamut of a normal [2]. Any filter modifies the color coordinates of color stimuli, but always within this reduced gamut. This leads to the fact that no filter can make any observer (whether CVD or not) see a new color, i.e. a filter cannot push a color stimulus beyond the color gamut of the observer, so it will not increase the size of their gamut. Therefore, a filter will never improve the color vision of a CVD observer in the sense of allowing the perception of new colors that were not visible before, or making the subject's color vision closer to that of a normal color vision observer.

Nevertheless, a filter can improve color discrimination in certain areas of the gamut, at the cost of worsening it in others. This means that specific filters could have a limited utility helping a CVD observer to carry out specific tasks. The filter transmittance will depend on both the type and severity of the CVD and the task; more precisely on the stimuli involved in the task. In this sense, the filter must increase the contrast (either in luminance or chromaticity) above the discrimination threshold for the observer, to allow them to distinguish the colors that were confused without the filter. The filter should be designed in such a way that it does not make indiscernible other stimuli involved in the task that the observer could discern without the filter.

Thus, in order to implement this *ad hoc* limited solution (for each specific task and observer), it is necessary to know both the spectral sensitivity of the observer, and the spectral reflectance of the stimuli involved in the task. Moreover, building a filter with a particular spectral transmittance is still challenging.

Despite the conceptual and technical complexity of this ideal solution, it would be misleading to consider it as a color vision improvement for the CVD observer as we mentioned before.

5. Conclusions

To sum up, filters can assist in certain specific color-related tasks, allowing the discrimination between some colors, and consequently between objects, but not allowing the subject to have comparable color vision to those people who have normal color vision, because filters are unable to expand the color gamut of the subjects. Colored filters do not improve the color vision of CVD subjects, and even less “correct”, or “cure”, CVD.

We have identified the following open questions along the previous sections: how to effectively quantify possible color vision improvements considering the subject’s preference; to develop a personalized colorimetry for CVD subjects, and to design and build filters that could help for specific tasks.

It is a trait of human nature to chase “miracles”, and regretfully it is also a trait trying to exploit solutions that are not sufficiently tested when there is some money to be gained in the process. As Carl Sagan said, "extraordinary claims require extraordinary evidence". It is then likely that, even if someone could gather enough evidence to prove that color filters cannot compensate for CVD, new filter proposals would still regularly appear on the market and be advertised as being helpful for improving color vision of anomalous subjects. It is also more difficult to gain enough media coverage for scientific news of the negative kind than for marketing campaigns led by some of the companies that produce these filters.

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