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ORIGINAL ARTICLE

Coloration Technology

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

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Abstract
In the last 2 decades, there has been a resurgence of the idea that passive aids such as colour filters can be an effective solution to compensate colour vision deficiency (CVD) or improve colour vision for subjects with CVD. We examine briefly the scientific evidence that has to date 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 personalised colour space for subjects with CVD to gain some insight into the effect of aids.

1 | INTRODUCTION

Congenital colour vision deficiency (CVD) affects 8% of Caucasian males and 0.5% of Caucasian females.[1] Subjects with CVD have a limited colour gamut depending on their colour deficiency and its severity[2]; a significant proportion of these individuals would welcome a solution to "correct," "compensate" or "alleviate" their deficiencies because they face difficulties with daily tasks and are also 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]

To date, 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 then subsequently displayed to the subject with CVD.[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 deployed as passive aids for CVD, used either in only one eye, like X-Chrom and Chromagen, in both eyes with different filters,[6] or 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 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 analysed.[7-22] Considering the large variety of analyses, psychophysical experiments, simulations and number of subjects used in these papers, researchers have reached the following conclusions:

1. Any coloured filter placed in front of the eye will reduce the energy reaching the retina in some spectral bands.
2. Coloured filters can alter both luminance and chromatic contrast, which can be used to distinguish colours that some CVD subjects could confuse, but only to the detriment of confusing other colours that they could previously discriminate.
3. A better score can be achieved in certain colour vision tests, mainly in recognition tests based on pseudoisochromatic plates.

4. Performance was degraded in tests that required fine colour discrimination, such as Farnsworth-Munsell 100 Hue (FM-100) or colour assessment and diagnosis (CAD).
5. Filters do not expand the colour gamut of individuals with CVD, therefore they will not provide improved colour perception for observers with CVD.

2 | WHY IS IT AN OPEN QUESTION?

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

The first is that there is still not a universally accepted demonstration about the impossibility of a colour filter improving colour vision for these subjects. A thorough approach to prove this proposition could be to use simulations for a variety of individuals with CVD and all possible spectral transmittances with values of between 0 and 1. This has not been carried out yet, although Martínez-Domingo et al have analysed 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 colour vision by introducing changes in the signals that the photoreceptors respond to.

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

When there are psychophysical experiments available, the possible improvement obtained with the filter has been measured by studying colour discrimination thresholds (eg, CAD test[24]), recognition tests such as the Ishihara test, sorting tests such as Farnsworth D-15 or FM-100 (also used in simulations in Martínez-Domingo et al[21]), colour-naming[25,26] or a subjective evaluation by the subjects.[27] Among these tests, it has been proposed that sorting tests such as the FM-100 are more appropriate for evaluating possible improvements than recognition tests such as the Ishihara.[21] In addition, there are issues related to the way the tests are carried out; if they are displayed on a screen then the use of the filters could significantly alter the perceived colour 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 affirm that there is no standard protocol regarding the type of test and the number and classification of observers with CVD that should be used to analyse colour vision improvements derived from the use of passive aids. Therefore, further research needs to be performed to find an effective way of measuring this possible improvement, either by issuing recommendations to include some standard test (like the FM-100 or CAD) in the battery of tests, or else by performing discrimination experiments that include real scenes and real stimuli, or 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 proof that the CVD is compensated by the filter.

Finally, 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 their colour vision. The subject's preference could sometimes be based on a better discrimination ability for certain stimuli present in the scene, but at other times purely on aesthetic or cognitive factors, or even an inability of the subject to realise that they are not “seeing new colours”.

Summarising, open questions include the lack of a satisfactory demonstration for the filters’ effectiveness, the difficulty in quantifying colour vision improvements, and how to consider the influence of the subject's preference.

3 | A PERSONALISED COLORIMETRY FOR SUBJECTS WITH CVD

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. An assumption is made that standard colorimetry developed for non-CVD subjects could also be valid for observers with CVD. This appears to be particularly critical for luminance matchings as observers with CVD not only have a different chromatic perception, but also a different luminance perception.

Some authors have used other non-standard colorimetry strategies to study subjects with CVD, such as Moreland et al[28] and Richer and Adams.[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 the colour vision in observers with CVD in the terms of it becoming closer to observers with normal colour vision.

Standard colorimetry may be an adequate tool for simply assessing the effect of filters but it is not adequate for characterising the perception of subjects with CVD. Therefore, a customised colorimetry based on the perception of people with CVD needs to be developed.[30] We emphasise the term "customised" because there is substantial variability among observers, especially in the case of anomalous trichromats, as evidenced by tests such as the FM-100, anomaloscope and others.[31] To obtain this customised colorimetry system, the first step is measurement of the colour matching functions (CMF) of different subjects with CVD. After measuring the CMF, the next steps are computation of the perceptual attributes (lightness, brightness, chroma, saturation, colourfulness and hue) then testing the predictions of the developed models with psychophysical experiments. Finally, it is possible to propose and adjust specifically defined colour difference formulas.

This development would not only be useful for modelling the vision of CVD observers, but would also more realistically quantify the effect of different filters, as well as adding to existing knowledge regarding the vision of subjects with CVD.

4 | THE ULTIMATE FILTER SOLUTION? WHAT THE PERFECT FILTER SHOULD DO

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

Nevertheless, a filter can improve colour discrimination in certain areas of the gamut, at the cost of worsening it in others. This means that specific filters could have limited utility in helping an observer with CVD carry out specific tasks. The filter transmittance will depend on both the type and severity of the CVD and the specific 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 those colours that were confused without the filter. The filter should be designed in such a way that it does not make other stimuli involved in the task indiscernible (ie, those 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 remains challenging.

Despite the conceptual and technical complexity of this ideal solution, it would be misleading to consider it as a colour vision improvement for an observer with CVD, for those reasons outlined earlier.

5 | CONCLUSIONS

In summary, filters can assist in certain specific colour-related tasks, enabling discrimination between some colours, and consequently between objects, but not allowing the subject with CVD to have comparable colour vision with those individuals who have normal colour vision, because filters are unable to expand the colour gamut of subjects. Coloured filters do not improve the colour vision of subjects with CVD, and even less so either "correct" or "cure" CVD.

We have identified the following open questions in the previous sections: how to effectively quantify possible colour vision improvements considering the subject's preference, how to develop a personalised colorimetry for CVD subjects, and how to design and build filters that could help with specific tasks.

It is a part of human nature to chase "miracles" and, regretfully, it is also a human trait to attempt to exploit solutions which have been insufficiently tested when there is potentially some financial gain. As Carl Sagan said, "Extraordinary claims require extraordinary evidence". It is therefore likely that, even if enough evidence could be produced to prove that colour filters cannot compensate for CVD, new filter proposals would still regularly appear on the market promoted as being beneficial for improving the colour vision of anomalous subjects. It is also more difficult to gain sufficient media coverage for scientific news of the negative type than for marketing campaigns led by some of the companies that produce these filters.

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