The gray side of Ishihara bubbles

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Abstract

In this paper, we present a novel experiment on a modified Ishihara-like series of plates for color deficiency screening. This is a further experiment in the direction of exploring the spatial modifications of this classic test so to explore the role of visual spatial arrangement in the assessment of normal and color deficient observers. In this work, we present the test setup with some preliminary results on normal color vision observers.

Keywords: color deficiency, color blindness, Ishihara plates.

Introduction

The Ishihara test plates are designed to offer a rapid and usable instrument to diagnose color deficiency. The original test, as well as other PIP (Pseudo-Isochromatic Plates), consist of a set of plates, composed by a circle filled with colored dots of different colors and sizes. Modern Ishihara color plates are combined with a manual for the interpretation of the results (GIMA, 2021), which makes this test very simple.

The Ishihara test is widely accepted to assess congenital red–green deficiencies (protanopia, deuteranopia, protanomaly and deuteranomaly), but cannot be used screen tritanopia, which is a very rare condition (Rodriguez-Carmona, *et al*., 2021). Main advantage of this test is that it is not only highly usable but also presents a high reliability in detecting color vision deficiencies, even if this method is not clinically appropriate to classify the type of defect (Barbur, *et al*., 2021).

Ishihara plates and PIP are designed starting from the transformation of different type of color deficiency in chromatic coordinates in CIExy space, considering that each one of the color deficiency types is linked to an anomaly in the *photopsins* in L, M or S cones cells. Considering the CIE chromaticity diagram, color deficiency types can be graphically represented by their relative *confusion lines* (see Fig. 1). Here, the colors in PIP are aligned on the confusion lines, in order to be visible just to trichromats observers and to be "confused" (i.e., indistinguishable) by color deficient

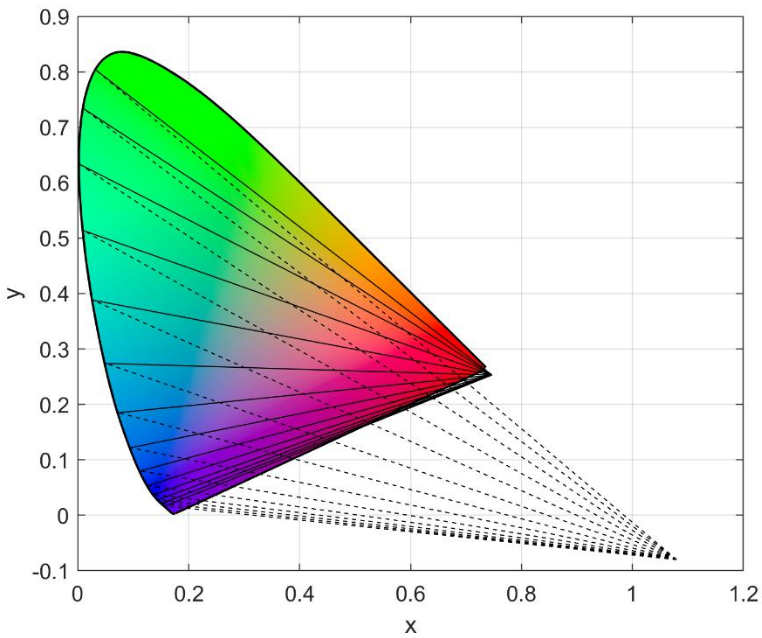

Fig. 1 - CIE chromaticity diagram, with confusion lines of protanopia (solid lines), deuteranopia (dashed lines)

observers. Following this idea, many different test images can be generated and today, these tests can be performed on printed papers, but also on digital versions (Seshadri, *et al.*, 2005), *(*Sorkin, *et al*., 2016). The clinical Ishihara version, as well as other Ishihara-based test (on paper and in digital) presents a white background and some millimeters/pixels of space among colored points. This standard arrangement is designed to assess color deficiency at retinal level, thus employing confusion lines derived from transformations of specific characteristics of L, M and S cones. However, several studies in biology, neuroscience and ophthalmology confirm that color vision is way more complex, and it is not limited to retinal transduction. Final color sensation depends also by the brain signal processing which is mainly spatial (McCann, 2017). This effect has been demonstrated by different experiments, some of these also applied to color deficiencies, showing the increment in the correcting rate by color deficient observers in Ishihara-based charts with larger dots (i.e., reducing or totally eliminating the space among dots) (Rizzi, et al., 2014) (Eschbach & Nussbaum, 2021).

These observations underline the importance of defining new approaches in describing color deficiencies and in developing related aids and tests, because of the strong scene dependency of color vision also for deficient observers.

This work starts from the experiment presented in (Eschbach & Nussbaum, 2022), where authors found a surprising improvement in distinguish colors on confusion lines for color deficient observers by changing the background color of PIP tests to neutral gray levels. From these finding we developed the same experiment applied on color normal observers, to assess if a different gray background level will also change recognition rate/time for color normal observers, further evidencing a spatial behavior in color vision system.

Related works

For the visual test, we used pseudo-isochromatic charts as described in (Eschbach & Nussbaum, 2022), obtained combining colors located on CIExy confusion lines. In Fig. 2 a cropped window of the used charts is shown.

In this experiment we used charts which have been tested in a larger experiment for color-normal and color-deficient people (Eschbach & Nussbaum, 2021). The PIP charts are composed by ten numerals (from 0 to 9) and colors from 10 confusion lines. From this overall set, 34 charts have been used to form the base set. This base set had a roughly 97% recognition rate for color-normal observers, keeping in mind that observers sometimes hit the wrong key on the keyboard by accident, while color deficient observers had a recognition rate of roughly 43%. For that reason, we consider the charts we created and used to be a good implementation of pseudo-isochromatic charts.

In a previous version of this experiment (Eschbach & Nussbaum, 2022) we changed the white background of the charts to different gray levels in order to examine the response of color deficient observers. For this, we changed the white RGB background (255) to 4 additional values 0, 64, 128

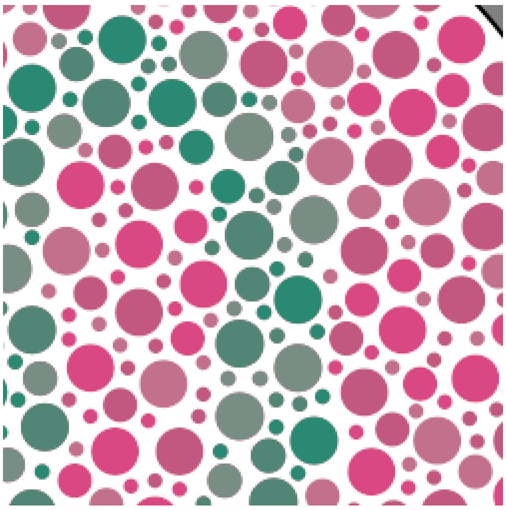

Fig. 2 – Example of PIP chart.

and 192. It is important to note that the RGB values of the colored dots have not been changed. Their chromaticity values remained constant, their sizes and positions remained constant, and their spatial relationship remained constant. Considering Fig. 2, only the white areas have been replaced by grays and blacks. This leads to charts, where the gray-level contrast between background and colored dots changes, with the two end values [0, 255] having maximum contrast. In this preliminary experiment we recruited a small number of color deficient people (N= 6) and to perform the test. The experimental data, however, showed that the gray background actually improved the recognition rate (see Table 1).

Background RGB value	0	64	128	192	255
Recognition Rate (rounded)	54%	67%	54%	32%	17%

Tab.1 – Recognition rate of color deficient observers from (Eschbach & Nussbaum, 2021).

Experiment

The results presented in the previous section poses an immediate question color normal observer, which can be phrased as:

If there is a clear mechanism or channel for a color deficient observer, does this mechanism also exist for a color normal observer, although at a lower level?

In other words: a person with good color discrimination will rely on his/her capability without the need to incorporate a different mechanism. In that manner, the additional channel would be "masked" by the stronger signal from the color discrimination channel. A color deficient observer would not have that masking and thus a different mechanism might be exposed. A secondary examination of color normal then might be used to verify if that mechanism is available, but "hidden" as a very low signal superimposed on a strong signal.

For this reason, we re-ran the experiment of (Eschbach & Nussbaum, 2022) on a set of color normal observers. The only modification to the analysis was the incorporation of response time. For color deficient the response time was heavily influenced by a few charts were the observers had the feeling they "might" see something. For normal color observers, we did not expect a variation in recognition rate and expected to see a variation in response time with lower response time indicating an easier visibility.

We performed the experiment on 11 color normal observers with a total of 881 charts, with the standard pseudo-isochromatic chart having a background level of 225. The results are reported in Tab. 2.

Background level	0	64	128	192	255
#charts	127	151	132	141	165

Tab.2 – Number of charts displayed for every background gray-level (e.g., the chart with background at 128 has been displayed 132 times).

The reason that we had different usage numbers for the different background levels is the random number generator used in PsychoPy (PsychoPy, 2022). The only chart that had a deterministic number was the standard white background chart (255) since we wanted to make sure that all observers would be qualified as color normal. This can also be seen in the accumulated data in Tab. 3.

Background	0	64	128	192	255
Recognition Rate	96.99%	97.52%	99.30%	99.24%	96.97%

Tab.3 – Recognition rate of color normal observers.

Comparing Tab. 1 from (Eschbach & Nussbaum, 2022) and Tab. 3, we can observe that the "trend" for color normal observers mirrors the one of color deficient observers at a much smaller scale. For a color deficient, the change was from 17% to 67%, for a color normal it was from 96.97% to 99.30%. For both the observers groups the end points of the background level were performing worse than the

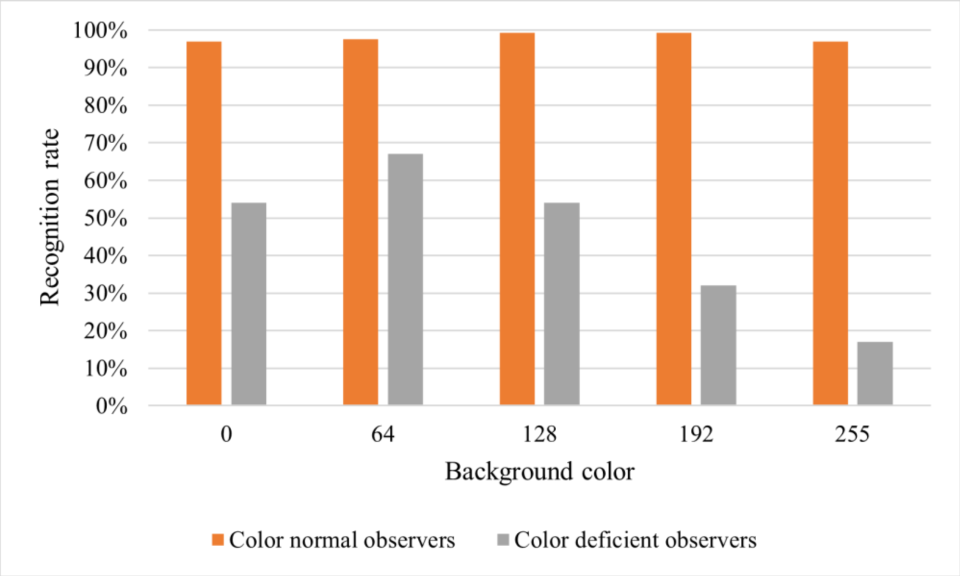

Fig. 3 – Recognition rate of color normal and color deficient observers using different gray-level background values.

center levels (roughly). When looking at the data embedded as a Fig.3, the trend becomes more obvious.
Considering Fig. 3 values is understandable that such a small effect can easily be asked by the experimental surroundings.
Additionally to the recognition rate, we also examined the color normal observers response time.

Background	0	64	128	192	255
Response Time (in seconds)	1.710	1.657	1.587	1.859	2.449

Tab.4 – Color normal observers response time.

Fig. 4 shows a clear decrease in response time for the mid-gray values. Again the extreme background levels have a higher response time than the middle terms, mirroring the recognition rate, under the assumption that recognition rate and response time are inversely correlated, meaning a "harder to recognize" (thus more errors) leads to a higher response time (harder to recognize).

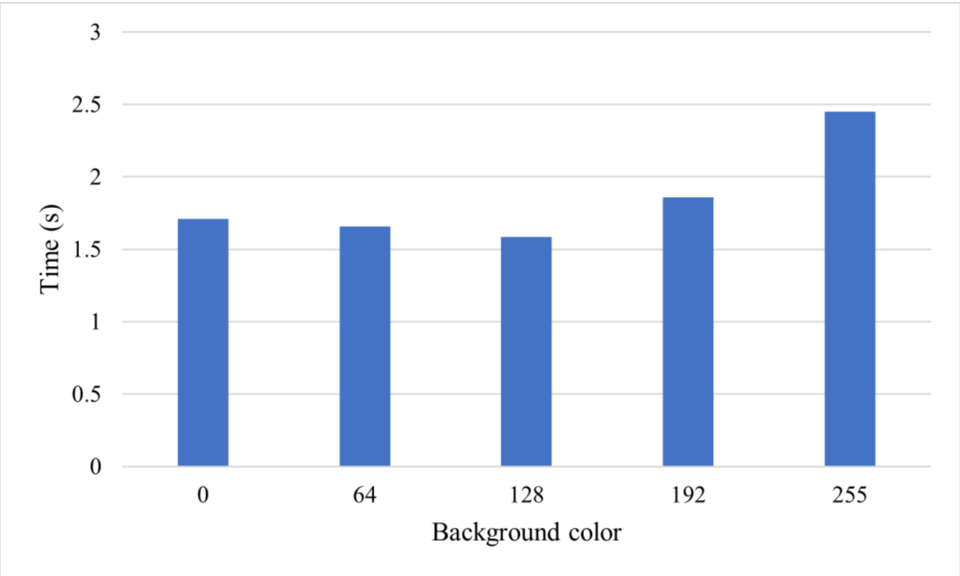

Fig. 4 – Response time of color normal observers.

Conclusions

Color vision and color vision deficiency is commonly simplified considering vision just at retinal level, without considering the higher-level signal elaboration, which is mainly spatial. This approximation includes also color vision screening tests, like pseudo-isochromatic plates.

In this work we explore the introduction of spatial modifications on classis PIP tests, to determine if changes in the plates background can influence color vision in normal and color deficient observers.

A previous experiment published in the literature revealed that changes in PIP tables background could effectively influence the recognition rate in color deficient observers, from 17% (with white background) to 67% with RGB 64 gray and 54% with RGB 128 gray. In this study we have tested some color normal observers revealing the same trend (96.97% of recognition rate with white background vs 97.52% with RGB 64 gray and 99.30% with RGB 128 gray).

These results shows that color discrimination mechanisms rely on spatial behaviors not only for color deficient people, but also in color normal viewers, increasing not only the recognition rate, but also lowering the recognition time.

In future works this phenomenon should be furtherly investigated, and those findings should be considered also in methods to develop innovative color vision aids and tests.

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