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Effect of varying background lightness on performance on a pseudo-isochromatic colour vision test

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Abstract

Pseudo-isochromatic plates with varying background lightness were used in a display-based colour vision experiment. As in previous work, the background was found to have a small effect on the ability of observers to identify the patterns on the plates. The time taken to recognize the patterns was significantly affected for both colour-normal and colour vision deficient observers, with darker backgrounds associated with shorter response times and white backgrounds having the longest response times, suggesting a greater degree of task difficulty. Possible reasons for the results when test plates were presented with a white background are suggested, including lower apparent colourfulness and greater difficulty in visual integration of the figure.

Introduction

Pseudo-isochromatic plates (PIP) have been used for many years as a diagnostic test of impaired colour vision, as they are able to identify individuals with dichromacy, anomalous trichromacy or achromatopsia. While they are not able to evaluate a person's colour vision with the diagnostic equivalence of an anomaloscope, they do give an indication of whether the subject has a moderate or severe deficiency and (in the case of retinal anomalies) which cone (or cones) are likely to be affected.

The Ishihara test [1] is an early example of PIP test, and is still in widespread use in specialist clinical settings such as London's Moorfields Eye Hospital. It consists of a series of pages with numbers and patterns that can only be distinguished if the user is able to discriminate between two hues which lie on the dichromat confusion lines. The numbers and patterns are formed from circles of varying size and apparent random distribution across each page.

In the Ishihara test plates, and many other such tests, the test patterns are presented on a white background. Previous work investigated spatial effects such as element size and background lightness [2][3] on test performance. In one case, the background lightness was varied in steps from black to white, and results indicated that mid-grey backgrounds were associated with the weakest test performance. As in much research into colour vision deficiency, the number of participants in this previous study was too small to generate significance in the outcomes, and it was considered useful to investigate with a larger number of participants, both with and without colour vision anomalies.

Experimental

In the present research we created a similar set of test stimuli to those of [2][3], using 25 patterns with varying colour combinations and backgrounds, with the goal of verifying the previous results with a larger pool of observers, and also investigating the time taken by observers to identify the patterns.

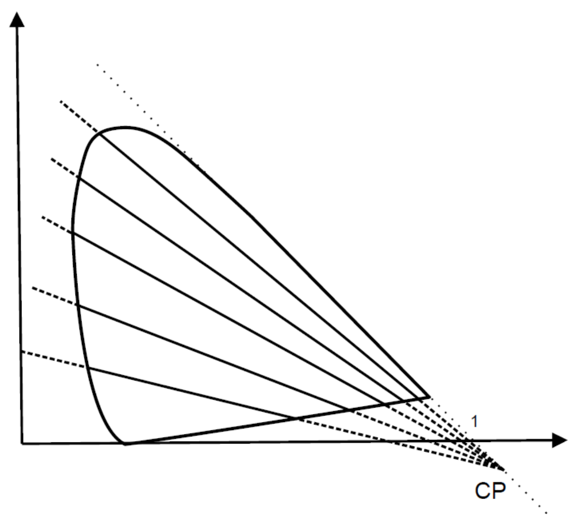

Figure 1.CIE xy chromaticity diagram shpwing lines of constant dichromatic chromaticity emanating from a copunct point (CP), whereby deuteranope observers are unable to discriminate colours lying on a given line. [4]

Pairs of colours were selected along 10 confusion lines, representing deuteranope and protanope confusion lines [4] with intersections with the spectral locus of the normal observer at intervals of approximately 2.5nm from 495nm to 515nm.

True dichromats are relatively rare in the population, with the majority of colour vision deficient observers being anomalous deuteranopes or anomalous protanopes (i.e. having L and M cone responses which deviate significantly from those of the normal observer). For this reason the selected confusion lines do not necessarily represent the true axes of confusion of all the observers in the study. In addition there is some deviation between the chromaticity coordinates of the chosen test colours and their actual chromaticity on the display, due to small errors in the device model and adaptation effects in the viewing environment. The experiment is thus not intended to have high sensitivity and specificity in identification of observers with colour vision deficiencies, but nevertheless represents a task with which such observers will have some degree of difficulty.

Test images were presented on a mid-grey surround, with test backgrounds L0 to L4 as shown in Table 1.

Table 1. RGB and luminance of test image backgrounds

	L0	L!	L2	L3	L4
RGB	0	64	128	192	255
Cd/m^2	1.12	5.75	26.41	64.44	110.79

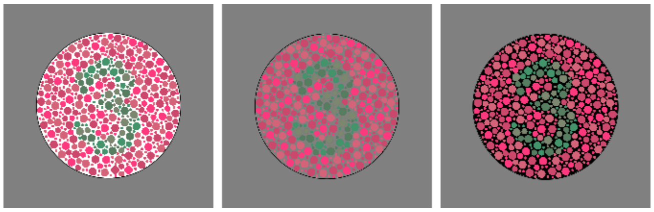

Figure 2. Test plates B3HN4 with white (L4), mid-grey (L2) and black (L0) backgrounds

The test was presented in a user-friendly game-like environment at the Science Centre in Gjovik, Norway [5], with patterns presented on a vertically mounted Samsung SyncMaster 710N display, and physical buttons corresponding to the numerals 0-9 on a sloping console. The display was positioned to face away from a nearby small window and primarily illuminated by indoor LED lighting with a colour temperature of 3000K. The luminous flux incident on the installation was measured using a Konica Minolta CL-200, yielding a value of 166 lux.

The display primaries and white point were measured in-situ with a Konica Minolta CS-3000 telespectroradiometer, and are shown in Table 2. The white point corresponds to a CCT of approximately 5690K, and the EOTF was found to be 2.2.

Table 2. Colorimetry of display primaries and white point

	X	Y	Z
Red primary	47.59	25.28	1.49
Green primary	30.92	65.03	10.66
Blue primary	16.14	9.68	81.77
White	110.86	110.79	104.5
Black	1.24	1.12	0.76

A characterization model of the display was used to determine the colorimetry of the test colours, using the display white point as reference white. As an example, CIELAB values for test colours on the copunct line at 495nm are given in Table 3.

Table 3. CIELAB values of test colours on copunct line at 495nm

L*	a*	b*	C*	h_{ab}
47.23	-51.77	-18.67	55.03	199.84
48.44	-32.31	-19.87	37.93	211.60
59.53	-18.22	-24.11	30.22	232.92
52.03	-0.00	-21.66	21.66	269.00
53.30	14.15	-22.50	26.58	302.17
66.18	31.97	-26.57	41.57	320.27

An explanation of the test and a short training sequence of seven patterns was given, followed by a random sequence of 25 patterns. For each test pattern the user pressed a button corresponding to the numeral they identified.

It was not possible to record details of the test users, but it is believed that most were children and young people. The experiment is on-going, and here we summarise results from approximately 8000 users during 2023-4.

Results

Due to unsupervised nature of the setup, a significant proportion of the responses were not serious attempts to complete the test. Some users abandoned the test while still in the training sequence; others attempted to complete the entire sequence in the shortest possible time by pressing the same numeral as fast as possible. Incomplete responses were filtered out prior to the data analysis.

After filtering, observers were divided into two groups: those with fewer than 6 incorrect responses were considered to be colour normal, while those with 6-12 incorrect responses were considered to have some degree of colour vision deficiency. An observer with a severe colour vision deficiency might make more than 12 incorrect responses, but as there was no way to separate this group from the non-serious users they were also discarded. Inevitably this approach excludes dichromats and achromatopes.

With 25 unique tests seen by each participant, and 10 numerals to choose from, it could be expected that a participant would obtain on average 2-3 correct results by random selection of responses. It can be seen that the filtering described above should exclude participants whose responses are mostly or exclusively random.

A summary of the number of participants in each category is shown in Table 4. Retaining only participants with 0-12 errors in the analysis results in 2709 observers considered colour-normal and 291 considered to have a colour vision deficiency (a total of 3143). The implies a CVD rate of 13.8%, considerably higher than the expected rate of around 4% (depending on the gender balance of participants) [6], and likely to be the result of colour-normal participants making errors due to the experimental setup and the task difficulty.

Table 4. Numbers of participants grouped by number of incorrect answers

0-2	3-5	6-12	13-16	16+	Incomplete
1926	783	434	291	3426	1143

A summary of the results is shown in Figures 3 and 4.

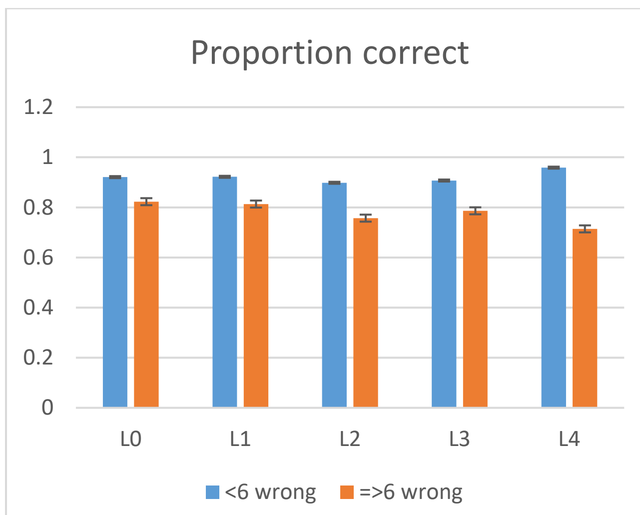

Figure 3. Mean proportions correct for inferred colour-normal (blue) and colour vision deficient (orange) observers. Error bars represent standard error.

In Figure 3 the abscissa indicates the relative lightness of the background (L0 represents black background and L4 represents white background. L1 to L3 represents intermediate grey backgrounds) and the ordinate represents the proportion of correct answers, averaged across all colour combinations.

Figure 4. Mean response times (seconds) for colour-normal and colour vision deficient observers. Error bars represent standard error.

Figure 4 shows the mean response time of observers as a function of background relative lightness. As indicated in Figure 3, the proportion of correct answers of the colour vision-deficient observers is in broad agreement with [3], although with much smaller confidence intervals and thus indicating significant differences across the different backgrounds. Figure 4 indicates that all observers needed less time to identify patterns on the darker backgrounds; perhaps surprisingly the white background (L4) required the longest time.

Owing to the large number of observers the uncertainty of the results is small. Table 1 shows the standard deviation and standard error of the results, where SE=SD/√*n*, and where *n* is the number of observers.

Table 5. Standard deviation and standard error of results of scores shown in Figure 3

	L0	L1	L2	L3	L4
SD <6 wrong	0.193	0.193	0.200	0.201	0.065
SE <6 wrong	0.004	0.004	0.004	0.004	0.001
SD >=6 wrong	0.285	0.294	0.296	0.287	0.000
SE >=6 wrong	0.014	0.013	0.014	0.014	0.000

Table 6. Standard deviation and standard error of results of scores shown in Figure 4

	L0	L1	L2	L3	L4
SD <6 wrong	1.193	0.819	0.939	1.104	1.332
SE <6 wrong	0.023	0.016	0.018	0.021	0.026
SD >=6 wrong	1.473	2.118	1.352	1.376	2.022
SE >=6 wrong	0.071	0.102	0.065	0.066	0.097

Discussion

Hue discrimination could considered as a two-stage process, whereby the first stage consists of opponent-colour signals being extracted from the stimulus by the retina, and the second stage being a recognition of the corresponding colour sensations in the visual cortex. Given the degree of overlap between middle and long wavelength cone receptors, this process could be said to require a significant amount of amplification to produce highly-differentiated red and green sensations. For the colour deficient observer, the first stage in the process is characterized by a reduced signal-to-noise ratio, making the second stage more challenging. However, it has been suggested that there is no reason to assume that the range of available sensations is impaired by the lack of differentiated signals [8].

A dark background increases the perceived brightness of adjacent stimuli, thus possibly making the colour discrimination task easier since the apparent contrast (in terms of the ratio of perceived luminances) is substantially greater than with the mid-grey background and in many cases greater than the white background.

Although the effect can be context-dependent, a darker background tends to increase perceived colourfulness; and since an important attribute of increased colourfulness is that is makes the hue of a stimulus more apparent, it would be expected that a dark background aids a pattern recognition task based on hue discrimination.

The white background increases response time even compared to mid-grey backgrounds, and this result was very reproducible throughout the set of observations. This result may be explained through the ON and OFF channels which provide excitatory signals from the retina to the visual cortex for both increases and decreases in light energy [9]. Red-green colour channels have ON and OFF variants: with a white background, OFF variants are favoured over ON. Redness is thus signalled by M-OFF and L-ON, and greenness by M-ON and L-OFF. With a white background the transitions from white to colour will be mainly M-OFF and L-OFF. As well as OFF chromatic signals, the white background will produce larger OFF luminance signals than the grey, which will be smaller and more balanced between ON and OFF. This luminance imbalance could also affect the visual integration of the figure.

Conclusions

In an on-going experiment observers perform a display-based PIC test with varying background lightnesses. Results from the first 3143 observers confirm preliminary conclusions from a previous smaller test, showing that observers were more able to discriminate between hues when presented on a darker background, and that the reduced contrast of a mid-grey background resulted in the highest difficulty for observers. It is also shown that across all observers the recognition time was shortest when the stimuli were presented on dark backgrounds, and longest for white backgrounds. These results have implications for universal design: where information requires hue discrimination for visual understanding and processing, response times are shortened and information recognition enhanced when stimuli are presented on black backgrounds.

Acknowledgement

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