Visual Search for Normal Color and Dichromatic Observers Using a Unique Distracter Color

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Abstract. It is well known that color coding facilitates search and identification in real-life tasks. The aim of this work was to compare reaction times for normal color and dichromatic observers in a visual search experiment. A unique distracter color was used to avoid abnormal color vision vulnerability to background complexity. Reaction times for normal color observers and dichromats were estimated for 2° central vision at 48 directions around a white point in CIE $L^*a^*b^*$ color space for systematic examination on the mechanisms of dichromatic color perception. The results show that mean search times for dichromats were twice larger compared to the normal color observers and for all directions. The difference between the copunctual confusion lines and the confusion direction measure experimentally was 5.5° for protanopes and 7.5° for deuteranopes.

Keywords: Visual search · Dichromatic vision · Color vision tests · Color deficiencies

1 Introduction

Color is a relational attribute of objects that facilitates search and identification tasks [1][2]. This attribute is explored in the natural environment by plants and animals as well by humans in urban environment such as transports, medical diagnosis or commercial purposes. Observers with abnormal color vision may perform many of these tasks poorly. Particularly, the dichromatic population that comprise about 2% of the male population [3], seems to have longer search times and the target color object was less salient to them compared with normal color observers [4]. Although this is an important result no systematic examination was performed for dichromatic observers around a white point.

It has also been reported that reaction time depends on the color difference between a target and a distracter color. That is, the reaction time increases for

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small color differences, but for large color differences response time was constant [5]. Two distracters color are typically used [6], being the target color in between the distracters at the middle chromatic distance. Although this is a convenient configuration the number of distracters is a significant factor in search time whereas the color deficient observers are more vulnerable to increased background clutter [4]. Therefore, in experiment 1, we tested a visual search paradigm with a unique distracter color in order to determine (1) how critically the chromatic separation between the target color and the unique distracter color influence reaction time and (2) to characterize the response direction produced by the visual search paradigm.

Finally, in experiment 2 we used the visual search paradigm for systematic reaction time examination of normal and dichromatic observers for 48 positions around a white point in the CIE $L^*a^*b^*$ color space.

2 Methods

2.1 Stimuli

Stimulus was a target color with a diamond like shape and 150 color distracters (50 circles, 50 triangles and 50 squares) on a gray background as shown in Figure 1. The centre of the monitor was market with a plus sign and constitutes the fixation point. The target was always displayed 2° around the centre of the monitor in one of eight possible positions (up, down, left, right, up-left, up-right, down-left, down-right) whereas distracters were randomly distributed over 391 positions across the scene. The background subtended a visual angle of 6.7°× 8.5° and both target and distracters subtended a visual angle of 0.2°. This configuration resembles that of Cole et al. 2004 [4].

The target color was uniquely color coded, i.e. none of the distracters was the same color as the target. All distracters had the same hue and one of five luminance levels (9.5, 11.4, 13.2, 15.1 and 17.0 cd/m^2) attributed randomly. The background had chromaticity (0.31, 0.316) expressed in CIE 1931 (x, y) diagram and luminance 13.2 cd/m^2. The luminance of the target and the mean luminance of the distracters were identical to that of the background. The color of the target and distracters were always $\Delta E_{ab} = 20$ units from the background color represented in Figure 2 at coordinates (0,0) assuming the CIE $L^*a^*b^*$ color space.

In experiment 1 the color of the target and distracters varied along 24 positions centered on the color of the background and the hue angle between target and distracters was +60°, -60°, +90°, -90°, +120° or -120°. In experiment 2 we duplicated the number of positions corresponding to a hue-angle variation of 7.5° and the target color was always at a hue angle of +60° relative to the distracter color. Both experiments enable two opposite colors to be collinear to the deutan confusion line and almost collinear to the protan confusion line.

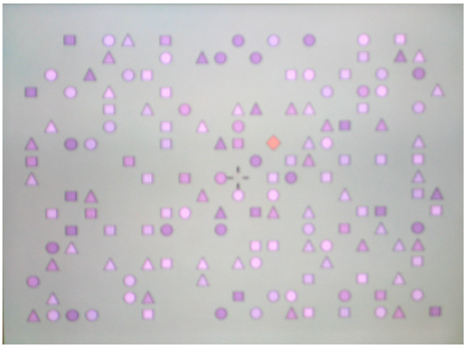

Fig. 1. Stimulus of the visual search paradigm viewed from observers point of view. The background had a mean chromaticity equivalent to illuminant C (CIE 1931 x=0.31, y=0.316) and subtended a visual angle of 6.7°× 8.5° provided by the monitor screen. The color target was always a diamond located 2° around the centre of the monitor (plus sign) and in one of eight cardinal positions. The distracters were 50 circles, 50 triangles and 50 squares randomly distributed over 391 positions across the scene. Both target and distracters subtended a visual angle of 0.2°. None of the distracters had the same color as the target and all distracters had the same hue and one of five levels of luminance in the range 9.5-17cd/m^2. The luminance for the target, background and mean of the distracters was 13.2 cd/m^2 .

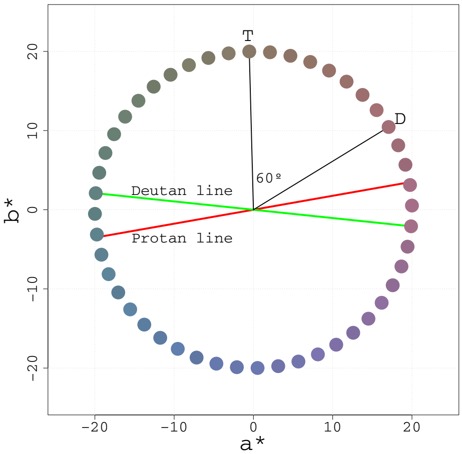

Fig. 2. The 48 testing directions around the background color used in experiment 2. It shows an example of a target color (T) at the fixed hue angle of +60° relative to the distracter color (D). In experiment 1 only 24 directions were tested. The two collinear colors to the deutan confusion line and the two almost collinear colors to the protan confusion line were present on both experiments.

2.2 Apparatus

Stimuli were displayed on a 19-inch CRT monitor (Samsung Sync-Master 750p, Samsung Electronics Corp. Ltd, RPC) driven by a Visual Stimulus Generator VSG2/3 graphics card (Cambridge Research Systems, Rochester, Kent, UK). The monitor was calibrated by a telespectroradiometer (SpectraScan Colorimeter PR-650; Photo Research, Inc., Chatsworth, CA). The stimuli were displayed with a refresh rate set at 80 Hz with a spatial resolution of 1024×768 pixels. The maximum error allowed in chromaticity was 0.0035 in the CIE (x, y) diagram and 0.4 cd/m^2 in luminance. The stability of the color and luminance was checked in the beginning of the sessions and once per day. The reaction time was measured by means of a custom-made response box with precision of 2 ms.

2.3 Procedure

In each trial, observers saw the stimulus monocularly after a 3 min adaptation to the background color. Observers were instructed to find a diamond-shaped target among the circles, triangles and squares, in one of eight possible cardinal positions, and signal its presence as quick as possible by pressing the response box. The stimulus was immediately replaced by the uniform background color after target-detection response or if there was no response after a 1 sec interval for experiment 1 or after a 3 sec interval for experiment 2. If there was a response observers were asked to indicate on a numeric keyboard the cardinal position of the diamond-shape target. If observers press the response box unintentionally they were asked to press the central key on the numeric keyboard. This error and any keyboard mismatch or no response after a 3 sec interval were not accounted as a response but repeated once again at the same session. The experiments were carried out in a dark room.

In experiment 1 the target color was shown counterclockwise compared to the distracter color (Figure 1) for three hue angles (+60° , +90° and +120°) and also for the clockwise direction (-60° , -90° and -120°). There were two sessions and 6x24 trials were randomized over session. For experiment 2 only the +60° combination were used. Each session consisted of 144 trials and a sequence of three different sessions was generated so that all observers saw the same sequence. The trials were randomized over session.

2.4 Observers

Five normal color observers participated in experiment 1. In experiment 2 there were thirteen observers; six had normal color vision, two were deuteranopes and five were protanopes. Color vision was assessed using the Ishihara plates, the City University Color Vision Test (Keeler Ltd) and the Nagel Anomaloscope (Oculus Heidelberg Multi Color). All subjects had monocular visual acuity of at least logMAR 0.00 with correction if needed. Two of the authors (J.S. and V.A.) served as observers and had prior experience in visual search experiments, all other observers were naïve.

3 Results

The results for experiment 1 (Figure 3) represents the reaction time as a function of the response direction. The response direction, calculated as:

$$T - \left(\frac{T - D}{2} + 7.5\right), \tag{1}$$

where T is the target-angle and D the distracter-angle, corresponds to the direction that best tune the six target-distracter pairs of colors or any other pair. This response direction fit in between the target-distracter pair and differs from the mean direction by 7.5° clockwise. Reaction time tended to be constant with large color differences (± 120°) and increase nonlinearly for small color differences (± 60°). The +60° target-distracter pair corresponds to the best amplification.

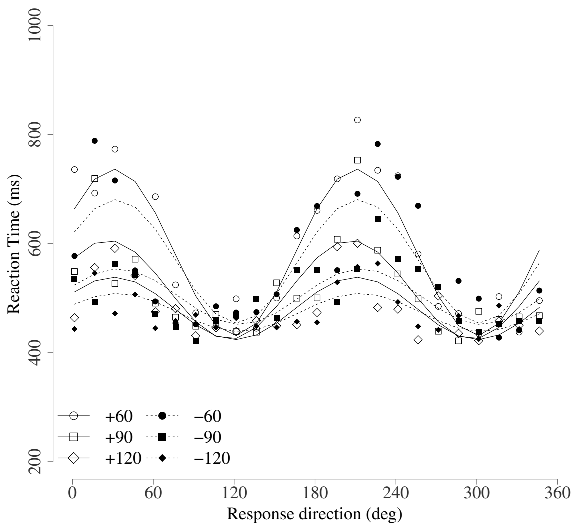

Fig. 3. Results for experiment 1. Represents the variation on reaction time as a function of the direction that best tune any target-distracter pair (response direction). The response direction was calculated as $T - ((T - D)/2 + 7.5)$, where T is the target-angle and D the distracter-angle. The plot shows the results of six target-distracter pairs for five normal color observers. Symbols represent the mean reaction time and the lines the interpolation sino functions of the data.

Figure 4 shows the results of experiment 2 for normal color and dichromatic observers for 48 positions and the +60° target-distracter pair. On the left side the reaction time for six normal color, two deuteranopes and five protanopes are expressed as a function of the response direction for the 48 directions. The interpolation line corresponds to the sino function that best fit the data. Error

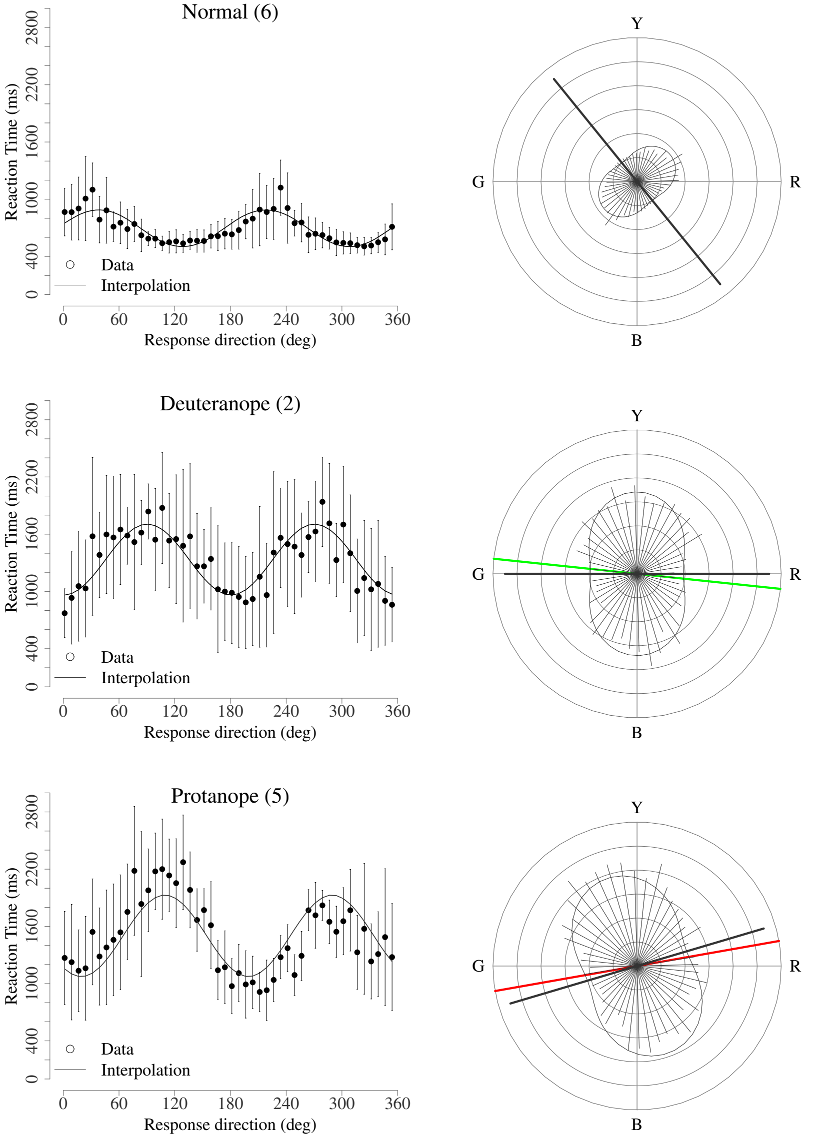

Fig. 4. Results for experiment 2. On the left side are represented the data for six normal color, two deuteranopes and five protanopes for 48 directions using a +60° target-distracter pair. The interpolation line corresponds to the sino function that best fit the data. Error bars represent standard deviation across trials. On the right side the mean data and the interpolation line for the 48 directions were plotted in polar coordinates, signaling the CIE $L^*a^*b^*$ color space directions. The confusion line for deuteranopes (green line) and protanopes (red line) are also showed. The thick-black line corresponds to the confusion direction.

bars represent standard deviation across trials. On the right side the mean data and the interpolation line were plotted in polar coordinates, signaling the CIE $L^*a^*b^*$ color space directions. Each circle corresponds to a 500 ms increment. The confusion line for deuteranopes (green line) and protanopes (red line) are also shown. The thick-black line, collinear to the minimum response direction, corresponds to the confusion direction. That is, color pairs along or parallel to this line show the highest reaction time.

4 Conclusions

It has been reported that the number of distracter colors is a significant factor for search time being the color deficient observers more vulnerable to background complexity [4]. A visual search paradigm using a unique distracter color was first tested to characterize the response direction (experiment 1) and then used for systematic examination on the mechanisms of dichromatic color perception (experiment 2).

The response direction for this unique-distracter paradigm fit in between the target-distracter pairs and differs from the mean direction by 7.5° clockwise. The results also show that decreasing the color difference between target and distracter amplifies the reaction time signal. This result agree to Nagy (1990) observation.

Mean search times for dichromats were twice larger (1.92 for deuteranopes and 2.16 for protanopes) compared to normal color observers and for all directions. Protanopes performed poorly on the yellow-green direction comparatively to the opposite blue-red direction. If the pop-out occurred in the initial 500 ms interval only the normal color observers could detected it on the yellow-green and blue-red directions. Finally, the results show that for both dichromats the difference between the conpuctual confusion lines and the confusion direction measure experimentally was 7.5° for deuteranopes and 5.5° for protanopes.

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