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Chromatic Characterization of Afterimages

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ABSTRACT: Chromatic properties of negative afterimages induced foveally by quasi-monochromatic stimuli have been matched with a test stimulus. A new psychophysical method is introduced based on a "one choice at a time" paradigm. Matched stimuli were found to be approximately complementary in hue. Their chroma was reduced in the short wavelength part of the visible spectrum.

1. Introduction

Afterimages have been the subject of many analyses (e.g. [1], [2],), they served as a tool of many investigations (e.g. [3], [4], and an especially interesting application in [5], where oculomotoric sensors were also studied by using afterimages in eye position determination for spatially stable vision), but today, neither the role of afterimages in vision, nor the location of afterimage forming in the visual system is perfectly clear.

While photo-pigment bleaching is commonly attributed to be one of the causes of perceived afterimages[6] it was shown[7] that afterimages may also possess the ability to induce simultaneous contrast revealing higher-order mechanisms included in the afterimage process.

Afterimages do have their role in parallel visual search[8] but *increment threshold detection* for briefly flashed targets was claimed to be one of their primary tasks[9].

The negative afterimage (which will be referred to as NA) we deal here with is defined[6] as a *strong* afterimage, and the corresponding color perception complementary to the hue of the inducing stimulus, thus we call it *negative*. By investigating afterimages induced by monochrome gratings it was concluded[2] that afterimage formation is due to "blocking" signals in the parvo-cellular pathway. This hypothesis could be strengthened by studying the chromatic properties of this "blocking" i.e. by analyzing the NA induced by monochromatic stimuli. It is worth mentioning that the corresponding pupillary responses were found to be mediated by the magno-cellular pathway[10].

As the NA is a *dynamic* effect it may lead to lengthy or imperfect measurement procedures to find out the wavelength-response of NA. Moreover, as visual experience shows, broadband inducers result in more vivid afterimages than monochromatic ones. Therefore, characterizing the spectral response is not an easy task to perform. Recently, an interesting method was introduced[11] to measure the chromaticity of afterimages. In this method using a CRT, circular inducers were arranged around the perimeter of a circle, leaving one inducer “blank” (the same color as the background). This structure was rotated with an appropriate angular velocity to maintain a seemingly rotating stable afterimage, with which a match could be made. However, it might be the case, that this technique cannot perfectly separate the NA process from other processes, such as simultaneous and successive contrast; the relation between the latter and afterimages (not necessarily chromatic or negative) is also unclear today.

In this paper, a new psycho-physical method is described. This method enables the observer to match the quasi-monochrome-induced afterimage to a test stimulus in a convenient way.

2. Apparatus and Stimuli

The apparatus (shown in *Fig. 1.*) consisted of two channels. One channel projecting from the observer’s side was a calibrated HP vp6210 DLP projector (1). The other channel projecting from the other side was a 300 W Xe arc lamp (2), which was filtered by quasi-monochromatic (HBW=10 nm) metal interference filters (3). Beam intensity was set by using a computer controlled diaphragm (4) connected to the serial port. The beam could be turned on and off (100 % modulation depth) by a computer-controlled rotating filter disc (5) including (amongst 16 others) a 100% and a 0% filter. The beam was imaged to the translucent central part of the screen (6).

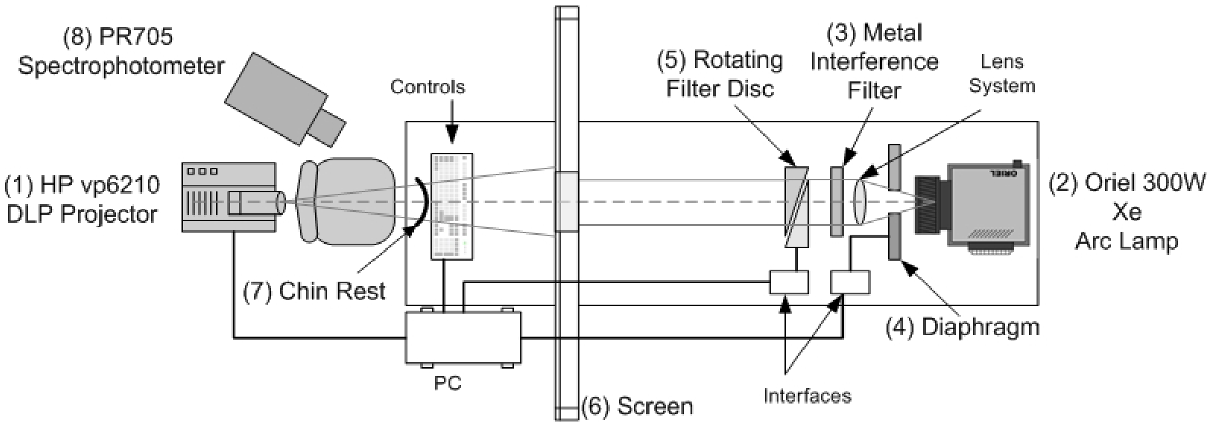

Fig. 1. Apparatus

The inducing stimuli were homogeneous[12] quasi-monochromatic lights of the same luminance[1], ranging from 460 to 640 *nm* in 40 *nm* increments in series $\mathbf{W_0}$. In series $\mathbf{W_1}$ and $\mathbf{W_2}$, there were 6 additional wavelengths: 470, 480, 490, 590, 600, and 610 *nm*. The inducing stimuli were of 6.5º diameter. They were viewed monocularly. In this work, inducers were presented foveally although in somewhat different

[1] Approximately 60 cd/m^2, with the exception of those where the maximal luminance achievable with the setup was below this value.

experiments[13] it was reported that para-foveal stimulation results in more saturated corresponding colors.

The matching stimulus structure projected by the HP projector is detailed below.

Parts of the screen other than the inducer and the matching structure were dim (below 1 cd/m^2). The observer's viewing distance of 0.35 m was fixed by using a chin rest, see (7) in Fig. 1. The inducer and the matching structure were separated spatially by about 10º due to technical difficulties. But, as the exposed area of the retina was marked by the afterimage itself, apart from the neglected Stiles-Crawford effect (of the second kind), no such artifacts were expected. Spectral measurements were made by using a calibrated Photo Research PR705 spectro-photometer (8).

A 25 years old, well-trained female observer was used. She was one of our standard paid observers with good color vision. She was familiar with all perceptual color attributes such as hue, chroma and lightness.

3. Method

After the warm-up time (30 min) of the experimental set-up, the observer was allowed to adapt to the dimly lit room for five minutes before beginning the experiment.

In each step, the inducing stimulus was presented for an adaptation period of 3 s with a step-function on-set and off-set. On-set and off-set durations were less than 80 ms.

After the adaptation period the inducer was turned off. Then the observer was presented an achromatic (white) disk (in series $\mathbf{W_0}$ and $\mathbf{W_1}$: Y=246.6 cd/m^2, u'=0.1840, v'=0.4582, in series $\mathbf{W_2}$: Y=216.6 cd/m^2, u'=0.1863, v'=0.4490). This disk had a similar diameter as the inducing stimulus but it was slightly larger to avoid confusion because of the diffuse edges of the afterimage. The background disk was chosen to be achromatic in order *not* to suppress the color signals of the afterimage which were expected to be rather small. The background disk was surrounded by a colored annulus containing 40 sectors of different hues. The annulus appeared as a continuous circle of colors with a discontinuity at 0º (see Fig. 2). The approximate perceptual uniformity of the hue scale was ensured by using the CIECAM02 *H* (hue quadrature). Moderate lightness (*J*) and chroma (*C*), *J*=80 and *C*=35, respectively, were initially set. At the beginning of each test run, the annulus covered the entire color circle. The white point of the color appearance model was the maximum display white (Y=246.6 cd/m^2, u'=0.1840, v'=0.4582), and "*dim*" surround was considered by setting Y_b=20%.

Following the model of [2] which states that NA formation has an exponential rise with a time constant of approximately 4.7 s, 8 s yields an adaptation level of 80 percent, thus the observer was given an answer period of 8 s to make her choice i.e.

to indicate, by using a mouse, which part of the color circle has a hue most resembling that of the afterimage projected to the white inner disk.

The primary task of the observer was to match the hue (using the pointer) but she had control over lightness and chroma as well (using the keyboard). This means that the observer was instructed *primarily* to set the *hue* but in case of a disturbing mismatch, set lightness and chroma, as well.

Then, another adaptation period followed. Now, the annulus had a different color sequence. The selected color was rotated by 180º and the *H* interval was half the previous *H* interval. It was centered around the selected color. Thus the procedure resulted in an ever tightening series of *H* intervals. If a choice regarding lightness or chroma was also made then the same color sequence was presented with the modified lightness/chroma value. If the answer period was over, before a choice was made, then the same interval was displayed again. A common color indicated those colors which fell out of the gamut of the projector thus not available for afterimage matching.

The observer was instructed not to take any positive afterimages (i.e. afterimages of the same hue) into account when making a match. Our observer has not mentioned to see any positive afterimages, nor were the interesting curves of afterimage forming reported by[14] in the case of red inducers apparent in our case. The experiment terminated when the discontinuity of the color circle at 0º disappeared (see Fig. 2). In this condition the afterimage and the annulus formed a uniform disk of the same hue, possibly of slightly different lightness and chroma.

In series $\mathbf{W_1}$ and $\mathbf{W_2}$ an additional restriction was added: the ΔH values of the two ends of the matching annulus had to be closer than 25 *H* units, to reduce the freedom of the observer.

Fig. 2. Matching structure

The matching structure is shown in *Fig. 2*. On the left, the initial matching annulus is shown, while the right side of Fig. 2 shows the structure after making one choice (bluish-green at 270º). Please note the discontinuity of hue at 0º in the right structure. (As they appear in the paper, these are of course un-calibrated images for illustration purposes only.)

Both ends of the final *H* interval were saved to a file, and, at the end of the session, they were measured spectrally by the calibrated Photo Research PR-705 spectrophotometer.

Six wavelengths were covered in a session. Each wavelength was repeated five times and each session lasted about 2 hours.

4. Results

Fig 3. shows the results of the two main experimental series **W_1** and **W_2**. In Fig. 3, inducing stimuli and the chromaticity of the matching stimuli of the afterimages are connected by solid lines and depicted with the same color.

Adding the restriction on the exit condition (the ΔH values of the two ends of the matching annulus had to be closer than 25 H units) reduced the average variance of the measurements by a factor of 2. Variances are depicted in Fig. 4. showing 3σ (three times the variance of the chromaticity coordinates) of each measurement (5 times repeated trials at each wavelength) in series **W_2**.

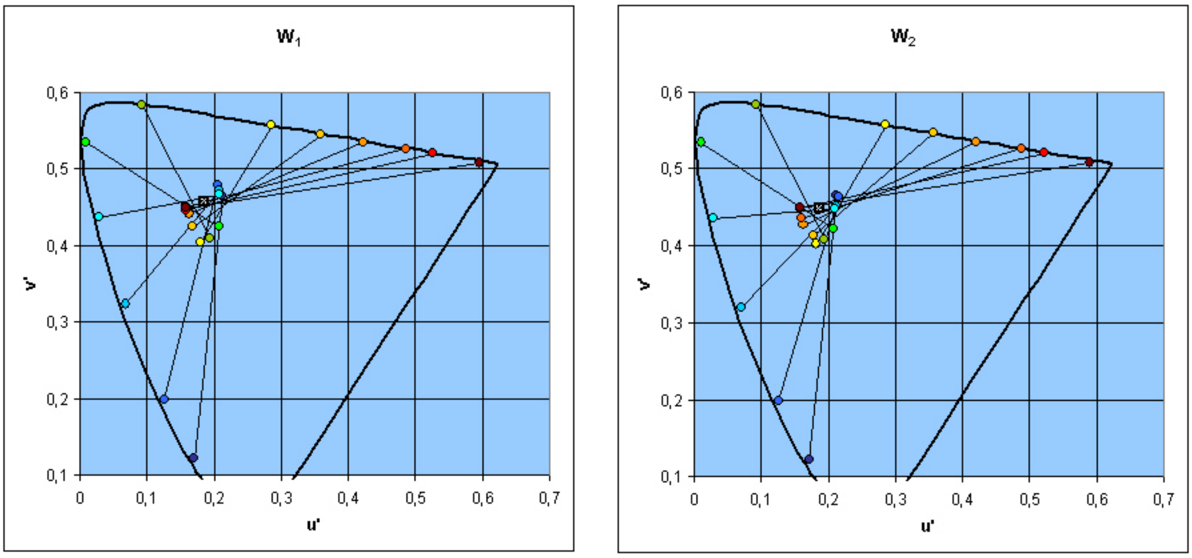

Fig. 3. Results of the W1 and W2 experimental series depicted in the CIE 1976 (u',v') chromaticity diagram (Average of *n*=5 repeating)

The variance of the matching procedure was highest in the blue-green – green part of the spectrum. There is an apparent effect of the white point of the background on the loci of the corresponding points, but it needs more data to show if this change is significant. The average hue difference (CIECAM02 Δh) between inducer and the matched stimulus is close to 180 ° in both cases (177.07 and 178.79 respectively), even though this is affected by the fact that the connecting lines do not cross the achromatic point in most cases.

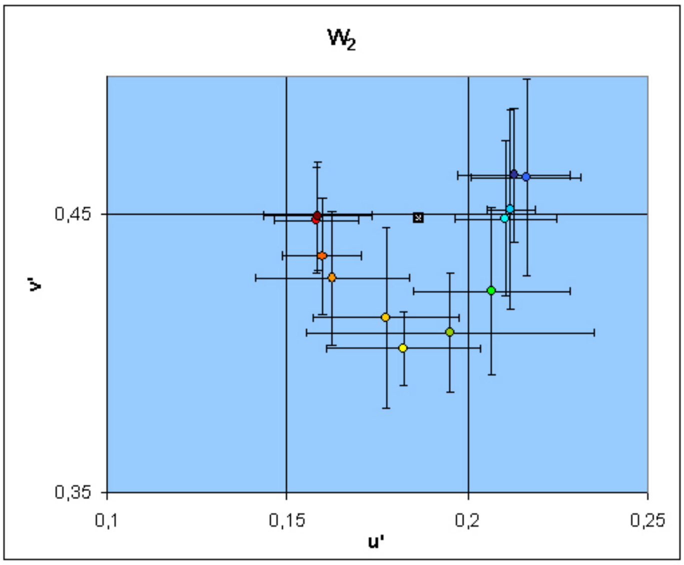

Fig. 4. 3σ of the chromaticity coordinates of the stimuli the matching stimulus depicted in the CIE 1976 (u',v') chromaticity diagram

Chroma values were reduced by the observer only in the blue part (by 55.5 % in average) and increased only at 580 *nm* (only 7.1 % in series $\mathbf{W_1}$) from the initially set value of 35, which means that the afterimages induced by bluish stimuli (below 490 nm) are less saturated than those induced by other colors. This chroma loss is abruptly changed at 500 *nm* to the initial value. Lightness values were reduced in the green and yellow part by an average of 20.6 %, and more or less left at the initial value in the case of other inducer stimuli. It is interesting to note that variances of matching were usually higher in the v' direction.

5. Discussion

Afterimages induced by monochromatic stimuli reveal that they are complementary colored in the sense that the hue difference between inducer and the matching stimulus is close to 180 º. Present data does not support the hypothesis of [11] that the connecting lines between the inducer stimulus and the matching stimulus cross in one point. However neither are we able to reject this hypothesis.

Even though the observer did not notice the change in the white of the background disk, her responses show that the background does have an influence on the NA. The loci of the corresponding points seem to have shifted into the direction of the white point change, more in the red and blue region and less in the green region. Again, this has to be confirmed by a larger set of experimental data.

The chroma values of the matching stimuli are significantly lower between 460 and 490 nm than those above 500 nm in both experimental series, and also in[11], which may point toward the different mechanisms fed by the ρ-cones, or possibly toward rod-cone interactions[14].

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