SIMULATING IMAGES PERCEIVED BY SUBJECTS WITH ABNORMAL COLOUR OR SPACIAL VISION

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INTRODUCTION

Acquired vision defects, in particular those affecting ganglion cells in the Parvocellular or in the Koniocellular pathways, changes the relative spectral sensitivities of the chromatic and achromatic mechanisms and selectively reduce chromatic and achromatic contrast sensitivity for certain spatio-temporal frequencies, altering therefore image perception. In this work, we propose a modification of the corresponding pair algorithm [1,2] to simulate how subjects with acquired vision defects see a colour image.

METHOD

The appearance a stimulus **T** has for a variant observer can be described if a stimulus **S** is found verifiying that a normal observer experiences the same sensation viewing **S** as the variant subject viewing **T**. If normal and variant versions of the same vision model, with adequate mathematical properties [1],[2], are available, the tristimulus values of S(x,y) are obtained by applying the inverse of the normal model to the perceptual descriptors of T(x,y) given by the variant model, i.e.:

$$\mathbf{S}(x,y) = m^{-1}(m(\mathbf{T}(x,y),\mathbf{p}_n),\mathbf{p}_v) \qquad (1)$$

where m is a mathematical operator comprising all the transformations of the vision model, and pn and pv are, respectively, the set of parameters defining normal and variant vision. In what follows, sub-indexes n and v mean "normal" and "variant".

If the alterations suffered by a subject can be separated in changes affecting spectral sensitivity of certain colour mechanisms and changes in contrast sensitivity of certain spatial mechanisms (which are also colour selective), Eq. 1 becomes

$$\mathbf{S}(x,y) = m^{-1}(m(\mathbf{T}(x,y),\mathbf{p}_{nc},\mathbf{p}_{ns}),\mathbf{p}_{vc},\mathbf{p}_{vs}) \qquad (2)$$

where pnc and pvc are the parameters defining the spectral sensitivities of the normal and variant colour mechanisms and pns and pvs the parameters defining their spatial properties. Basically (see Figure 1), a colour vision model provides the responses of an achromatic (A(x,y)), a red-green (T(x,y)) and a blue-yellow (D(x,y)) mechanism for each point of the image and spatial processing is then performed separately in these three mechanisms.

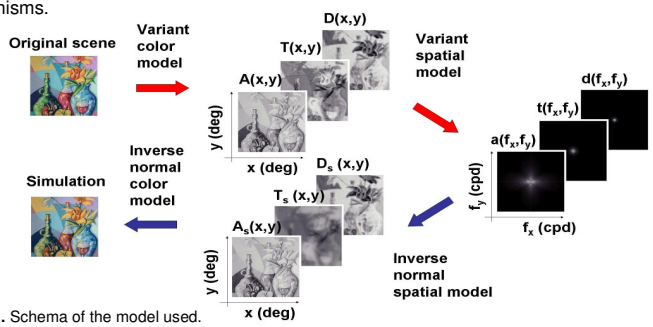


Figure 1. Schema of the model used.

The colour mechanisms used are those of ATD05 [3] and only subjects with normal or dichromatic colour vision have been considered. We assume that for protanopes L cones contains the M pigment and that for deutaranopes the M cones contain the L pigment (cone substitution hypothesis) and that for both the red-green mechanism is nulled. For tritanopes, we have nulled the S cones (cone-null hypothesis) and the yellow-blue mechanism. With these hypotheses, good dichromatic versions of ATD05 are obtained [2].

The spatial vision model is simply a set of three linear filters, one for each of the ATD. These filters are the observer's contrast sensitivity functions (CSFs), as measured psychophysically with sinusoidal gratings isolating each mechanism. The achromatic filter is band-pass peaking around 4 cpd and with a cut-off frequency at approximately 50 cpd, The chromatic red-green and blue yellow filters are low-pass with cut-off frequencies at approximately 14 and 6 cpd, respectively. The achromatic band-pass filter was implemented as a difference of two Gaussians, and the chromatic low-pass filters are gaussians peaking at the origin. Variant subjects were simulated by changing both the amplitude (maximum sensitivity) and the cut-off frequency (resolution) of either the red-green of the blue-yellow spatial CSFs, as in Figure 2. With all this, an image S(x,y), that for a normal subject, simulates how an image T(x,y) appears to a variant subject, is obtained as follows:

$$\mathbf{S}_{n,i}(x,y) = FT^{-1}\left(FT(\mathbf{T}_{v,i}(x,y))\frac{CSF_{v,i}(f_x,f_y)}{CSF_{n,i}(f_x,f_y)}\right) \qquad (3)$$

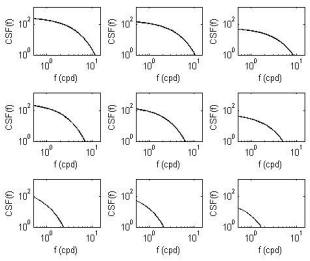


Figure 2. Intact chromatic CSF, up-left. Overall sensitivity (rows) and cut-off frequency (columns) have been reduced in linear steps. Normal aging and different pathologies produce this kind of changes in contrast sensitivity. Note that scaling of the normal CSF is arbitrary, but that as only the CSFv to CSFn ratio is relevant, this is not a problem.

where FT means Fourier Transform and sub-index i refers to one of the three mechanisms (i=A,T,D). Thus, pns and pvs in Eq. 2 are simply CSFn,i(fx,fy) and CSFv,i(fx,fy), respectively. Eq. 3 is a straightforward extension to three-dimensional colour space of the algorithm proposed by de Fez et al. [4].

RESULTS

Figures 3-4 shows how a subject with normal colour vision would perceive the image in the upper-left corner, when either the red-green (Figs. 3) or the blue-yellow (Fig. 4) mechanism have CSFs altered as in Fig.2. As the gravity of the defect increases, the image palette becomes restricted to yellows and blues for damage in the red-green mechanism (Fig. 3), and to bluish-greens and purples for damage in the blue-yellow mechanism (Fig. 4). No defocus appears, however, since the achromatic mechanism is intact in this example. Note that all figures should subtend 4º.

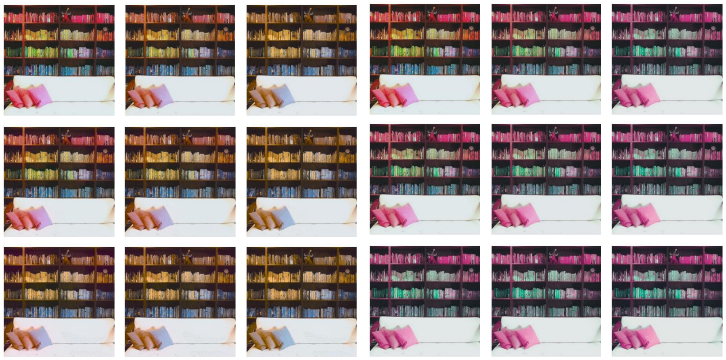


Figure 3 **Figure 4**

With alterations in the spatial CSF of one of the chromatic mechanisms, the subject's perception becomes similar to that of red-green or blue-yellow detectives (Fig. 5), again with intact achromatic mechanisms. Note that although the images corresponding to alterations in spectral sensitivity or in contrast sensitivity in the colour mechanisms (dichromatic subjects), have the same colour palette, they do not coincide pixel to pixel, since parameters pnc and pvc in Equation 2 are different in the case of dichromats.

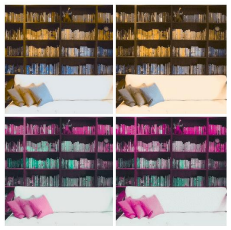
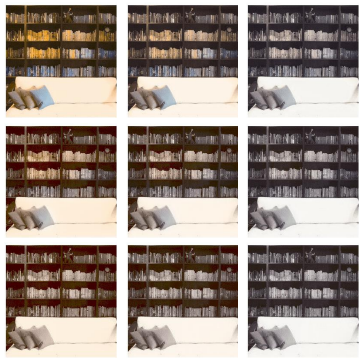


Figure 5



In Figure 6 we show an example of alterations both in spectral and contrast sensitivities: a protanopic subject with the spatial CSF of the yellow-blue mechanism altered as for the subject in Figure 4. As the gravity of the defect increases, the image becomes achromatic. The original image is not shown: the image in the upper-left corner corresponds to the dichromat with intact CSFs. For a tritanopic observer, similar results would be obtained for alterations in the remaining red-green mechanism (not shown).

Figure 6

Finally, in Figure 7 we simulate the perception of a subject with intact spectral sensitivities in their colour mechanisms, but CSFs presenting reduced overall sensitivity and cut-off frequency in the three mechanisms (figure), so as to mimic the behaviour of the subject reported by Sakai and co-workers [5]. Ocular media are assumed to be clear, and therefore the mean luminance value of the image is maintained. Note that both defocus and loss of sensitivity for chromatic differences are present in the simulated image.

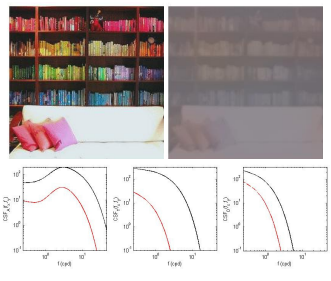


Figure 7

REFERENCES

1. P. Capilla, M.A. Díez-Ajenjo, M.J. Luque, J. Malo. The corresponding pair procedure: a new approach to simulation of dichromatic colour perception. J. Opt. Soc. Am. A, 21, 176-186, 2004.
2. P. Capilla, M.J. Luque, M.A. Díez-Ajenjo. Looking for the dichromatic version of a color vision model.J. of Optics. A: Pure and Applied Optics, 6, 906-919, 2004.
3. L. Guth. Further applications of the ATD model for color vision. Proc. SPIE- The International Society for Optical Engineering, 2414, 12-26, 1995.
4. M.D. de Fez, M.J. Luque, V. Viqueira, Enhancement of Contrast Sensitivity and Losses of Chromatic Discrimination with Tinted Lenses, Opt. Vis. Sci. 79, 590–597, 2002.
5. S. Sakai, K. Hirayama, K. Ogura, N. Sakai, M. Sudoh, N. Murata, S. Iwasaki. Visual function of a patient with advanced adrenoleukodystrophy: Comparison of luminance and color contrast sensitivities, Brain & Development, 30, 68-72, 2007