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Effect of a Small Blue Adapting Field on the Spectral Sensitivity of the Red-sensitive Colour Mechanism of the Human Eye

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Effect of a small blue adapting field on the spectral sensitivity of the red-sensitive colour mechanism of the human eye

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Abstract. The field spectral sensitivity of the red-sensitive colour mechanism is determined in the presence of a 1° blue (468 nm) auxiliary conditioning field. The effect of this auxiliary conditioning field is shown to reduce the relative sensitivity of the red-sensitive mechanism at short-to-medium wavelengths. This depression in sensitivity does not occur, however, when the auxiliary conditioning field is made much larger than the test stimulus. An inhibitory interaction between red and either green- or blue-sensitive mechanisms is hypothesized.

1. Introduction

The action spectrum of the red-sensitive colour mechanism of the human eye, the Stiles π_5 mechanism, may be evaluated by a *field spectral sensitivity* determination [1–4]. In this procedure, the radiance of a monochromatic conditioning field that raises the threshold intensity of a red test flash by ten times its value on zero field is measured as a function of the conditioning-field wavelength. The purpose of this communication is to report the finding that the introduction of a small blue auxiliary conditioning field modifies the measured field spectral sensitivity : the resulting curve shows a depression in relative sensitivity at short-to-medium wavelengths. It is suggested that the effect may be due to an inhibitory interaction between colour mechanisms.

2. Methods

The experiment was carried out with a conventional three-channel maxwellian-view optical system with a single tungsten–halogen lamp powered by a stabilized d.c. supply. The spectral compositions of the channels were controlled by Balzers B40 interference filters with half-bandwidths not greater than 12 nm. The wavelength of the test flash was fixed at 664 nm, and that of the auxiliary conditioning field at 468 nm ; the main conditioning-field wavelength ranged over the values 431, 465, 503, 543, 605, 651 and 702 nm ; a violet gelatin filter, Ilford No. 621, was added to the 431 nm interference filter to reduce unwanted long-wavelength transmission. The spatial configuration of the test and main conditioning fields was similar to that used by Stiles [3, 4]. The test flash was circular and subtended 1° at the eye ; the main conditioning field subtended 10° and was concentric with the test stimulus (see figure 1). Foveal fixation was aided by four small red lights forming a 3° square symmetrically placed about the test stimulus. The quantum intensity of the 1° 468 nm auxiliary field, which was concentric with the test stimulus,

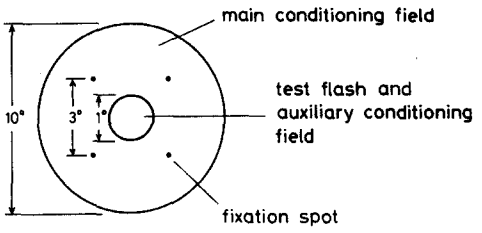

Figure 1. The stimulus configuration (not to scale).

was fixed at 7·4 log quanta s^{-1} deg^{-2}. In the absence of the main conditioning field, this auxiliary field raised the test-flash threshold by not more than 0·1 log units. (Radiometric measurement of the light output of the various channels at the exit pupil of the instrument was carried out by means of a silicon photodiode linked to a linear amplifier which, as a unit, had previously been calibrated absolutely and spectrally against a Hilger–Schwarz thermopile.) The intensities of the test and main conditioning-field channels were adjusted with neutral density wedges. The duration of the test-flash, fixed at 200 ms, was controlled by an electromagnetic shutter. The stimuli were viewed through a 2 mm artificial pupil with the right eye and a dental bite bar was used to steady the head. Each observation session was preceded by 10 min of dark-adaptation. There were three subjects: JAH, DHF (the author), and JTL. All had normal colour vision and were aged between 21 and 33 years.

In the method used by Stiles to determine field spectral sensitivity, threshold-versus-radiance curves are obtained for each main conditioning-field wavelength, and from these curves the field spectral sensitivity is computed. For the present investigation, a direct method of measurement was used: the test flash was set at a fixed intensity, 0·5 log units above absolute threshold (or increment threshold if the auxiliary conditioning field was present), and the intensity of the main conditioning field adjusted to bring the test flash to threshold. Care was taken, however, to ensure that at each field-intensity setting the value arrived at represented the steady-state sensitivity ([5], p. 225). As a control on this procedure and on the normality of the observer's π_5 mechanism, a field spectral sensitivity measurement was first made by the direct method without the auxiliary conditioning field. In each field spectral sensitivity determination, the main-field wavelength was run systematically through the selected range of values, and, at each wavelength, three settings of the field intensity necessary to bring the test flash to threshold were recorded. Each observer performed four runs, two with field wavelengths in ascending order and two with field wavelengths in descending order.

3. Results

Figures 2 (*a*) and (*b*) show results for subjects JAH and DHF respectively. (Results for JTL, not shown here, are similar.) The reciprocal of the quantum intensity of the main conditioning field at which the test flash is at threshold is plotted against field wavenumber. Each point represents the mean of twelve readings; for JAH the mean S.E.M. is 0·04 log units (maximum 0·06) and for DHF 0·02 log units (maximum 0·04). There are no corrections for light

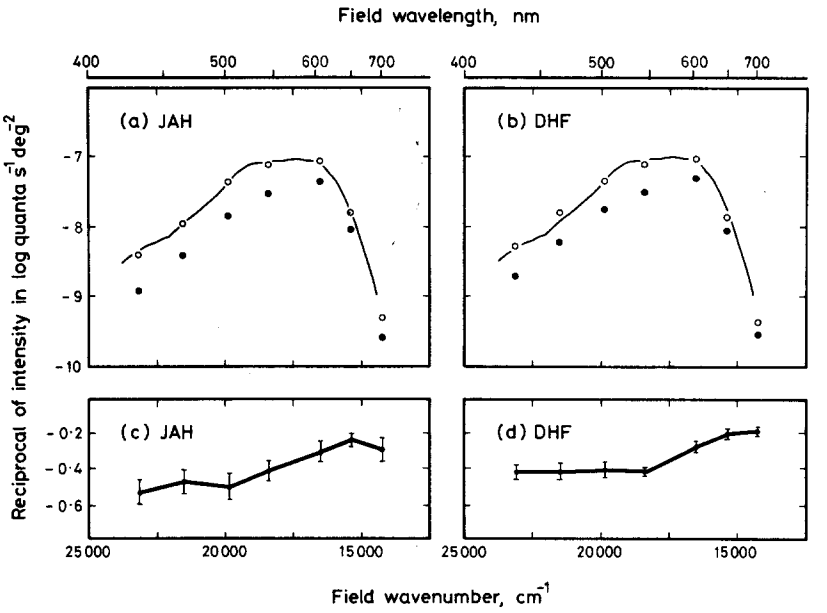

Figure 2. (*a*, *b*) Field spectral sensitivity of the red-sensitive colour mechanism π_5 for subjects JAH and DHF. The reciprocal of the quantum intensity of the main conditioning field which brings the test flash to threshold is plotted against field wavenumber. The test flash subtends 1° and the main conditioning field 10°. The duration of the test flash is 200 msec. Open circles represent data obtained on zero background, and the filled circles represent data obtained on a 1° 468 nm auxiliary conditioning field, intensity 7·4 log quanta s^{-1} deg^{-2}. Each point represents the mean of 12 measurements ; for JAH, the mean S.E.M. is 0·04 log units (maximum 0·06) and for DHF 0·02 log units (maximum 0·04). The smooth curve shows the field spectral sensitivity of π_5 (from [6], table 7.6) shifted vertically to give the best (least-squares) fit to the zero-background data. (*c*, *d*) Difference in field spectral sensitivities obtained with and without the 1° auxiliary conditioning field. The vertical bars indicate ±1 S.E.M.

losses in the eye. The open circles indicate the action spectrum obtained without the 468 nm auxiliary conditioning field and the smooth curve depicts the field spectral sensitivity of π_5 (from [6], table 7.6) shifted vertically to provide the best fit (in the least-squares sense) to the data. The action spectrum of π_5 obtained by the method used here is seen to be in good agreement with the Stiles curve. The filled circles in figures 2 (*a*) and (*b*) indicate the action spectrum obtained when the 1° 468 nm auxiliary field is introduced. The reduction in field sensitivity at short-to-medium wavelengths is evidently greater than that at long wavelengths. The difference in field sensitivities obtained with and without the auxiliary conditioning field is shown as a function of field wavenumber in figures 2 (*c*) and (*d*), the vertical bars representing ± 1 S.E.M. For both observers, the magnitude of the mean sensitivity difference over the range 431–543 nm is at least 0·2 log units greater than over the range 651–702 nm, and this difference is highly significant ($p < 0{\cdot}001$; t test for a linear comparison).

It does not necessarily follow from the above experiments that the small size of the auxiliary conditioning field is an essential factor in the production of the

modified action spectrum. It might be hypothesized that the observed effects are due to a general failure in field additivity [7] which has also been reported [8, 9] for the blue-sensitive mechanism π_1. To test this hypothesis, the field spectral sensitivity was redetermined, precisely as before, except that the 468 nm auxiliary field, quantum intensity 7·4 log quanta s^{-1} deg^{-2}, was extended in diameter to 10°, the size of the main conditioning field. The wavelength of the main conditioning field was varied over the full range for DHF, but set at only two values, 431 and 651 nm, for JAH. It was found that the magnitude of the difference in spectral sensitivities at short and long wavelengths was not significantly greater with the 10° auxiliary field than with the zero background ($p > 0{\cdot}2$; t test for a linear comparison).

One explanation of the present findings is that the small auxiliary conditioning field gives rise to an inhibition of the short-to-medium wavelength sensitivity of π_5 by modifying the activity of the green- and possibly blue-sensitive mechanisms in the region of the test stimulus [10–14]. This effect could arise retinally, the result of a lateral inhibitory interaction between colour mechanisms at the border of the auxiliary field. On the other hand, it may be central in origin. Lennie and MacLeod [15] have shown that a contour detected only by cones can affect the threshold of a test flash detected only by rods. They have suggested that their results may be interpreted in terms of the activity of certain size-sensitive mechanisms in the cortex which can be stimulated by both rods and cones. In the present experiments, cone signals alone would be involved. On the basis of the present data, however, it is not possible to distinguish between these two hypotheses.

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