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SPATIO-TEMPORAL INTERACTION BETWEEN VISUAL COLOUR MECHANISMS

DAVID H. FOSTER and IBRAHIM I. M. IDRIS

Applied Optics Section, Department of Physics, Imperial College of Science and Technology, London SW7 2BZ, England

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Abstract—Interaction between Stiles colour mechanisms π_1, π_4 and π_5 is examined in the case of a certain discrete-stimulus apparent-movement effect. It is found that this effect is exhibited between different as well as the same π mechanisms, and, moreover, that is has the same temporal-frequency dependence in each case.

INTRODUCTION

By hypothesis, the visual colour mechanisms of Stiles act independently of one another in simple increment threshold measurements (Stiles, 1939, 1949, 1953, 1959). This independence of action has been shown by Alpern and Rushton (1965) to extend to the after-flash effect (Alpern, 1965); it has also been demonstrated by Du Croz and Rushton (1966) for dark adaptation, by Green (1968) for the spatial sinewave response (but see Kelly, 1973), by McKee and Westheimer (1970) for "centre-surround antagonism" (see also Guth, 1973, and Bender, 1973), and by Krauskopf and Mollon (1971) for temporal integration. However, non-interaction between different colour mechanisms is not always the case: Boynton, Ikeda and Stiles (1964) have shown that there is inhibition between different mechanisms in certain complex increment threshold measurements (see also Ikeda, Uetsuki and Stiles, 1970), and Boynton, Das and Gardiner (1966) have indicated that adaptive effects are not necessarily restricted to what happens within the same mechanisms.

The purpose of the present study is to determine whether mechanism specificity is exhibited in the spatio-temporal interaction effect *beta motion* (Kenkel, 1913; Kolers, 1972). It is recalled that beta motion is the apparent-movement effect induced by the sequential presentation of two (spatially resolvable) flashes of light to the visual system.

The experiment we performed was as follows. We presented the two flashes of light foveally; the one flash stimulated mechanism π_i and the other stimulated mechanism π_j. That each flash stimulated one and only one mechanism was ensured by the use of two-colour threshold method (Stiles, 1949; Wyszecki and Stiles, 1967). The stimuli were presented in an alternating sequence and the proportion of times the effect was observed was recorded as a function of the temporal frequency of the sequence. Graphs were thus obtained for all the mechanism pairs (π_i, π_j), $i, j = 1, 4, 5$.

Experiments on apparent-movement phenomena using coloured stimuli have also been carried out by Wertheimer (1912) and Squires (1931). Neither of these studies provide information on π mechanism interaction.

EXPERIMENTAL APPARATUS

A diagram of the experimental apparatus is shown in Fig. 1. It consisted essentially of four channels, each forming a Maxwellian view system. Channels LH_1 and LH_2 gave rise to the two alternating test stimuli and channels RH_1 and RH_2, the associated conditioning fields. The full stimulus field appeared as in Fig. 2. The angular subtense of the two test bars was 0·5°.

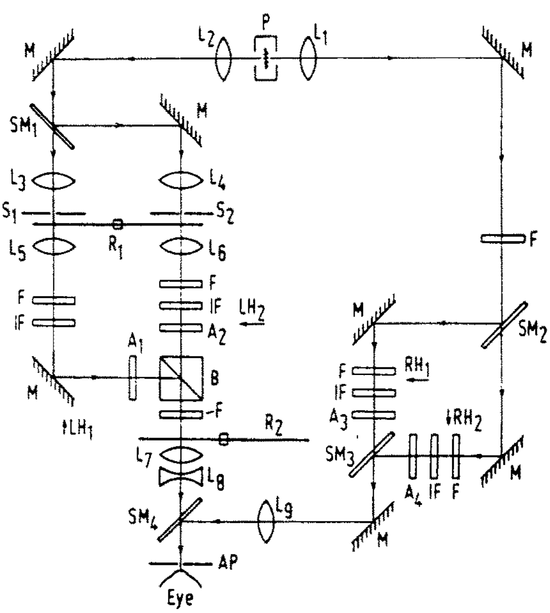

Fig. 1. The experimental apparatus: *P*, light source; *M*, mirror; *SM*, semi-reflecting plate; *L*, lens; *S*, stop; *F*, neutral density filter; *IF*, interference filter; *R*, rotating sector; *A*, pattern mask; *B*, biprism; *AP*, artificial pupil.

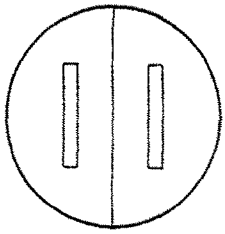

Fig. 2. The stimulus field (to scale). The angular subtense of the circular background field: 1·5°; the angular separation of the two test bars: 0·5°.

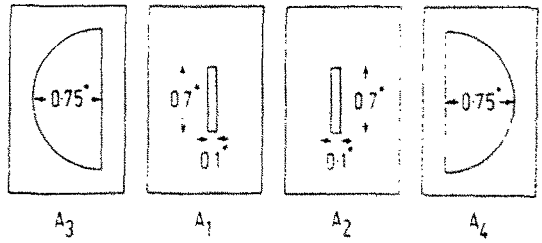

Fig. 4. The masks A_1, A_2, A_3 and A_4 (to scale). Angular subtenses (when in situ) are marked.

Detailed description

The single light source P was a 12 V, 100 W quartz–iodine lamp with a compact coiled filament. This was run from a stabilized power supply (fluctuations of the light level being within 0·25 per cent of the mean). Light was taken from both sides of P and rendered parallel by the collimating lenses L_1 and L_2. The left-hand beam was split (amplitude-division in all cases) by the semi-reflecting plate SM_1 and the two resulting beams focussed by the lenses L_3 and L_4 onto the stops S_1 and S_2. The light from S_1 and S_2 was then recollimated by the lenses L_5 and L_6. The parallel light beam in channel LH_1 transilluminated the mask A_1 and that in channel LH_2 the mask A_2. The two beams were brought together by the biprism B, and then, via lenses L_7 and L_8, to a focus at the 2 mm artifical pupil AP. The right-hand beam was split by the semi-reflecting plate SM_2. The parallel light beam in channel RH_1 transilluminated the mask A_3, and that in channel RH_2, the mask A_4. The two beams were brought together by the semi-reflecting plate SM_3, and then, via the lens L_9 and the semi-reflecting plate SM_4, to a focus at AP. The aperture was completely filled with light.

The channels LH_1 and LH_2 were alternately interrupted by the rotating 90°-sector R_1. (The temporal course of the stimuli is shown in Fig. 3.) The sector was driven by an electric motor with feedback stabilization and continuously variable speed-setting. The overall exposure-time of the left-hand side of the system was determined by the rotating 180°-sector R_2. The masks A_1, A_2, A_3 and A_4 are shown, with dimensions, in Fig. 4. Patched together, the field appeared as in Fig. 2.

The colour temperature of the field (without colour filters) was 3200° K. The interference filters IF (Balzers, types B20 and B40) inserted in each of the channels were chosen according to which mechanisms were to be isolated; intensity levels were set in relation to the absolute thresholds of the selected mechanisms (see next section).

EXPERIMENTAL PROCEDURE

Mechanism isolation

Use was made of the data presented by Wyszecki and Stiles (1967, Table 7.6). In order to achieve the most efficient

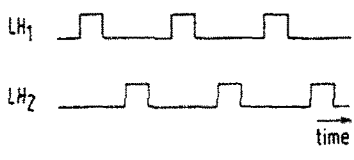

Fig. 3. The temporal course of the two test stimuli associated with the channels LH_1 and LH_2.

isolation in each case, we took into account both the absolute sensitivity of the selected mechanism and the ratio of its sensitivity to that of the next most sensitive mechanism. The wavelengths of the test fields (channels LH_1 and LH_2) and conditioning fields (channels RH_1 and RH_2) were accordingly chosen as in Table 1. For these test and conditioning field wavelengths, the t.v.i. (threshold vs intensity)

Table 1.

	Test field wavelength (nm)	Conditioning field wavelength (nm)	Mechanism to be isolated
(1)	439	574	π_1
(2)	516	650	π_4
(3)	656	465	π_5

curves are in cases 2 and 3 (Table 1) one-branched [see Fig. 5. (b and c)], and correspond uniquely to π_4 and π_5 respectively. Hence, for any conditioning field level (up to at least the values shown in Fig. 5), the test may be assumed to be "seen" solely by the selected machanism, providing the test field level is set at or just above increment threshold. In case 1, however, the t.v.i. curve is three-branched [see Fig. 5(a)] with only the centre branch corresponding to π_1 (Stiles, 1953). Hence, only for the restricted range of conditioning field levels shown can the same assertion be made.

To obtain a comparable level of excitation in each mechanism, we set each of the conditioning field intensities I_{574}, I_{650}, I_{465} (Table 1) at such a level that for the mechanism concerned increment threshold was 0·5 log units above its absolute threshold. In case 1, the appropriate level was determined by extrapolation (see Fig. 5). Typical values were $I_{574} = 2{\cdot}2$ log td, $I_{650} = 3{\cdot}0$ log td, $I_{465} = 1{\cdot}8$ log td. Test field levels were then fixed at 0·2 log units above increment threshold. (Thresholds in the one half of the stimulus field were not affected by the presence of the conditioning field in the other half.)

The main experiment

The subject, using a dental bite-bar, monocularly fixated the centre of the stimulus field. (The circular conditioning field was always visible.) For a preselected temporal frequency (of the fundamental) ω_k, the alternating test-stimuli were presented for 10 sec. The subject was then required to indicate (by means of a hand-operated buzzer) whether or not well-defined beta motion occurred between the bars. were considered with one trial being performed at each frequency ω_k. The order of the trials T_1, T_2, . . . , T_{14} was chosen

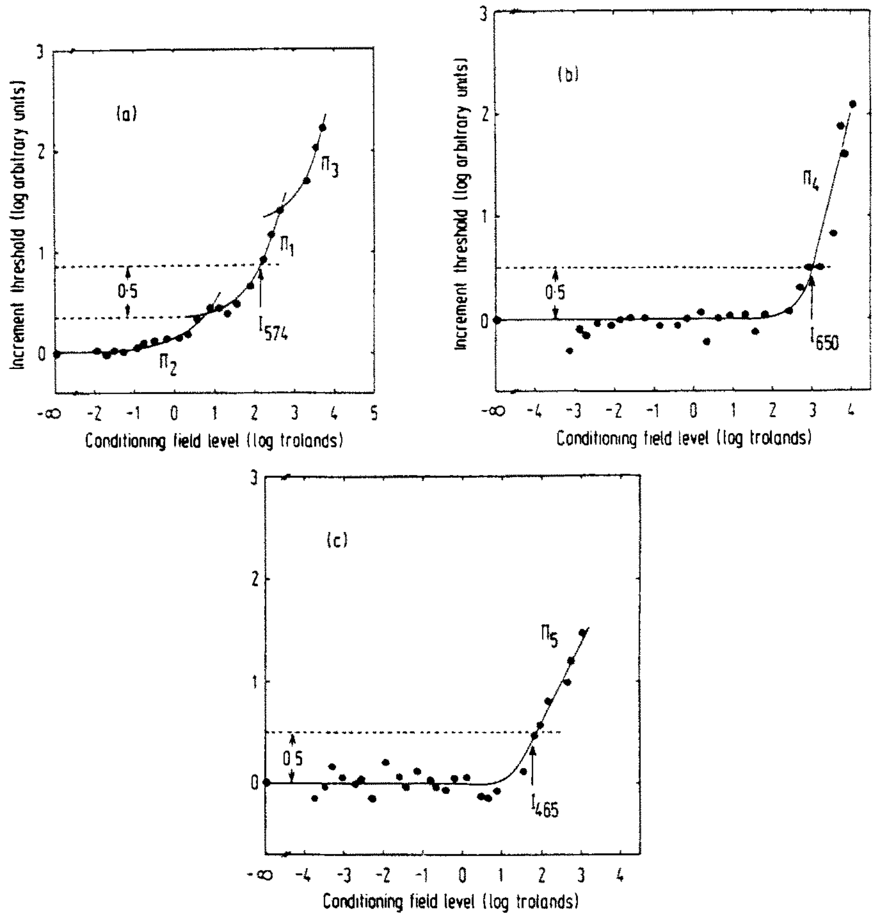

Fig. 5. t.v.i. curves for subject FMF. Test and conditioning field wavelengths are in (a) 439 and 574 nm, in (b) 516 and 650 nm, and in (c) 656 and 465 nm.

at random. This test procedure was repeated four times with different random orderings of the T_l in each case. At each ω_k five independent binary data values were thus obtained.

Six separate experiments were performed, one for each different pair of the three mechanisms. Preliminary trials showed no differences between (π_i, π_j) and (π_j, π_i), $i \neq j$.

Two subjects were used: FMF, who was slightly myopic and aged 26 yr, and WHK, who was emmetropic and aged 52 yr. The apparent distance of the test stimulus was within the range of accommodation of the subject's naked eye. Both subjects were unaware of the purpose of the experiment.

RESULTS

In Fig. 6 the results for each of the two observers are shown. The number of affirmative responses (beta motion obtained) is plotted against temporal frequency ω for each pair (π_i, π_j) of mechanisms considered. The maximum possible number of affirmative responses at each frequency ω_k is five. Linear interpolation is employed at values of $\omega \neq \omega_k$, though no use of this was made in the formal analysis.

DISCUSSION

It appears from Fig. 6 that for each subject the graphs associated with each pair of π mechanisms form a homogeneous collection. For the sake of completeness, we also subjected the data of Fig. 6 to a formal analysis, using two of the procedures described in Cox (1970). The six graphs for each observer were taken a pair at a time (15 pairs in all) and each pair examined for an underlying constant (vs non-constant) difference and for an underlying zero (vs non-zero) constant difference (constancy in each case being with respect to frequency ω). At the 5 per cent significance level, no underlying difference could be detected between any of the graphs. (If there is, in fact, a lack homogeneity, then larger numbers of trials will probably be needed to reveal it.)

We therefore conclude that, unlike most of the interaction phenomena referred to in the introduction, the present one is not mechanism specific. Not only can beta motion be generated between different as well as

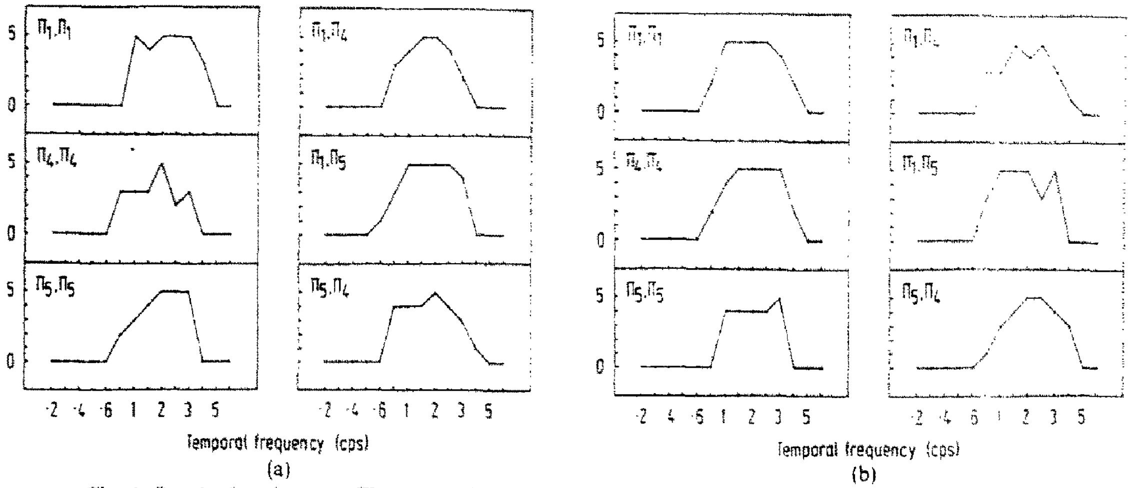

Fig. 6. Results for observers FMF (a) and WHK (b). Graphs show for each pair of mechanisms (π_i, π_j) the number of times beta motion is obtained as a function of temporal frequency (see text).

the same π mechanisms, but when the level of excitation of each mechanism exceeds absolute threshold by the same amount the same temporal-frequency dependence is observed.

The results of the present investigation may have relevance to a rather different problem. Thorson, Lange and Biederman-Thorson (1969) and Biederman-Thorson, Thorson and Lange (1971) have investigated an apparent movement effect which they have called the "fine-grain" movement illusion. This is similar to beta motion in that it is induced by the sequential presentation of two spatially distinct stimuli. It differs, however, in that (a) the stimuli are presented in peripheral view with spatial separation such that they cannot be resolved and (b) the illusion subtends a greater angle than does the stimulus pair. The dynamic characteristics of the illusion are like those of the after-flash effect, and Thorson *et al.* (1969) have suggested an experiment similar to the one reported here to test for π mechanism specificity.

The Thorsons have advanced the hypothesis that the fine-grain illusion involves interaction with the (real-) movement perception part of the visual system. If this is correct, and if the illusion is mechanism specific, then in conjunction with the outcome of the present study we should have strong support for Kolers' assertion that the processes underlying real- and apparent-movement phenomena are *not* the same (Kolers, 1963, 1972; Robinson, 1972).

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Résumé—On examine l'interaction entre les mécanismes colorés de tiles π_1, π_4 et π_5 dans le cas de certains effets de mouvement apparent d'un stimulus discret. On trouve que cet effet se présente entre des mécansimes π différents aussi bien qu'avec le même et en outre qu'il présente dans chaque cas la même dépendance temporelle à la fréquence.

Zusammenfassung—Bei einer bestimmten Scheinbewegung bei diskreten Reizen wird die Wechselwirkung zwischen den Stiles'schen Farbmechanismen π_1, π_4 und π_5 untersucht. Es wurde gefunden, dass der Effekt sich bei unterschiedlichen π Mechanismen genauso wie beim gleichen π Mechanismus zeigt und dass darüberhinaus auch die zeitliche Frequenzabhängigkeit in beiden Fällen gleich ist.

Резюме—Исследовано взаимодействие между цветовыми механизмами Stiles—π_1, π_4, π_5, в случае определенного эффекта кажущегося движения дискретного стимула. Найдено, что этот эффект проявлтяется как междур азличными, так и между одинаковыми π механизмами, и, более того, что он имеет ту же самую частотно-временную зависимость в каждом случае.