
Making Mayhew and Frisby effortlessly discriminable

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Abstract. Mayhew and Frisby (1978) demonstrated that patterns which differ markedly in their spatial-frequency content may be very hard to discriminate. This they took as evidence against any model which proposes that the processes underlying texture discrimination have direct access to some local piecewise Fourier analysis of the patterns performed by spatial-frequency channels. It is shown that Mayhew and Frisby's patterns can be discriminated easily if their components have been incorporated into a pattern-contingent colour aftereffect. This demonstration suggests that the location in the visual pathway for contingent aftereffect adaptation must lie before the construction of the raw primal sketch, to which, according to Marr, we have conscious access. This location must also allow the orientation specificity seen in the aftereffect. This points to a locus in the striate cortex.

1 Introduction

Although the processes behind texture discrimination by the human visual system remain obscure, there can be little doubt that the earliest parts of the visual pathway comprise spatial-frequency-tuned channels. It has been proposed that these channels may allow the local piecewise Fourier analysis of the visual scene and that higher visual processes may have direct conscious access to the outputs of these channels. This appears to be a widely held belief in some quarters. For example, Campbell (1980, page 7) writes of three pictures of a tank filtered to pass low, medium, and high spatial frequencies only:

“An enemy soldier would be most interested in the low-frequency components, and having established that a tank is approaching him, will turn his attention to survival in the undergrowth. The tank troop commander, however, will be most interested in the intermediate frequency components, which reveal the tank type and number, while the sergeant of the maintenance wing will examine the high-frequency components for signs of damage to the trackwork.”

Campbell's position, that we have direct conscious access to the outputs of spatial-frequency channels, is far from unique; statements of the same tenor, if usually less blatantly stated, are ubiquitous throughout the literature. For example, consider this passage from Blakemore and Nachmias (1971, page 173):

“One obvious function for such neurones [orientation-selective units] is that they actually encode the orientations of parts of retinal images and thus contribute directly to form perception.”

This general position was attacked most strongly by Marr (1982), who emphatically rejected the notion that we have conscious access to processes prior to the level of the raw primal sketch; specifically he rejected the idea that there is conscious access to the zero-crossing information from which the raw primal sketch is constructed. He cited Harmon's pixelated picture of Abraham Lincoln (Harmon and Julesz 1973) as evidence for his position; the zero-crossings in the lower spatial channels which represent Lincoln's face are adequately accounted for by the zero-crossings which occur in the

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higher frequency channels. Hence the sharp-edged blocks are perceived but the low-frequency face remains hidden. If the higher frequency information is removed by our blurring the picture or by screwing up our eyes, then the low-frequency information may be dissociated from the zero-crossing information contained within the high-frequency channels, and Lincoln's face emerges.

Compelling evidence for Marr's view came from Mayhew and Frisby's (1978) elegant study on the discrimination of simple textures. In these experiments, subjects were presented with a texture discrimination task. Each stimulus had three identical quadrants and one of a different texture. The subject's task was to identify the odd quadrant. The textures used were made up of one, two, or three sine-wave gratings. When the discrimination required was between textures comprising single gratings presented with a 30° difference in orientation between the gratings in three quadrants of the pattern and the grating in the fourth quadrant, discrimination was 'effortless'; the odd quadrant was identified within 1–2 s (see figure 1a). However, a texture comprising three sinusoids at angles of (say) 15° , 75° , and 135° could not be effortlessly discriminated from an identical pattern rotated through 30° , ie with components at 45° , 105° , and 165° (see figure 1b). Such a discrimination took Mayhew and Frisby's subjects nearly 7 s.

Mayhew and Frisby's interpretation of these findings was that any model which proposed some local piecewise Fourier analysis of the textures by the visual system would predict that the discrimination of the three-component textures would be trivial because these patterns consist of widely separated pure sinusoids. However, a model which proposed that the mechanisms of texture perception have access only to Marr's primal sketch and not to the more peripheral spatial-frequency channels, would correctly predict that effortless discrimination would not occur with the three-component pattern. Thus, although the different quadrants have very different Fourier spectra, these differences are largely lost in the primal sketch, where 'assertions' about the presence of 'blobs' of various sizes and contrast are held.

If Mayhew and Frisby's interpretation of their findings is correct, then texture discrimination may be used as a tool to determine the locus within the visual pathway of

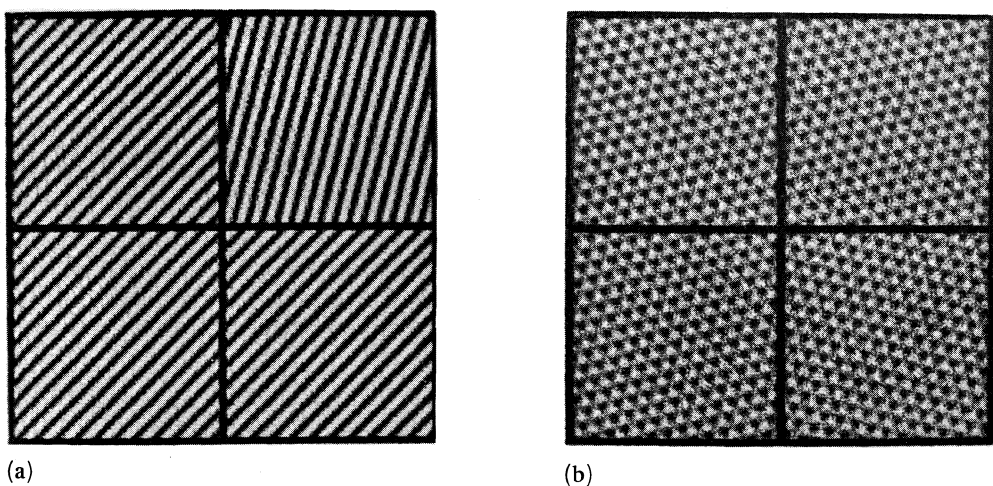


Figure 1. Examples of the stimuli used in the experiment. Subjects have to select the quadrant that is different to the other three. (a) An effortless discrimination task. The patterns are single sinusoidal gratings, differing in orientation by 30° in one quadrant (top right). (b) A more difficult discrimination task, with a three-component stimulus. Three of the quadrants comprise gratings at 15° , 75° and 135° , the odd quadrant (bottom-right) has components oriented at 45° , 105° , and 165° .

various phenomena. Consider the McCollough effect, in which adaptation to alternating red vertical and green horizontal gratings leads to a subsequently seen black and white vertical grating appearing tinged with green and a horizontal grating tinged with pink. Some features of this effect suggest a peripheral locus, for example its orientation tuning (Fidell 1970) and its dependence on the wavelength rather than the colour of the adaptation patterns (Thompson and Latchford 1986). Other aspects, particularly the astonishing duration of the aftereffect (eg Jones and Holding 1975), suggest a more central locus.

Fidell (1970) demonstrated that the colour aftereffect could be made contingent upon gratings whose orientations differed by less than 90° ; indeed adaptation to red vertical gratings alternating with green gratings oriented 22° from vertical produced a full-strength orientation-contingent colour aftereffect. In Mayhew and Frisby's three-component texture discrimination each component of one pattern differed by 30° from the nearest orientation present in the other pattern. Therefore it should be possible to adapt to the components of one pattern against a red background and to adapt to the components of the other pattern against a green background with the result that one pattern will appear tinged pink and the other tinged green after adaptation. This colour difference could then provide the basis for the effortless discrimination of the patterns.

2 Method and procedure

Sixteen undergraduates naive as to the aims of the experiment acted as subjects. They were randomly assigned to two groups of eight. All the texture discrimination stimuli were copied from Mayhew and Frisby's original stimuli. These were displayed in a tachistoscope and latencies for the discrimination of the odd quadrant were measured by a Camden Instruments timer/counter 565. In the preadaptation test, all subjects were shown sixteen stimuli with the instruction to identify, as rapidly as possible, the odd quadrant in each figure. Four of these stimuli involved the three-component discrimination shown in figure 1b. The remaining twelve stimuli required the discrimination of simpler one- and two-component sine-wave patterns with one quadrant rotated by 30° from the other three. All the sinusoidal components within all stimuli were of spatial frequency $2.2 \text{ cycles deg}^{-1}$. These simpler discriminations served to familiarise the subjects with the discrimination task without undue practice with the three-component patterns. The location of the four three-component cards within the sequence was randomised, but the first three presentations were constrained to be examples of the one- and two-component discriminations. Latencies were obtained for all presentations but only the latencies to the three-component stimuli were analysed.

The adaptation stimuli were back-projected slides of high-contrast sine-wave gratings of $2.2 \text{ cycles deg}^{-1}$. The black and white slides were projected through either a red (Wratten no 26) or a green (Wratten no 55) filter. Half of the experimental group saw the following sequence of slides:

red 15° –green 45° –red 75° –green 105° –red 135° –green 165° .

Each slide was presented for 3 s, with 1 s of darkness between each presentation. The whole sequence was continued for 30 min. The other half of the experimental group saw the same sequence of slides but with the red and green filters reversed. The control group was exposed to 30 min adaptation to red and green homogeneous fields, alternating at the same frequency as in the experimental group adaptation. For half of the control group the first homogeneous field was red, for the rest it was green.

All subjects returned to the tachistoscope for the second texture discrimination task 2 min after the adaptation period ended. Subjects were first shown a black and white discrimination card requiring the simple discrimination of a single sinusoidal grating at 45° from a sinusoidal grating at 15° . All the experimental subjects performed the task

effortlessly and reported that the gratings appeared tinged with colour, appropriate for an orientation-contingent colour aftereffect. All the control subjects also made the discrimination effortlessly but there were no consistent colour reports. This test confirmed that the adaptation procedure had produced a robust McCollough effect in the experimental group. All subjects were now shown four three-component discrimination slides (figure 1b) in random order. In each slide one quadrant was different. Discrimination times were recorded for all subjects.

3 Results

The results are shown in figure 2. Only the times to discriminate the three-component textures were of importance to the experiment. Before adaptation the mean discrimination times for the four exemplars of this stimulus type were 4.30 and 4.02 s for the experimental and control groups respectively. After adaptation the mean discrimination times for the same stimuli were 1.22 and 3.55 s for the experimental and control groups respectively. A split-plot analysis of variance (Kirk 1968) was performed on the data. This revealed that there was no significant main effect of group ($F_{1,14} = 2.40$, $p > 0.05$), but there was a significant main effect of test condition ($F_{1,14} = 28.12$, $p < 0.01$). The interaction was also significant ($F_{1,14} = 11.57$, $p < 0.01$). The nature of this interaction was investigated further by a test of simple main effects. This revealed that there was no difference between experimental and control groups in the pretest ($F < 1$) but there was a difference in the groups after adaptation ($F_{1,14} = 8.11$, $p < 0.02$).

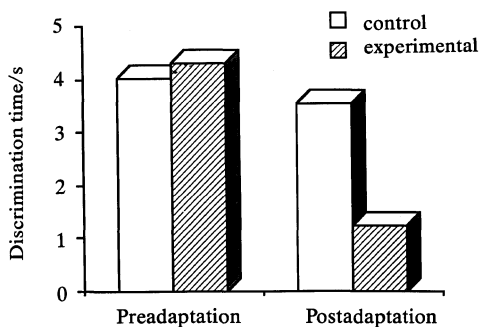


Figure 2. Mean discrimination times for three-component textures for control and experimental groups, before and after adaptation. ($n = 8$ in each group.)

4 Discussion

These experimental findings bear directly upon the question of the site of adaptation in the McCollough effect. Presumably adaptation must occur at a stage in the pathway before the information explicitly available in the spatial channels has been lost in the computation of the raw primal sketch. Marr's descriptions of the raw primal sketch suggest that it is computed directly from the output of the spatial-frequency channels which appear to have their physiological existence in the neurons of the striate cortex. Given that this is the earliest point in the human visual system at which orientation selectivity is found, it would then appear that the locus of the McCollough effect can be tied down to this point in the visual pathway. This agrees with other reports (eg Thompson and Latchford 1986) which suggest a relatively peripheral locus for McCollough adaptation.

If we accept Marr's position on the availability of the activity of spatial channels to conscious processing, or rather the lack of it, we can point to the probable locus of the McCollough effect adaptation. However, the results themselves do not provide any

evidence on whether Marr's position is correct. Our experiment may be of little help, also, in determining how colour information is combined with information in the raw primal sketch. In Marr's own work there are few clues to the role he envisaged for colour. In the course of the 'Socratic dialogue' at the end of his book (Marr 1982, page 352) the Marrian antagonist enquires:

"You mean if a raw primal sketch process finds an edge, and a color process finds its color, the relation between the two is implicitly available? I don't quite follow."

Marr's protagonist replies in a fashion which suggests that colour processes are separate from the descriptors of the raw primal sketch. These are tied together, "though only implicitly", at the $2\frac{1}{2}$ -D sketch level, and do not become fully tied together until the construction of the 3-D sketch.

Finally, the present findings do open the way for one intriguing experiment, suggested to us by 0 J Braddick. If we were to adapt to the high-spatial-frequency content of Julesz and Harmon's pixelated Abraham Lincoln viewed in red light and the low-spatial-frequency content in green light, would we then be able to discriminate effortlessly a pinkish face of Lincoln peering out from behind a greenish graticule?

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