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Monocular lustre from flicker

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Abstract

A spot that flickers at 16 Hz between two luminance levels (on a grey surround) has an appearance of metallic lustre, which we call 'monocular lustre'. Binocular and monocular lustre were measured in comparable conditions by a rating procedure, and both were reported only when the light and dark values of the flickering (or binocularly fused) spot straddled the surround luminance, so that the spot was alternately brighter and darker than the surround. We attribute lustre to competition between ON and OFF visual pathways. © 2000 Published by Elsevier Science Ltd.

Keywords: Flicker; Brightness perception; Binocular fusion; Binocular rivalry; Lustre

1. Introduction

How does the visual system combine two luminances? We have previously reported (Anstis & Ho, 1998) that the changes in apparent brightness that are induced into a spot by a surround can be greatly enhanced either by flickering the test spot between two luminances, or by binocularly fusing a pair of spots of different luminances. Thus a mid-grey spot looks light grey on a dark surround, and dark grey on a light surround (Heinemann, 1955; Whittle, 1992a,b), but a black/white *flickering* test spot looks almost white on a dark surround and almost black on a light surround. (For precursors of some of these findings see Harvey, 1970; Corwin & Giambalvo, 1974; Magnussen & Glad, 1975a,b,c). The reason is that the phase of the flickering spot that differs more from the surround is over-weighted by the visual system. On a light surround the black phase is much more salient than the white phase, so the black phase is over-weighted and the spot looks almost black. On a dark surround the white phase is more salient and the flickering spot looks almost white. Similarly, when spots of different luminances are binocularly fused, the spot that differs more from its surround is over-weighted. We measured (Anstis & Ho, 1998) the combination rules for pairs of luminances which were presented either successively as flicker or else dichoptically (and fused binocularly). The brightness averaging functions for spatial increments (light spots) on dark surrounds were quasi-linear for binocular fusion but quadratic for flicker. For spatial decrements (dark spots) the brightness averaging functions were strongly nonlinear winner-take-all functions for both binocular fusion and flicker. We concluded (Anstis & Ho, 1998) that the visual rules for combining luminance excursions, whether in flicker or binocular fusion, favour disproportionately the spot with the higher contrast.

In this paper we study a *failure* of pairs of luminances to combine. We find that a flickering spot sometimes has an oddly metallic, shimmering or lustrous appearance, similar to the well known 'binocular lustre' that is seen during binocular rivalry (von Helmholtz, 1909/1962; Wolfe, 1986; Blake, 1989; Lehky & Blake, 1991; Logothetis, Leopold & Sheinberg, 1996; Logothetis, 1998). This is probably identical to the descriptions by Magnussen and Glad (1975a,b,c) of an overlay of pulsating light and dark perceived in flickering spots. We asked our observers to make magnitude estimates of this metallic lustrous appearance of a spot, which we call 'monocular lustre'.

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2. Method

Observers viewed a flickering stereo display of little square grey spots on a grey surround. The spots were presented on a computer-controlled monitor screen (Anstis 1986; Anstis & Paradiso, 1989) and were fused binocularly by means of a prism stereoscope equipped with a septum. Two spots from the display are diagrammed in Fig. 1a, with time plotted as running into the page. The upper spot is light in one eye and dark in the other, leading to binocular lustre and/or binocular rivalry, but it does not change physically over time. The lower spot is the same for both eyes, but it flickers or alternates over time at 16 Hz between light and dark, leading to the phenomenon that we call monocular lustre. Observers were asked to rate the perceived magnitude of both the binocular and monocular lustre.

In practice we used not two black and white squares (Fig. 1a) but two separate rows of five grey squares (Fig. 1b). Each square subtended 0.75° and was separated from its neighbours by 0.75°. When one row was fed to each eye and fused binocularly (left hand labels in Fig. 1b) each square had a different luminance in each eye, which tended to yield binocular lustre. During flicker (right hand labels in Fig. 1b) the same two rows of squares were presented in temporal alternation at 16 Hz, with both eyes seeing the same flickering squares, which tended to yield monocular lustre.

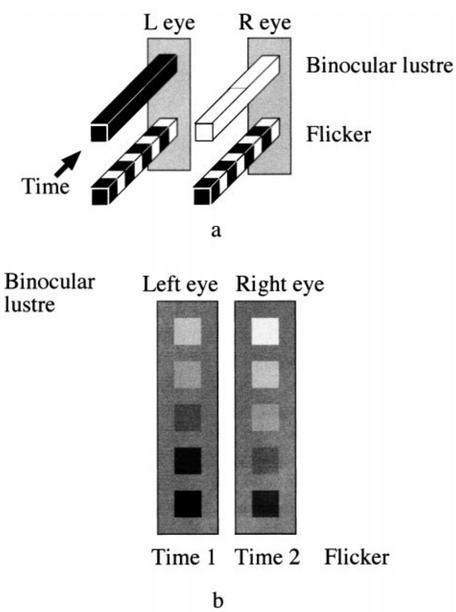

Fig. 1. (a) Stimulus to demonstrate binocular and monocular lustre. When fused binocularly in a stereoscope, the upper spot was light in one eye and dark in the other, yielding binocular lustre (and also binocular rivalry). The lower spot was always the same in both eyes but flickered between two different luminance levels, yielding a metallic appearance which we call monocular lustre. (b) In the binocular lustre condition (left-hand labels), each eye was presented with a row of five squares, whose luminances were different in the two eyes. Only one square, in this case the middle square, was a spatial increment in one eye and a spatial decrement in the other eye. This was the square that showed binocular lustre. In the flicker condition (right-hand labels), the same set of squares was presented in alternation at 16 Hz. Only one of the flickering squares, in this case the middle square, was alternately a spatial increment and a spatial decrement. This was the square that showed monocular lustre. Greys are not reproduced accurately in this figure.

We express all luminances as percentages of the maximum output of the monitor screen, which was 229 cd/m^2. Six grey levels were selected for the spots, namely 15, 21, 30, 42, 60 and 84%, which were equally spaced on a logarithmic scale and 0.15 log units (a factor of $\sqrt{2}$) apart. In the flicker condition, each spot alternated between two adjacent luminances within this range, so the first square alternated between 15 and 21%, the second between 21 and 30%, and so on (Fig. 1b). In the binocular fusion condition, the first square had a luminance of 15% to one eye and 21% to the other eye, the second square had a luminance of 21% to one eye and 30% to the other eye, and so on. So in the flickering row, two luminances alternated over time to yield monocular lustre, whilst in the binocularly fused row the same two luminances were presented one to each eye, with no changes over time, to yield binocular lustre. The display of ten squares was replicated on five fixed surrounds of luminance levels 18, 25, 35, 50 and 70%. These luminances are chosen to be interleaved between the spot luminances. On the surround shown in Fig. 1b the middle square reverses in contrast over time or across eyes. On a darker (lighter) surround it would be a darker (lighter) square that reversed in contrast.

The observer's task was to make numerical ratings on a scale from 0 to 10 of the subjective lustre of the flickering or binocularly fused test spots. There were 50 spots in the display (five spot luminances $\times$ five surround luminances $\times$ two modes of alternation). Also, to reduce left/right biases, the display was flipped left to right and also switched across eyes on the second trial run. Four observers were run, of whom three were naïve to the purpose of the experiment, and each observer made two judgements of each square.

3. Results

Results are shown in Fig. 2 (mean of four observers $\times$ two trials). The data curves have been slid sideways to bring the polarity-reversing luminances of each spot into coincidence. The rated lustre peaks sharply at this value, both for monocular and binocular lustre. Each spot yields a set of data points whose heights indicate the rated lustre, with each curve normalized to a maximum of 10. The abscissa is the ratio of the mean spot luminance to the surround luminance. Vertical lines show $\pm$ 1 SE.

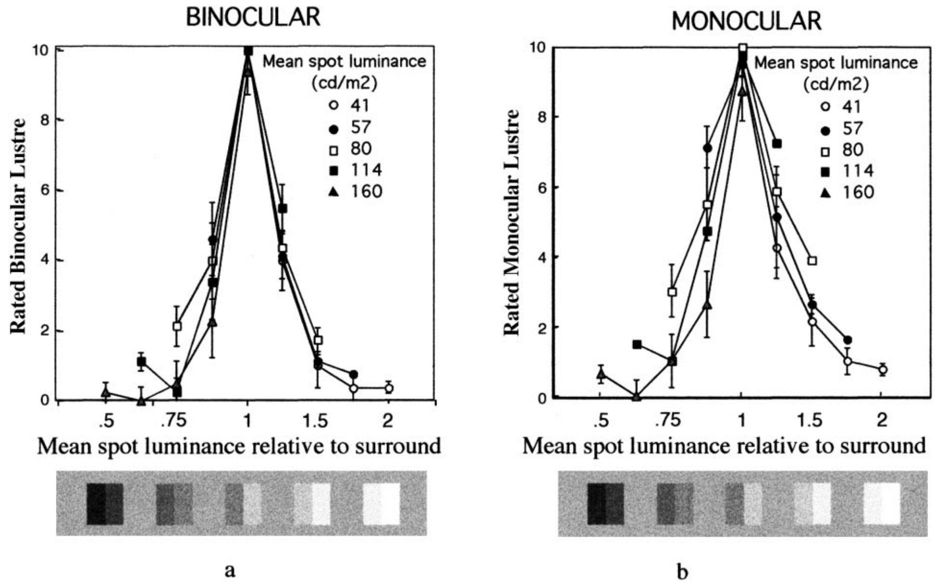

Fig. 2. Binocular lustre peaked when the fused spots seen by the left and right eye had opposite polarities, being lighter than the surround in one eye, darker in the other. Correspondingly, monocular lustre peaked when the flickering spot changed polarity, being alternately lighter and darker than the surround. The curves have been normalised to a maximum of 10 and slid sideways into superimposition. See text.

The important finding is that the rated lustre, both binocular and monocular, peaked sharply for each curve when the two luminance values of the alternating spot straddled the surround's luminance value. Thus, for a spot to show monocular or binocular lustre it had to reverse its brightness polarity repetitively, becoming alternately a spatial increment and a spatial decrement. Results were similar for monocular and binocular lustre.

Clearly it is the contrast reversal of the spot that makes it appear lustrous, in both the monocular and binocular conditions. Peaks were somewhat sharper for binocular than for monocular lustre.

4. Discussion

We regard monocular lustre as the temporal analog of binocular lustre. Both occur under similar conditions, namely during contrast reversal, when opposite luminance polarities have been combined either across eyes or over time. We conjecture that a flickering spot stimulates an ON pathway while in its spatial increment phase, and a separate OFF pathway while in its spatial decrement phase (Schiller, 1992), and we attribute monocular lustre to rivalrous competition between the ON and the OFF pathways.

We found in our earlier paper (Anstis & Ho, 1998) that when a spot flickers between two luminance phases of the same polarity, a weighted average is perceived in which the higher contrast phase is greatly overweighted. We now find that when the two phases are of equal contrast but opposite polarity, both phases are given equal weight and perceived simultaneously, giving a percept of lustre. In pilot experiments (not shown here) we also used phases of *unequal* contrast but opposite polarity. For instance, when a spot alternated between 45 and 90% on a 50% surround, its mean luminance looked close to 90%, so the high contrast 90% phase was overweighted. But the spot still looked lustrous and never showed any slow rivalrous changes. Thus it is the polarity reversal, not equal contrast of the two phases, that is responsible for monocular lustre.

Monocular lustre can be compared with three other flicker-related phenomena, namely increased sensitivity to flicker (Harvey, 1970), the crispening effect (Whittle, 1992c) and brightness- and darkness-enhancement (Corwin & Giambalvo, 1974; Magnussen & Glad, 1975a,b; Glad, Magnussen & Engvik, 1976). Although all of these occur specifically when the two phases of a flickering post straddle the surround luminance, we believe that monocular lustre can be distinguished from all of then.

1. *Increased sensitivity to flicker*. Harvey (1970) found that when a grey test spot was centered in a slightly lighter steady grey surround, the spot was apparently darkened by the surround, but the threshold for flicker was reduced (sensitivity increased) if the spot's flicker straddled the surround luminance. Increased sensitivity to flicker is a threshold effect, and has no known binocular analog. So it is not the same as lustre.

2. *Crispening effect*. Whittle (1992c) asked observers to adjust the luminances, L, of 16 or 25 circles, all visible at the same time on a computer monitor, to make equal-interval brightness series. The background

was black, white or grey. The luminance steps between adjacent circles showed a sharp minimum at the background luminance, Lb: the 'Crispening Effect'. The effect was abolished by a thin outline or a hue difference between circles and background.

Stated differently, consider five panels of 0.1, 0.2, 0.3 and 0.4 log units of luminance, which look equally spaced in brightness. If placed on a surround of 0.25 log units, then crispening will make the brightness step between 0.2 and 0.3 look much greater than the other steps. Emerson and Semmelroth (1975) attribute crispening to competition, in the form of mutual-shunting-feedback inhibition, between target and surround. Crispening does not depend upon alternation, but occurs in stationary displays. So crispening is not the same as lustre.

3. *Brightness enhancement*, also known as the Broca–Sulzer phenomenon, refers to the fact that a target may appear up to five times brighter when flashed than when viewed continuously (see Brown, 1965; van de Grind, Grüsser and Lukenheimer, 1973).

Corwin and Giambalvo (1974) found that a target looked 2.17 times as bright when flashed once for 70 ms as when viewed continuously. A dimmer target, or the same target that looked apparently dimmer because it was embedded in a luminous surround, gave lesser brightness enhancement. Magnussen and Glad (1975a,b) and Glad et al. (1976) also examined the effect of steady surrounds upon brightness (and darkness) enhancement of a 1° target that flickered at rates between 0.5 and 20 Hz. The observer's task was to match the light phases ('brightness' matches) or dark phases ('darkness' matches) to a 0.4 s comparison 'flash' presented every 2 s. These comparison flashes were either positive (an increase in luminance) or negative (a decrease in luminance) or zero, and were controlled by the observer. Both lightness and darkness enhancement peaked at a flash rate of 5–6 Hz, but darkness enhancement was more than twice as great as brightness enhancement. Moreover, the brightness and darkness enhancement studied by these authors, like our monocular lustre, were maximum when the light and dark phases of the flickering target straddled the steady luminance of the surround.

Brightness and darkness enhancement can apply separately to the appearance of the bright phase and of the dark phase of flicker, whereas lustre requires both. Also, monocular lustre has a binocular analog (namely binocular lustre) but brightness and darkness enhancement have no known binocular analog. We conclude that monocular lustre is not the same phenomenon as brightness or darkness enhancement.

Monocular lustre can also be profitably compared with various forms of rivalry that have been described in the literature, namely binocular, monocular and motion rivalries (Breese, 1899; Campbell, Gilinsky, Howell, Riggs & Atkinson 1973; Crassini & Broerse, 1982; Georgeson, 1984; Burr, Ross & Morrone, 1986; Bradley & Schor, 1988; Logothetis et al., 1996; Dayan, 1998; Logothetis, 1998).

The subjective difference between lustre and rivalry is that during lustre *two* different luminances are seen simultaneously in the same position. In binocular lustre the two luminances come from the two eyes, and in monocular lustre they come from the two phases of a flickering spot. In binocular rivalry, on the other hand, two luminances are seen in slow alternation, not simultaneously. Specifically, a rivalling patch appears to alternate every few seconds over time between the two different luminance (or colors, or textures) seen by each eye. Small patches tend to change all of a piece, whilst larger patches alternate in independent patches.

Where in the visual pathways does this slow rivalrous alternation occur? Recordings have been made from monkey visual neurons during binocular rivalry (Logothetis et al., 1996; Logothetis, 1998), while the monkey was pulling levers to indicate its perceptual state. Many cells in V1 remained active during perceptual suppression. The neurons that were affected by suppression were almost exclusively binocular, and were mostly in higher processing stages of the visual system, predominantly in the temporal lobe. Logothetis et al. concluded that the competition during rivalry is not interocular but is between the two different central neural representations generated by the dichoptically presented stimuli. Dayan (1998) proposed a hierarchical model of binocular rivalry based upon this competition between top-down cortical explanations for the visual inputs.

Several studies (Breese, 1899; Campbell et al., 1973; Crassini & Broerse, 1982; Georgeson, 1984; Bradley & Schor, 1988) have found that 'monocular rivalry' can occur during inspection of a static grid of two orthogonal, coarse light/dark sinusoidal gratings of different colors. The percept is alternately dominated, for example, by vertical red stripes or horizontal green stripes (Campbell et al., 1973). Two explanations have been proposed. The first suggests that the alternating perceptual dominance of vertical and horizontal reflects some inherently unstable neural interactions — a competitive 'rivalry' — between orientation selective cortical neurons. The other explanation regards monocular rivalry as an artifact based upon afterimages and eye movements (Crassini & Broerse, 1982; Georgeson, 1984) and the conflict between these two explanations is still unresolved (Bradley & Schor, 1988).

Monocular lustre is not the same as monocular rivalry. In crossed gratings viewed monocularly, the rivalling contours are orthogonal and are seen in slow alternation, but in our monocular lustre the rivalling contours are congruent but of opposite brightness polarity and two brightness levels are seen simultaneously. We attribute monocular grating rivalry to competition between orientation detectors, but monocular lustre probably arises from competition between ON and OFF pathways that respond to contours in identical positions, but of opposite polarity.

Burr et al. (1986) reported 'motion rivalry' in a plaid consisting of a superimposed vertical and horizontal sinusoidal grating. (The term 'motion lustre' might be better). When this plaid was flickered in counterphase at 10 Hz it looked like a lattice of hard-edged diagonal lines forming lustrous diamond-shaped shimmering elements. This lustre was akin to binocular lustre or rivalry (von Helmholtz, 1909/1962). A counterphasing grating is equivalent to two gratings sliding over each other in opposite directions, and Burr et al. (1986) attributed the diamond illusion to mutual inhibition generated when detectors of opposing directions are simultaneously stimulated. This generates a form of 'rivalry' which gives rise to the impression of lustre. The authors speculate more generally, and we concur, that lustre is vision's response to two conflicting signals from one region of the visual field.

All these phenomena — monocular lustre, monocular grating rivalry, and motion rivalry — seem to involve competition between neural detectors which signal incompatible values of some visual property (orientation, direction of motion, luminance polarity) from a given region of the visual field. Instead of seeing some average or compromise value of the visual property, one sees the two incompatible values simultaneously during lustre, and in slow temporal alternation during rivalry. Binocular rivalry has been studied for more than a century (von Helmholtz, 1909/1962; Wolfe, 1986; Blake, 1989; Lehky & Blake, 1991; Logothetis et al., 1996; Logothetis, 1998) and has often been regarded as an isolated oddity, but these newer phenomena suggest that competitive rivalry may be widespread throughout the visual system.

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