

## Short Communication

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### The eyes of man as a photic bisensor system

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Non-patterned photic stimulation of the eyes of human subjects was obtained by homogeneous illumination of the closed eyes. The subjects perceived a difference between the stimulation intensity of the left and of the right eye as a field of view consisting of a bright and a dark half, adjoined across an indeterminate vertical midline. It is not clear which parts of the visual system mediate the residual perceptual functions that survive this stimulatory reduction of man's eyes to a photic bisensor system. It is argued that animals with side-set eyes might use this perceptual ability for photic orientation in an anisotropic light field.

Elaborate schemes for classifying orientational responses have been developed on the basis of the type of stimulus, the type of response, and the arrangement of the relevant receptors. For tropotaxis the organism must be provided with two sense organs (sensors, see Schöne, ref. 22) which are so arranged that they are not equally strongly stimulated in most of the positions that the organism can adopt. According to the tropism theory of Loeb [16] the central nervous system strikes a balance between the inputs from the two sense organs, for instance the eyes. Loeb's idea that an organism therefore moves straight towards or straight away from a light source was adopted by Kühn [14], Fraenkel and Gunn [6], and Jander: basotaxis (in ref. 13). It is doubtful, however, whether basic directions or positions actually exist (see ref. 22, pp. 68–69). From a cybernetic point of view it seems more likely that an animal selects any appropriate position or direction on the basis of a predetermined difference between the stimulation intensities of the two sense organs (bisensor system, ref. 22). The fact that an organism in which one eye is put out of action keeps turning towards one side (circus or manege movements) would result from the organism's inability to establish the ratio of stimulation intensities which corresponds to a selected orientation (open-loop condition of the control system).

The question of whether organisms actually can and do perceive the amount of light falling on each of their eyes, and whether they transmit the relevant information to integration centres has, however, been frequently ignored. The more frontal-eyed a species is, and the greater the overlap between the unocular fields and the fewer the fibres that cross at the optic chiasm, the less likely it is that there will be any difference between the stimulation intensities of the left and the right eye, and the poorer will be the information processing underlying the transformation of such a quantitative difference in stimulation into a 'brightest direction'. Consequently man might not be a very suitable subject for the study of this type of perceptive or orientational ability. A human subject can, however, indicate or describe whether and how he perceives a difference between the stimulation intensity of his left and right eye, whereas for obtaining similar data from an animal a rather sophisticated training procedure would be necessary. Therefore we decided to test whether a stronger stimulation of, for instance, the right eye is perceived as an entirely bright field of view, or as a field of view which is brighter at the right side.

We used two simple set-ups for stimulus presentation. In both set-ups the subject's eyes were closed and his eye-lids fixed with plaster in order to eliminate configurational visual stimulation, to ensure homogeneous stimulation of each single eye, and to prevent any directional cue from being received by each eye. Thus we also eliminated the visibility of the nose and other parts of the face around the eyes (ref. 7, Fig. 7. 1), and we avoided any non-coincidence of the borders of the fields of view of the two eyes such as might occur when a person looks through some tubular optical instrument.

In the set-up with screen the subject sat in front of a homogeneously illuminated screen of opaline perspex (homogeneous luminance  $100 \text{ cd/m}^2$ ). The screen was 50 cm broad and 40 cm high, and was divided into two equal parts by a wooden partition which was fitted against the subject's forehead and nose by means of a plastic foam cushion, and which extended to the screen. The screen was illuminated from behind by a 75 W incandescent light bulb (Philips Photocrescenta) mounted in a box lined with crinkled aluminium foil. A difference in the stimulation intensity of the left and the right eye was obtained by shading one half of the opaline screen with an opaque mask.

In order to prevent the subject from deriving acoustic or other information from the experimenter's manipulations this mask took the form of the half of a double mask with the same dimensions as the opaline screen. Four double masks – (1) both halves clear; (2) both halves opaque; (3) right half clear, left half opaque; and (4) left half clear, right half opaque (i.e. the third mask reversed) – were placed over the screen in random order and in the dark. After the placing of a given mask the light was switched on for 5 sec, and the subject was instructed to indicate verbally whether his field of view was bright, dark, bright at the right, or bright at the left. Subjects took part in one 20 min session which consisted of

30 presentations, during which the uniformly clear and the uniformly opaque mask were used 5 times each, and the clear/opaque masks 10 times each. Subjects were of the laboratory population. In the projector set-up similar stimulation situations were produced by means of a 35 mm film slide-projector and 4 slides consisting of two halves in the combinations described above for the masks in the screen set-up. A given slide was projected on the subject's face and closed eyes such that the border between the two halves of the slide fell on the subject's nose. In both set-ups the opaque part of the mask or the slide could be replaced by a grey filter (Agfa Gevaert; neutral density 0.5; transmission for 'red'  $\pm 28\%$ ). Originally we planned to run 10 sessions with each stimulus situation, but the results of 10 sessions with the screen set-up using masks with opaque material, and 4 sessions with the projector set-up – 2 with slides with opaque material and 2 with slides with grey filter – showed already that the perceptive task was an easy one, since no incorrect responses were recorded (total number of responses 420).

We conclude that human beings are able to perceive a difference between the photic stimulation intensity of their left and right eye. On the basis of reports of subjects and personal observations the perception can be described as follows: the moment the light is switched on a vaguely contoured disc-shaped field of view flashes on, with a reddish colour. When the right eye is more intensely stimulated, the brighter right and the darker left half of the reddish 'disc' are joined across the indeterminate vertical midline. The phenomenon shows some characteristics of after-images and stabilized retinal images such as blur, fragmentation and fading. After the 5-sec stimulation period a weak positive 'after-image' is sometimes perceived. If after the subject's prolonged exposure to the stimulus situation (light on for 10–20 sec) both eyes are stimulated equally strongly, a clear negative 'after-image' appears: the left half of the field of view is bright and the right half dark, and both halves are adjoined once more across the vertical midline. When the subject now moves his closed eyes to the left or to the right, this vague transitional zone between the bright and the dark half of the field of view moves in the same direction and roughly over the same angle. Although we did not intend to determine a threshold stimulation situation, it appeared that a filter with neutral density 0.1 (transmission for red  $\pm 65\%$ ) still elicited the perceptual phenomenon. The phenomenon can easily be observed by 'looking' with closed eyes at the sun or at the sky, then by shading one eye for 5–10 sec – it will be difficult to exclude all stray light from the shaded eye – and finally by leaving that eye again unshaded.

Because of the difference between the stimulation of the left and right eye our method might be considered to be a dichoptic method, and, consequently, binocular rivalry might be thought to affect the perception of the combined binocular stimulation. However, dichoptic stimuli usually show local luminance profiles representing rival spatial contrasts such as dots and lines, whether or not these are assembled into more complicated configurations like edge, bar or pattern, and such spatial contrasts are absent in our stimulation method. Although 'rivalry

in lightness' has been described [1] this is best brought out with contoured stimuli, such as a white circular target seen via one eye and a black one via the other. Our inability to discriminate whether a given percept is the result of the stimulation of the left eye or of the right eye is an obvious feature of the binocular perception of configurations, both with non-conflicting stimuli (binocular fusion) and conflicting stimuli (binocular rivalry).

It would be of considerable interest if we knew which peripheral and central portions of the visual system are involved in the described perception. However, the current classification of retinal ganglion cells has led to a profound controversy about whether a natural or functional grouping should be based on only a few or on 'all' cell properties (see refs. 11, 18, 19; see also ref. 9). On the basis of 'role-indicating' and other variations in the properties of cat retinal ganglion cells Rowe and Stone [20] suggest a two-level classification that might also be applicable to some primates: X and Y cells would subserve 'conscious' or 'foveal' vision – pattern vision and movement vision respectively – and W cells 'ambient vision'. 'Two visual systems' hypotheses have been proposed in various forms: ambient and focal [23], locating and identifying [21], noticing and examining [29], orientation and evaluation [12], localization and form discrimination [15].

With respect to the central portions of the visual system, divergent mapping techniques have revealed in all visual systems studied recently in primates, multiple topographic monocular and binocular representations of the two visual hemifields, but not of each single eye (reviewed in refs. 2, 8, 17, 31). Moreover, most theories of vision have emphasized the classical retino-geniculo-cortical system, and have identified this system with spatial stimulus attributes such as contrast, pattern and contour. Several investigators have maintained either implicitly or explicitly that for discriminating tasks animals – at least mammals – rely either on such 'spatial' cues or on 'diffuse' or 'intensity' cues, and that the responses to these two classes of stimuli are mediated cortically or subcortically respectively. That non-spatial 'diffuse' cues are often inadequately specified is exemplified in the experiments of Blochert et al. [3]. A rat wearing light-diffusing translucent occluders was trained to perform a 'light-dark' discrimination in a 'choice area' in the apparatus while its head was between two cue panels with different luminances. Since this is precisely the stimulus situation described in the present report the rats may well have perceived a light field with a bright and a dark direction. Consequently the cues employed by the animal, and presumably mediated by subcortical structures owing to brain surgery, may have been more complicated than the authors suggest.

The degree of bilaterality of the central projections is a major variation at the 'network level' [24] of the vertebrate visual system. Vertebrates with front-set eyes have bilateral visual systems with contralateral projections of the nasal part of each retina and ipsilateral projections of the temporal part of each retina. Vertebrates with side-set eyes and panoramic vision – many fish, amphibians and birds – have monolateral visual systems with only contralateral projections of each

retina as a whole (reviewed in refs. 10, 17, 24). It is easy to visualize that in such an animal a difference between the stimulation strength of the left and right eye can occur, and can lead to the perception of a bright direction, although actual evidence is lacking. For this purpose only the light arriving within the large left and right monocular field might be used. Similarly in a more frontal eyed organism (man) only the light accepted within the monocular crescents might contribute to the described perception of a bright and a dark 'crescent', but this is, of course, pure surmise.

Before we can understand that such an ability might be an adaptive feature of an organism [4] we should try to find out which types of stimuli occur in the natural optic environment. Traditionally three types have been distinguished, at least with respect to higher vertebrates, namely patterned, moving and light stimuli. An implied condition for a moving stimulus is pattern or contrast. Being preoccupied with vision, i.e. the ability to perceive the configurations of contrasts and patterns composing visible things, students of the visual system have not clearly defined the concept 'light as such'. Several experiments using homogeneous retinal stimulation have been reported. From these 'Ganzfeld' observations (reviewed in ref. 7) it has been concluded that 'light as such' is an inadequate stimulation for vision. With respect to its spatial properties 'light' can be defined as a light field with a spatial distribution of 'intensities' (scalar field) and of 'directions' (vector field; see ref. 25, 27). In nature the scalar and the vector field show spatial relationships, so an organism can frequently predict the spatial distribution of light intensities in the surrounding scalar field on the basis of the spatial (angular) distribution of light vectors perceived at a point of observation in the vector field. Thus the organism can select a bright place by moving in a bright direction, and a dark place by moving in a dark direction. Moreover, a bright or a dark direction specifies environmental 'affordances' [7] in that it enables an organism to select locations with invariant combinations such as bright-warm-dry, or dark-cool-humid. The concept light field as used here is related to Gibson's concept 'ambient light': 'ambient light converges to a point of observation'; 'ambient light can be thought of as a set of solid angles having a common apex' (ref. 7, p. 51). However, Gibson was obviously discussing a perceptual system that has a resolving power which is sufficiently high to be attuned to perceiving objects: '...the environment is all these various things – places, surfaces, lay-outs, motions, events, animals, people, and artifacts that structure the light at points of observation' (ref. 7, p. 66). I have argued [25, 26, 27] that orientation systems based on sensitivity to light can be divided into photic systems attuned to scalar and vectorial features of the angular light distribution, and visual systems attuned to configurational features (visible things).

Theoretically photic orientation in an anisotropic light field can be achieved by means of a unisensor, a bisensor, or a multisensor system (cf. refs. 22, 27). With an unisensor system the angular vector distribution can be scanned in order to

find, for instance, a dark direction (klinotaxis: see ref. 6). The results described in the present report demonstrate that a bisensor system can also mediate responses into a bright or dark direction. We found recently [28] that when the teleostean fish *Poecilia reticulata* jumps out of the water it can orient perfectly in the brightest direction of an anisotropic light field with only one eye. This might indicate that the fish perceives the angular vector distribution as an angular gradient and is thus using the eye as a multisensor system or raster. The sensitivity to an angular gradient – the gradual change of luminance with visual angle – has been studied in the human eye [30, 5]. The latter authors found that information about luminance gradients is detected by two different mechanisms: one for low-frequency gradients broader than  $0.5^\circ$ , and another for high frequency gradients narrower than  $0.5^\circ$ , contrasts. They suggest that ‘The world in large is detected by luminance gradients. The world in small is detected by frequency tuned mechanisms’. We suggest that what they call the ‘world in small’ is the world of visible things, and what they call the ‘world in large’ is the world of light fields as far as perceived by a multisensor system.

We conclude that when attempting to explain the peripheral and central contributions to the perceptual performances in vertebrates, which are assumed to rely on residual vision due to peripheral or central disorders or experimental interferences, one should be careful not to overlook the properties of light fields and of the perceptual systems attuned to guiding behaviour in these fields. It should be realized as well that hardly any of these properties have yet been investigated or identified.

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