

EFFECTS OF LIGHT AND LIGHT BEAMS ON BIRDS

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There is considerable disagreement about whether an aircraft-mounted light or a narrow beam would scare birds away, or, conversely, would attract them (Blokpoel 1976., Griffin et al. 1974, Larkin 1976, Yakobi 1978). I should like to discuss this problem with respect to midair collisions between nocturnal migrants and aircrafts. It will be suggested that the phase of the moon and the presence or absence of the moon above the horizon might well be crucial, but so far neglected, environmental variables which affect the outcome of these encounters.

The first step in any warning procedure is to attract the attention or eye of the party concerned. Light can be used for this purpose in two ways. Either a warning notice is brightly illuminated, or a warning is given by directing a bright beam towards the party concerned. In other words a warning can be given by light directed away from or, conversely, towards the party for which the message is intended.

Posters used in advertising in a sense function as "warnings". In a good advertisement the configuration should be such that the message of the poster comes over unmistakably. In behavioural terms the sign stimuli should qualitatively and quantitatively be such that they release the desired behaviour pattern.

In traffic the bright light of the headlamps of a car is in itself meaningless, but it can perform a warning function in that it appeals to the cognitive ability of man to associate the light with a specific danger, and can thus cause him to make an adequate evasive manoeuvre.

Which features of an aircraft-mounted light might signal "danger" to a nocturnal migrant bird, and thus induce an evasive manoeuvre? It is highly unlikely that a "light" conveys any configurational information to a bird. The movement of the light will neither be conspicuous to a bird which is directly in the aircraft's flight-path, because the light is coming straight towards the bird, nor will it frighten a bird by its sudden appearance because the perceived stimulus intensity increases gradually as the light approaches. Apparently, therefore, the only aspect which might determine whether a bird will be indifferent to a light, will approach it or make an evasive manoeuvre seems to be the degree to which the bird perceives the light as "uncomfortably glaring". With respect to the plausible inference that the more powerful a light the more a bird will avoid it, a word of caution: so far, very few people are aware of the tremendous orientational problems which artificial light fields may present to birds and other animals. Since animal orientation systems that use light are adapted in a highly complicated way to the spatial properties of natural light fields, these orientation systems cannot cope with some deviant properties of artificial light fields.

In my view it would be wrong to be unduly optimistic about the outcome of efforts to scare birds away by the use of artificial light. In order to get a more realistic view of the matter it would probably be helpful if I draw some distinctions between the spatial properties of natural light fields and those of artificial light fields. I shall then go on to analyse the ways in which optic orientation systems are adapted to natural light fields, and, finally, show how the unnatural spatial properties of artificial light fields may entail a disorganization of orientation.

Spatial properties of natural and artificial light fields

The angular radiance distribution (ARD)¹ at a given point in a given radiance field is obtained by making a number of measurements in various directions with a suitable detector. A three-dimensional display of the ARD, namely the radiance distribution solid (RDS) is achieved by constructing a surface through the end points of the pseudovectors, whose lengths are proportional to the radiances measured in the various directions by the rotating detector. The shape of the RDS is the result of the interactions of the radiation with the environment which either change the direction of the radiation (scattering; reflection) or decrease its intensity (absorption). Theoretically (Tyler & Preisendorfer 1962) the RDS would gradually change into either a sphere (complete isotropic radiance field) or a needle (extremely anisotropic radiance field: a parallel beam) if only scattering or only absorption were involved respectively (see Verheijen 1978, fig. 1). Because of the contributions made by the various factors that influence beam direction and intensity only a restricted group of RDS's out of the theoretical range of RDS's occurs within the habitat of a given species. I have recently proposed a vectorial measure to quantify the degree of anisotropy of a given radiance distribution: the directivity D (see Verheijen 1978). At a given point in a given radiance distribution the directivity D is determined as follows. Among all pairs of opposite irradiances E_1 and E_2 which can be measured at this point there is one pair that shows a maximum difference $E_1 - E_2$. The radiant vector $\vec{V}_R = \max (E_1 - E_2)$ quantifies the directional properties, or the degree of anisotropy, of the radiance distribution. A measure which quantifies the directional properties independently of the amount of scalar irradiance is obtained by dividing the radiant vector by the scalar irradiance. Thus the directivity $|D| \equiv |\vec{V}_R|/E_0$ is sensitive only to the "form" of the RDS, and not to the "size". Obviously the magnitude of D ranges between zero in an isotropic radiance field and one in a parallel beam.

With the help of the directivity concept two important deviant properties of the light field produced by an artificial light source - and more particularly by a narrow beam - can be demonstrated. The reduction or the elimination of the factors influencing the direction of the rays (scattering and reflection) entails an unnaturally high directivity, and at points above the light the directivity shows, moreover, a vertical component pointing downwards, whereas in natural light fields this component generally points upwards.

Orientational adaptations to the spatial properties of natural light fields

Orientation systems based on sensitivity to radiation (light) can be roughly divided into two categories (see for instance Schwerdtfeger 1977):

1. photic systems attuned to scalar and vectorial features of the natural ARD; and

2. visual systems attuned to configurational features.

This distinction goes back to much older literature. The German biologist Precht (1942), for instance, differentiated between "Phototaxis" (reaction to "light") and "Photocontaxis" (reaction to "visible things").

Although the Bird Strike Committee is concerned primarily with birds, a comparative approach is essential because most of the available evidence relates to animals other than birds. Therefore data on invertebrates

¹ Because neither the spectral distribution of a radiance field nor the spectral sensitivity of an organism are taken into account in this paper it does not matter whether I use the term light or radiance.

- especially insects - and on amphibians, fish, and even man, will also be reviewed.

The nature of the two categories of orientation systems can be illustrated by the contribution that each system makes to one and the same function, namely postural control in fish. Many species of fish tend to orient their dorsal side in the "direction of the light" (von Holst 1935, 1948), as do many aquatic invertebrates and flying insects. In addition to this Dorsal Light Response (DLR) some species of fish show the Ventral Substrate Response (VSR): a tendency to orient their ventral side towards a visible substrate. The mechanism of the VSR differs from the DLR in certain important aspects, for instance the VSR is guided by configurational visual cues representing a substrate, and it operates via a higher level of neural integration than the DLR (Meyer et al. 1976). Unfortunately there are practically no data about these orientation systems in birds.

Photic systems

It must be assumed that photic orientation systems underlying the DLR are attuned to the natural shape and "upright" position of the RDS, or, in other words, to a D showing a natural magnitude and a natural upward direction. I would suggest that this explains why sardine-like fish predominantly concentrate below an underwater lamp, a fact that is of extraordinary importance in fishing techniques that use light, e.g. light-and-pump fishing (Kurec 1969, Le Men 1971, and others). Fish swimming beside the lamp and especially above it frequently behave in an agitated and capricious way, which seems to indicate that they have orientational problems. In all probability a strong DLR also accounts for the similarly aberrant behaviour of insects flying in the vicinity of a lamp. It may be for similar reasons that birds tend to congregate on dark nights below the level of lights in tall structures. Animals swimming or flying close to an artificial light frequently exhibit a lateral inward tilt because of the locally abnormal position of D. This might automatically cause the animal to circle the light, because, at least in birds and bats, a turn is typically initiated by a banked movement in accordance with the principle of the banked turn (Lighthill 1975). It is conceivable that unnaturally large differences in the excitation of the sensory elements involved in photic orientation, which are induced by a RDS that is unnatural in shape and position, will provoke aberrant orientation, i.e. disorientation, if the error signals which the moving animal uses in its feedback control mechanism (cf. Schöne 1975) acquire values that are beyond the range to which that mechanism is attuned.

Visual systems

Because visual orientation systems are attuned to configurational features the eyes must reproduce or image the environment in some detail. In general the visual world is sampled more densely in some parts of an eye than in others. For this purpose one or more regions of an eye, each termed an "area", are characterized by a relatively small angle between adjacent receptors. In birds with laterally situated eyes the central area of an eye is stimulated by stimuli in the monocular lateral visual field of that eye, and the lateral or temporal areas of both eyes are stimulated by stimuli in the common binocular frontal visual field (Meyer 1977). A similar arrangement is found in many species of fish (Ali and Auctil 1976) and insects (Horridge 1977).

Movements of one or both eyes, of the head or the whole body (depending on the degree of mobility of the eyes and the head of the animal concerned) can cause any region of the environment to be imaged on an area of the eye. A large amount of literature on this response - the "visual grasp reflex" - has accumulated. The response can be released not only by environmental visual

stimuli, but also by the electrical stimulation of structures in the central nervous system. There are indications that in the latter case the absence or presence of "appropriate sensory cues" or the "organization of the environment" determine whether the response is an isolated stereotyped output, or is part of a more complex and purposeful behaviour pattern (see for instance Phillips and Youngren 1971).

During prolonged observation of a picture, fixations of the human eye appear to concentrate on two types of regions characterized by "contrast" and by "meaning" respectively (Yarbus 1967). Engel (1976, 1977) introduced the concepts of visual and cognitive conspicuity. Eye movements to visually conspicuous contrasts can occur involuntarily, and are probably controlled at an early and low level of neural processing. Visual fixations of cognitively conspicuous configurations occur voluntarily and are probably controlled at a late and high level of neural processing. In predators visual fixation of a stimulus can lead to capture of prey or to flight. The cognitive conspicuity of the stimulus - its dimensions, shape, etc. - determines which of these two behaviour patterns will be released. This has been studied extensively in toads by Ewert (1974). When there are lesions in the thalamus-pretectal region of the brain (Ewert and von Wietersheim 1974) toads are no longer able to distinguish visual patterns in a behaviourally relevant manner: prey-catching is disinhibited and occurs in answer to any visual stimulus. Obviously the key stimulus "prey" is reduced to "being visible" or "showing a contrast", or, according to the concepts of Engel (1976, 1977), to visual conspicuity.

Following bitemporal lobectomies the rhesus monkey shows as part of the Klüver-Bucy syndrome a compulsive tendency to orient visually towards and approach everything in sight (Klüver and Bucy 1939). Similar symptoms can occur in man as a result of cerebral dissolution, for instance in senility (Jackson 1884, see Ploog 1964). This apallic syndrome (Kretschmer 1940) was analysed in detail by Pilleri (1966) and more recently occurred in Japanese persons who suffered the effects of mercury poisoning upon eating fish contaminated with industrial effluent (the notorious Minamata disease, see for instance Takeuchi and Eto 1976), and in Iraq among persons who had eaten wheat preserved with a mercury compound (Gerstenbrand et al. 1977).

With regard to birds, Nye (1973) found that pigeons are very skilled at responding by pecking to stimuli located in the anterior visual field but not to stimuli presented laterally. Erichsen (1977) observed, however, that Barbary doves (*Streptopelia risoria*) orient their head towards lighted lamps placed in various positions, fixating it monocularly with the central area of one eye. It is not clear whether these differences should be attributed to differences in the species involved, the stimuli offered, or the responses required.

The visual orientation system of a bird flying in complete darkness in the vicinity of an artificial light source might be disorganized in the following way. Because of its visual conspicuity the light source will be imaged on the area, or one of the areas, of the bird's eye as a result of the orienting reflex. If the light source is imaged on the temporal area of both eyes, then the bird will fly straight towards the light source. If the light source is imaged on the central area of one eye only, e.g. the right eye, then the bird will start circling, keeping the light source to its right. Because the light source is not cognitively conspicuous, and because the dark environment does not produce cognitively conspicuous stimuli (the role of glare, which in itself is a complicated phenomenon, is not considered here) higher levels of the central nervous system that would normally decide to terminate this behaviour do not receive information about the dangerous situation. Thus the behaviour acquires a stereotyped "forced" character such as that shown by animals during central stimulation in a "poor" environment, or by animals with central defects similar to those resulting in the apallic syndrome in man. Consequently the animal may become a victim of the trapping effect (Verbeijen 1958, 1960, 1969) of the artificial light source.

The disorganization of the photic and visual orientation systems as outlined above is the result of the abnormal ARD in the vicinity of an artificial light source. Obviously moonlight reduces the abnormal character of the ARD. Thus moonlight would reduce the trapping effect of artificial light sources. There is in fact overwhelming evidence, that insects, fish and birds generally congregate at artificial lights on nights when there is a new or nearly new moon, or during periods of the night when the moon is below the horizon (Verheijen 1958, 1960, Southwood 1971, Ben Yami 1976). Recently I have considered the dates of 62 nights on which birds were reported killed at tall lighted structures in the U.S.A. between 1935 and 1973 as if they were a sample of a circular distribution of nights in a lunar month (Verheijen in prep.). The distribution proved to be non-uniform, with a highly significant clustering around the hypothetical direction, namely new moon.

Conclusions and recommendations

1. Many species of birds are attracted to artificial lights because of the "trapping effect" of this light.
2. Bird kills at tall lighted structures are correlated with two independent environmental variables: cloud cover increases the kills, whereas the presence of the moon above the horizon decreases the kills. Therefore reports of collisions between birds and aircraft and accounts of experiments designed to scare birds out of the path of an aircraft en route at night with the help of light should include data relating to the location, the date, the time, the cloud cover and the phase of the moon.
3. An aircraft-mounted narrow beam might be a more promising scaring device than the above mentioned factors underlying the trapping effect of artificial light would seem to suggest. An animal's orientation systems are only disorganized as long as they are stimulated by the unnatural light stimuli. Therefore many types of light traps are designed in such a way that the generally inevitable shadow cone occupies a minimum solid angle (insects: Southwood 1971, fish: Ben Yami 1976). A bird in the narrow collision zone in front of an approaching aircraft might move from this zone, and out of the aircraft-mounted light beam, were it to make an undirected startle response upon sudden stimulation by the narrow beam. Better still, the light beam might even induce the bird to make an evasive manoeuvre, as was suggested by Griffin et al. (1974) and Larkin (1976). I would suggest that the relations between a rigidly controlled optic stimulus situation and a bird's response could best be studied in birds trained to perform a specific task while flying in a wind tunnel.

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