



The Müller-Lyer Figure and the Fly

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the donor pineal. We have done this in 4 of our 12 successful cases and all 4 birds became arrhythmic as a result (Fig. 3).

Tissue transplanted to the anterior chamber is often reinnervated by sympathetic fibers from the superior cervical ganglion which normally supply the iris. In our view, however, the rapidity with which the reestablishment of rhythmicity follows the introduction of a pineal organ into the anterior chamber precludes an interpretation of our results which assigns a major role to such reinnervation. This markedly strengthens our belief, based initially on the results of chemical sympathectomy, that the avian pineal does not require sympathetic input, or any neural input, for the performance of its role in the birds' circadian organization [the situation in mammals is discussed in (10, 11)].

The success of the transplant experiments also confirms the conclusions that we reached on the basis of stalk deflection: the output of the pineal which affects other components of the circadian system must be hormonal and, further, it is probably capable of exerting its effect when released into the general circulation.

These results, however interesting, do not allow us to distinguish between the alternative hypotheses concerning the pineal's role in avian circadian organization outlined at the beginning of this report. Although our results may perhaps lend support to the idea that the avian pineal is an endogenously rhythmic driving oscillator, they do not preclude the possibility that it functions as a coupling device. The resolution of this question awaits the demonstration that it is (or is not) possible to transfer some specific property of the donor bird's rhythmicity (such as phase) along with its pineal organ.

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6. A skull cap is removed from above the pineal region and the meninges that lie over the cerebellum and immediately posterior to the pineal are slit. Through this opening a microhook is inserted past the pineal and placed around the pineal stalk. Withdrawal of the microhook deflects the stalk onto the upper surface of the cerebellum.
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8. In the chicken, chemical sympathectomy with 6-OHDA causes axonal degeneration of terminal axons in a large number of tissues. Regeneration time varies from days to weeks depending on the

- particular tissue [T. Bennett, G. Burnstock, J. L. S. Cobb, T. Malmfors, *Br. J. Pharmacol.* **38**, 802 (1973); T. Bennett, T. Malmfors, J. L. S. Cobb, *Z. Zellforsch. Mikrosk. Anat.* **142**, 103 (1973)].
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13. We thank W. Möller, Anatomisches Institut, Der Justus Liebig-Universität, Friedrichstrasse 24, 63 Giessen, West Germany, for this important suggestion.
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The Müller-Lyer Figure and the Fly

Abstract. *In the Müller-Lyer illusion two horizontal line segments of equal length are perceived by humans as unequal. The gaze of a fly presented with Müller-Lyer figures corresponds to human eye movements and human (illusory) evaluations of the segment lengths. It is suggested that a theory similar to the phenomenological theory which accounts for the fly's gaze may account for the human eye's movements during an observation of Müller-Lyer figures.*

Everybody looking at Fig. 1a will perceive the top horizontal segment as shorter than the bottom one, although an actual measurement shows that they are of equal length. This is the Müller-Lyer illusion (1), probably one of the best known of all geometric illusions. This illusion is still perceived with a stabilized retinal image (2, 3), so eye movements are not necessary for it.

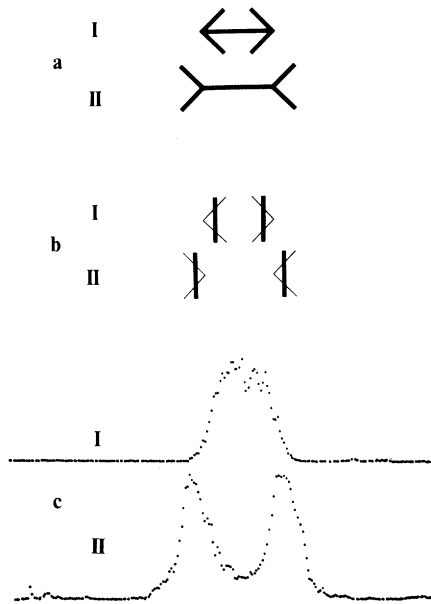


Fig. 1. (a) The Müller-Lyer illusion. In the experiment represented here, the angular length of the horizontal line, as seen by the fly's eye, is 60°. (b) Patterns equivalent to those in (a) for the orientation behavior of the fly (on its horizontal plane), according to theory (4, 6). (c) Histograms of the fly's gaze on the two patterns, aI and aII, respectively. The histograms extend from -180° to $+180^\circ$; 0° in the histograms gives the fraction of time the fly gazed on the midline of the horizontal segments (a). The appearance of two maxima depends on the angular separation between the vertical segments in (b), and therefore on the (angular) dimensions of the Müller-Lyer patterns. As can be predicted (4, 6), there are two maxima in the histograms when the angular separation in (b) is more than about 40° . Below this value only one maximum appears.

However, "many experiments ... show that the [human] subject's subjective evaluation may always be judged from the eye movements made during comparison of distances." This sentence of Yarbus (2) suggests a correlation between oculomotor response and subjective length evaluation, and in fact the visual evaluation of length and the amplitude of eye saccades during an observation of the Müller-Lyer figure are in mutual agreement (2). Thus, eye movements induced by Müller-Lyer figures may be connected to the psychophysical illusion; although the nature of this relation remains unclear, it prompted us to examine the oculomotor response of flies to Müller-Lyer figures. It is well known that flies orientate toward (fixate) black objects such as vertical stripe segments (if presented to the lower half of the compound eyes). This behavior has been much analyzed (4) and a phenomenological theory (4-6) can quantitatively describe it. Tracking of moving objects (7) as well as of other flies (8) can also be essentially explained in the same way.

We used this orientation behavior to compare the fly's gaze with the known human eye movements when viewing Müller-Lyer figures. A tethered flying fly (head fixed to the thorax) was capable of controlling the rotation of a cylindrical "panorama" through its torque (around its vertical axis) and an electronic simulation of the flight dynamics. This setup, described elsewhere (4), simulates a free-flight situation in which the fly is free to orientate toward a stationary pattern on its horizontal plane.

A fly was presented successively with the two patterns shown in Fig. 1a, on the cylindrical panorama in two sessions of 3 minutes each; the histograms in Fig. 1c show the fraction of time the fly gazed at any part of the two patterns. Figure 1cI is the histogram of the gaze on the pattern in Fig. 1aI and Fig. 1cII is that of the pattern in Fig. 1aII. The histograms show clearly

that the fly's gaze corresponds to our eye movements (2) as well as to our subjective (and illusionary) evaluation of the segment length. Whether flies are actually "susceptible" to the illusion is, of course, a logically separate and still open question.

The effect shown in Fig. 1 can be also expected from the phenomenological theory of the fly's orientation behavior (4, 5). In this theory the way a fly gazes at a pattern consisting of a black vertical stripe turns out to be equivalent to the motion of a particle in a nonharmonic one-dimensional potential well, which is associated with the "attractiveness" profile of the stripe for the fly. The minimum of the potential well gives the most probable direction of gaze (the maximum in the histograms). The potential profile associated with complex patterns composed of more vertical segments can be obtained, as a first approximation (6), by superimposing the individual contributions. Moreover, oblique segments are, in this respect, practically equivalent to their vertical projections (4). From this point of view, Fig. 1a is equivalent to the pairs of vertical bars in Fig. 1b. The potential that can be associated with Fig. 1bII has two minima which are far-

ther apart than those in Fig. 1bI; therefore, the two most probable directions of gaze are expected to be farther apart, in agreement with the experimental results in Fig. 1c.

Therefore, an intriguing possibility is that a similar theory may account for the human eye's movements corresponding to the Müller-Lyer pattern. In fact, the properties required (5) are quite general and are likely to be true for the human fixation system.

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Visually Evoked Magnetic Fields of the Human Brain

Abstract. *Magnetic field variations from the human brain produced by visual stimulation have been observed in a normal laboratory setting with a superconducting quantum interference device and no magnetic shielding of the subject. Previously unknown temporal and spatial features of the field near the scalp are reported.*

Conventional electrical measurements of sensory evoked responses monitor the difference in potential between electrodes applied to the scalp. Since the electrodes are separated from the active regions of the brain by low conductivity tissue and bone, there is only weak electrical coupling between the electrodes and the region in which interesting electrical activity originates. A more direct indicator is the external magnetic field associated with the

flow of strong currents within the relatively highly conductive tissues of the brain, for this field would be little affected by weak currents in the dermis. In addition, the source of the external magnetic field would be more precisely localizable than are the sources of potential change monitored by traditional techniques.

The magnetic field studies of Cohen (1) demonstrated that neural activity of the human brain produces a detectable mag-

netic field outside the head. Cohen observed both spontaneous activity (that is, at alpha frequencies) (2) and visually evoked responses (3, 4). The field is exceedingly weak, and Cohen's success depended upon the use of elaborate magnetic shielding to reduce the ambient field of terrestrial origin to a level below that of the brain's field. Our results demonstrate that it is possible to measure the evoked magnetic field of the brain without shielding and with relatively modest additions to the normal complement of equipment needed to measure potentials, thus making the phenomenon of neuromagnetism suitable for study in many laboratories. Our initial results also reveal some previously unknown characteristics of the magnetic response to a visual stimulus.

Temporal variations of the magnetic field near the scalp associated with brain activity have a peak-to-peak value of about 2×10^{-8} gauss for spontaneous activity at alpha frequencies, and about 5×10^{-9} gauss for visually evoked responses. The advent of the superconducting quantum interference device (SQUID) (5) provides a field monitor of sufficient sensitivity to detect such fields. The SQUID is maintained at liquid helium temperature in a Dewar made of glass and fiberglass (6), and is coupled to external fields by a loop of superconducting wire (a "flux transformer") mounted in the tail section of the Dewar, as illustrated in Fig. 1. The flux transformer is wound in the configuration of a second-order gradiometer (7); three coaxial coils 2.2 cm in diameter, separated by equal distances of 3.9 cm, each end coil with one turn of wire wound in the same sense, and the center coil with two turns wound in the opposite sense. This configuration is used to discriminate against the major sources of noise, changes in the ambient field due to micropulsations caused by disturbances in the upper atmosphere and other local sources which produce relatively uniform fields. In our laboratory the amplitude of this ambient noise is about 10^{-2} gauss. The second-order gradiometer is found to be less sensitive to vibration-induced noise than a simpler two-coil gradiometer.

To balance the flux transformer for minimal response to uniform fields, three orthogonal pairs of trim coils are wound in series with the second-order gradiometer. The effective area of the trim coil is then adjusted with superconducting shields to achieve minimal noise. After balancing, our peak-to-peak noise is typically 3×10^{-8} gauss for a bandwidth of 5 to 25 hz. There is substantially more noise below 5 hz from the low frequency content of the ambient field. The inherent noise from the SQUID and flux transformer of 8×10^{-10}

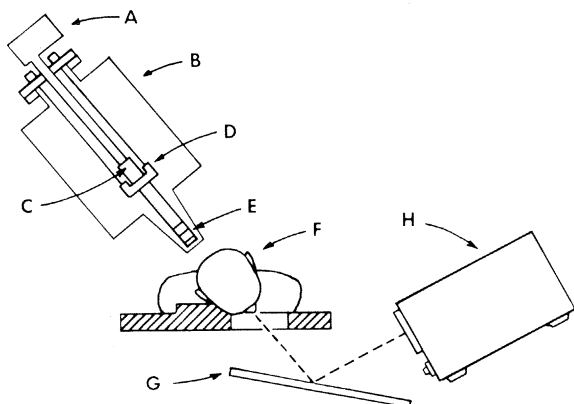


Fig. 1. Arrangement for monitoring evoked response: (A) SQUID electronics; (B) Dewar; (C) SQUID; (D) trim coils; (E) second-order gradiometer, the end coil of which is the pickup coil; (F) subject prone on table; (G) mirror; and (H) oscilloscope for presenting stimulus.