Technical Papers

The Informational Capacity of the Human Eye

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Critical examination of existing monocular visual acuity data has allowed an estimate of the informational capacity of a human eye to be made in this paper. The problem, analogous to that of the ear (*1*), is simpler in that visual acuity is ordinarily measured in a way which allows a calculation of total numbers of yes-no decisions, i.e., the standard informational units of "bits" (binary digits) to be made directly.

The maximum acuity of the eye, measured as the inverse of the minimum angular distance necessary to resolve two objects under conditions of good illumination and central fixation is 60/degree (1′ of arc is the acuity angle) for a person with "normal," or Snellen 20/20, vision. Consensus of data (*2–5*) indicates a variable, but higher, acuity figure for many eyes at high illuminations. We have somewhat arbitrarily taken 100/degree as the maximum acuity.

If the visual pattern be regarded as a fine mosaic of "acuity squares," which are either black or white, of an area corresponding to the square of the acuity angle, lasting for a time of the order of the fusion period, the informational capacity can be calculated. The tacit assumption is that the acuity square can be recognized as either present or absent, in a complex retinal pattern, thus furnishing one yes-no decision, or bit of information. With the Landolt ring method of measuring acuity, this is a defensible standpoint, since the discrimination of the presence or absence of the square that size in the pattern is the major task of the eye during the test.

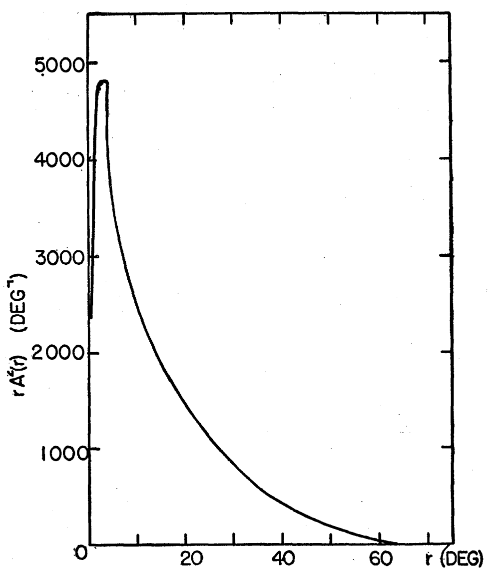

FIG. 1.

This model, which is a discrete "cell" representation of changes on the retina with time and space, will require a number of bits/sec for specification equalling the total number of such squares/mosaic multiplied by the frequency of appearance of new mosaics. This paper utilizes critical estimates of the best available experimental data bearing on these two quantities.

The classical study of the peripheral dependence of visual acuity is that of Wertheim (*6*). A number of more recent, and better, studies have been made on acuity in the macular region (*7–10*). A critical composite of the recent data up to $4\frac{1}{2}°$ peripheral, and of the Wertheim data beyond this, is replotted in Fig. 1, as the function $r\,A^2\,(r)$, where r is the peripheral angle of vision (degrees), and $A\,(r)$ the acuity, in inverse degrees. Assuming $A\,(r)$ to remain azimuthally constant, the total number of acuity squares is seen to be $\int_0^\infty \pi r\, A^2\,(r)\, dr$, or π times the area under the curve of Fig. 1.

Numerical integration of this curve, and multiplication by π gives a figure of 240,000 acuity squares/mosaic.

To find the maximum number of such mosaics perceptible in a second, two data are used: (*a*) the observation that the eye will integrate signals at high illumination and central fixation over a period of about 0.03 sec (*11*), and (*b*) the measurement that the decrease of the fusion frequency at a peripheral angle of 10° is about 1.8-fold (*12*). This is the center of density of the acuity squares plotted in Fig. 1. These data give $1/(.03 \times 1.8) = 18$ mosaics/sec, a number less than half the maximum fusion frequency, but sufficient to give good fusion of successive mosaics. Multiplying this figure by 240,000, we arrive at 4.3×10^6 as the maximum number of bits/sec of information transmissible through the human eye, considered as an informational channel.

This figure is valid under conditions of high illumination. For light of lower intensities, both the acuity and the fusion frequency decrease substantially. The only data available on over-all change in retinal acuity with decreasing illumination are those of Mandlebaum and Sloan (*8*). Fig. 2 is a plot of these data after integrating over the whole retina to convert to informational units, and correcting for decrease in fusion frequency. It resembles an ordinary acuity-illumination curve, but the usual break between rod and cone vision levels is smoothed out by the spatial integration used.

The increase in informational capacity from color perception has been ignored. It would certainly not

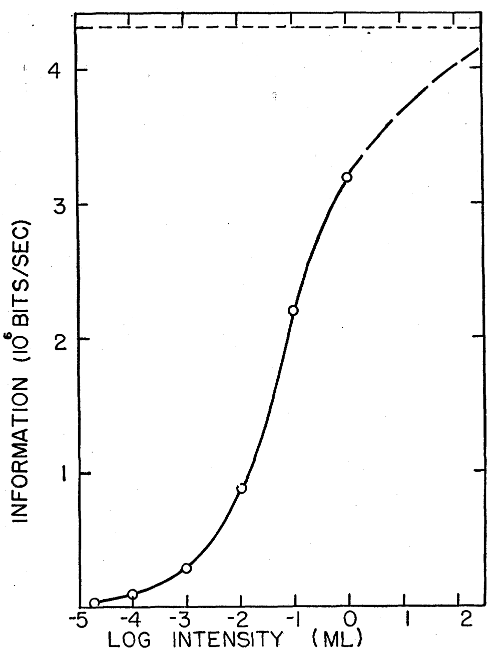

FIG. 2.

triple the capacity, and the increase is probably small compared to uncertainties in the data and methods of calculation.

Comparison with similar figures for the ear leads to interesting results. For "random" sound—i.e., sound evenly distributed in frequency and intensity throughout the hearing region—a capacity of 8,000 bits/sec has been calculated for the ear (*1*). Intense sounds will give a 10,000 bit/sec capacity, a result more nearly comparing to the high-illumination calculations of the present paper. A 430-fold difference, informationally speaking, is seen to distinguish the maximal capacities of the two receptors.

A factor of about 30 in the relative capacities of eye and ear can be accounted for by the ratio of nerve fibers leading from these organs (*13, 14*), but a further difference is evident in the efficiency with which an individual nerve fiber transmits information. The order of 5 bits/sec, av, can be produced by the 900,000 fibers of the optic nerve, compared with a maximum of about 0.33 bits/sec from each of the 30,000 fibers of the auditory nerve. This is clearly due to the greater independence with which the optic nerve signals are produced, in contrast to the prevalence of cooperative signals in the auditory bundles. The phenomenon of masking is less apparent in signals from the eye, which may be said to encode its observations more efficiently.

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The Percutaneous Absorption of Water

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The question whether externally applied water can penetrate the intact mammalian skin has long been debated. The gravimetric technique was employed in early experiments in which the subject was weighed before and after immersion. Working with human subjects, Stejskal (*1*) reported a retention of 200–300 g of water from the bath, Burr (*2*) observed a 5–7 g gain in body weight, and Pitta (*3*) reported a gain of 11.4–96.0 g, depending on the temperature of the bath. Schwenkenbecher (*4*) has criticized the results of Stejskal and others on the ground that the technique is not precise. More recently Whitehouse *et al.* (*5*) reported the results of carefully conducted experiments and concluded that water can pass inward through the human skin under certain conditions. These experiments have also been the subject of severe criticism, because the gravimetric technique was used, and Rothman (*6*) has claimed that water cannot pass through the mammalian epidermis.

Even if it can be proved that skin does take up water, none of the work so far reported offers final proof that this water enters the systemic circulation. Several investigators (*2, 7, 8*) have indicated that the answer to this question is important, and Burr (*2*) suggested that percutaneous absorption of even small amounts of water may exert a great influence on the water and mineral content of body fluids, on the circulation of nutrients, and especially on the exchange of substances between blood and tissues.

In the present study a tracer technique was used. Cylindrical wire containers with adjustable metal collars kept the animals in position and prevented the ingestion of D_2O. Young male rats weighing approximately 120 g were immersed for 6–7 hr in a mixture of 6 parts of H_2O and 4 parts of D_2O, maintained at a constant temperature of 35° C. The animals were then removed from the bath, drained, anesthetized lightly with ether, removed from cages, and quickly dissected to expose the heart. Blood samples were drawn from the pumping heart, using a syringe. Water was distilled from the blood samples,

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