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Automatic Gain Control Model for Vision

SINCE the work of G. T. Fechner (1859) the functional relationship between the physical luminance (input) and the perceived brightness (output) in the visual system has been taken to be logarithmic. This hypothesis seems to have been based primarily on the observed constancy of the ratio of the just-noticeable stimulus change to its absolute value, known as Weber's law. In fact, however, this constancy is observed only at the higher luminances and even there it has been difficult to justify the assumed logarithmic gain on grounds other than expediency.

It seems that Weber's law at high luminance can be explained far more simply and convincingly by assuming that the brightness (B) and the luminance (L) are related as

$$B = B_0 L(\varkappa + \overline{L})^{-1} \quad (1)$$

where B_0 and $\varkappa$ are constants and $\overline{L}$ is the mean luminance level. Alternatively, the "gain" may be written

$$g = \frac{B}{L} = B_0 \, (\varkappa + \overline{L})^{-1} \quad (2)$$

A relationship of this form results from the simplest chemical detection models in which the stimulus decomposes molecules, which subsequently recombine spontaneously. We may assume the rate of decomposition to be proportional to the fractional concentration (ρ) of the sensitive molecules and to the stimulus magnitude (L), and the recombination rate to be proportional to the concentration $(1 - \rho)$ of the decomposition products. Then at equilibrium, where these two must be equal, we have

$$\dot{\rho} = k_1 \rho L = k_2 \, (1 - \rho)$$

where k_1, k_2 are rate constants. Solving this for ρ, we find

$$\rho = \varkappa \, (\overline{L} + \varkappa)^{-1}$$

where $\varkappa = k_2/k_1$. If the response is assumed proportional to $\dot{\rho}$, equation (1) results with $B_0 = k_2$.

It is interesting to note that the identical equation covers the simplest "automatic gain control" system as used in radio receivers to equalize output volume when switching between transmitting stations of widely differing strengths.

Equations 1 and 2 imply that the gain is relatively high at low luminance levels, and becomes increasingly smaller at high levels, in such a manner that the equilibrium brightness approaches B_0 asymptotically. This immediately accounts fully for the phenomenon of brightness constancy—at least at high luminance.

Note that at high luminance the gain approaches

$$\lim_{\bar{L}\to\infty} g = B_0/\bar{L}$$

Thus a constant "Weber–Fechner fraction"

$$\Delta L/\bar{L} = C$$

implies a constant output-difference:

$$\Delta B = g \ \ \Delta L = CB_0$$

at high luminance. This accounts for the observation of Weber's law there.

To account for the threshold data in detail, we must consider the various sources of noise which must be present. These are: (1) Quantum noise due to the quantum nature of the incident radiation[1]. (2) "Dark light"[2] noise due to fluctuations in the response the detector makes even in the dark. (3) Fluctuations in the output due to spontaneous neurone activity in the cortex.

When these are considered, the observed threshold contrast data are predicted quite accurately on the basis of the proposed model, both for circular disk[3] and sinusoidal[4] objects.

L. Levi

Department of Physics,
City College,
City University of New York,
New York.

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