processing. The procedure is greatly accelerated by photographing more than one unit per frame, eliminating disk-weighing, and substituting readings of one wavelength for spectral curve planimetry, all possible under certain conditions.

The inherent superiority of photographic over photoelectric recording of absorbance in heterogeneous microscopic objects was eloquently outlined by Ornstein (*4*) and later extended to include color transparencies (*3*). Mendelsohn (*7*) also described a method for converting black-and-white films to monochromes, with special application to the "two-wavelength method." Only Niemi (*8*) has applied the photographic method (standard microscope, silver analysis) to a quantitative study of erythrocytes in types of human anemia. The use of two microscopes and one light source in the photographic method eliminates concern for light source fluctuations, that otherwise demand rigorous control. The simplifying substitution of white light and color film for monochromatic light and specially prepared monochrome transparencies shifts a measure of responsibility to the film manufacturer and processor, although monitoring of variations in film emulsions and processing is a function intrinsic to the dual microscope procedure.

The successful performance of these two light microscopes suggests similar arrangements for appropriate quantitative applications of ultraviolet, interference polarizing, and fluorescence microscopes. The photographic basis would be essentially the same: formation of a "chemical model" to a scale suitable for an object otherwise too small for dissection and macroanalysis (*9; 10*).

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9. I am indebted to Dr. Leonard Ornstein, who critically reviewed this manuscript and made available his published and unpublished information on precision photography in cytochemical analysis. Supported by grants H-1889 and A-6071 from the National Institutes of Health.
10. After submitting this manuscript, I learned that a binocular microscope has been described. [Shea, *J. Histochem. Cytochem.* **10**, 637 (1962)], which is suitable for this procedure, and available as a unit from AO-Spencer.

13 September 1962

Correspondence between Stevens' Terminal Brightness Function and the Discriminability Law

Abstract. Stevens' terminal brightness function, an adaptation curve derived from power law data, closely agrees with Troland's just-noticeable-difference (jnd) summation for brightness. The power law itself describes sensation magnitude *before* adaptation to a test stimulus, whereas the Fechnerian discriminability law describes sensation magnitude *after* adaptation. This suggests their synthesis in a more general psychophysical equation.

Stevens, Garner, Helson, and others (*1*) have done considerable work since the 1930's in developing scales to describe the relation between the physical intensity of a stimulus and the resulting subjective sensation. In the main, Stevens' work has been the most influential and his proposed power function law of sensation has found considerable acceptance, even though such acceptance has seemed to necessitate the rejection of Fechner's law, which has been in use for the last 100 years.

The sensory scaling system developed by Fechner was based on Weber's law, $\Delta I/I = C$, in which the minimum detectable change in a physical stimulus, ΔI, is related to the associated intensity of the stimulus, I, by a constant, C. The idea of Fechner was that the C in Weber's law corresponded to a basic sensation unit, $\Delta\Psi$, the "just-noticeable" sensation change which was associated with an incremental change in physical stimulus. He hypothesized further that the just-noticeable difference (jnd) had the same sensation magnitude at all intensity levels of the physical stimulus. Fechner's hypothesis was, then, that, $\Delta I/I = K_1\Delta\Psi$. If the equation is integrated after suitable mathematical assumptions, a form of Fechner's law is found that gives the magnitude of sensation as a function of physical stimulus intensity, $\Psi = K_{\log} I + C$. Fechner's law is a theoretical discriminability law, since it is based on a mathematical integration of jnd's, units of discrimination. An empirically based discriminability law can be obtained, however, by the summation of empirically determined jnd's. This was done, for instance, by Troland (*2*). In both scales the basic assumption is that the sum of jnd's (sensation units) equals a sensation magnitude.

Stevens, however, has found by direct estimation of the magnitude of sensation associated with a physical stimulus, that the psychophysical law is not a log function but is a power function, $\Psi = KI^n$ (sensation magnitude is proportional to a power of the physical stimulus intensity). He has, therefore, suggested that Fechner's law be "repealed" (*1*).

It is important to note, however, that a significant operational difference exists between the methods of Stevens and those of classical psychophysics, a difference which accounts for the discrepancy between the two formulations. In power law experiments, Stevens' experimental subject is first adapted to a given stimulus level and then is asked to estimate the sensation magnitude of a test-stimulus to which he is *not* adapted. But in classical psychophysics, the jnd's on which the discriminability law for brightness is based were determined only at stimulus levels to which the experimental subject was essentially adapted. Troland's discriminability scale, it should be noted, is based on Hecht's averages (*3*) of the work of Aubert (1865), Konig and Brodhun (1889), and Blanchard (1918), all of whom determined jnd's at levels to which their subjects were essentially adapted. It can be inferred, then, that Troland's discriminability scale can be valid only *after* adaptation to a stimulus level, whereas power law scales can be valid only *before* adaptation.

With this methodological difference in the construction of brightness scales in mind, it is of interest to consider the following: In a recent paper, Stevens (*4*) describes a brightness-luminance (psychophysical) relationship derived from power law data which he calls the "terminal brightness function" and of which he says, it "does *not* follow a power law." Of significance is the fact that the terminal brightness function represents the brightness (sensation magnitude) which would be experienced by an observer *after* adaptation to the test stimulus. In other words, the function seems to represent the brightness-luminance relationship which would be obtained by the use of Stevens' method of direct estimation of sensation magnitude, after adaptation to the test stimulus.

Perhaps the most important point to be made, however, is that the terminal brightness function corresponds very well to Troland's formulation of the discriminability law of brightness for the moderate and high intensities, over which Weber's law is most valid. Thus, the existence is implied of a psychophysical law of which discriminability and power function laws are special cases and in which time (adaptation time) is an important variable. A recent theoretical formulation by Stewart of signal-noise interrelations as applied to sensory systems (*5*) seems to be a step in the direction of such a general psychophysical law, since it allows time-varying phenomena to be represented and provides a mathematical framework into which newly discovered psychophysical relationships possibly can fit. Figure 1 shows the correspondence between the discriminability curve of Troyland (originally expressed in jnd's and photons) and the terminal brightness function of Stevens, against a background family of power law curves.

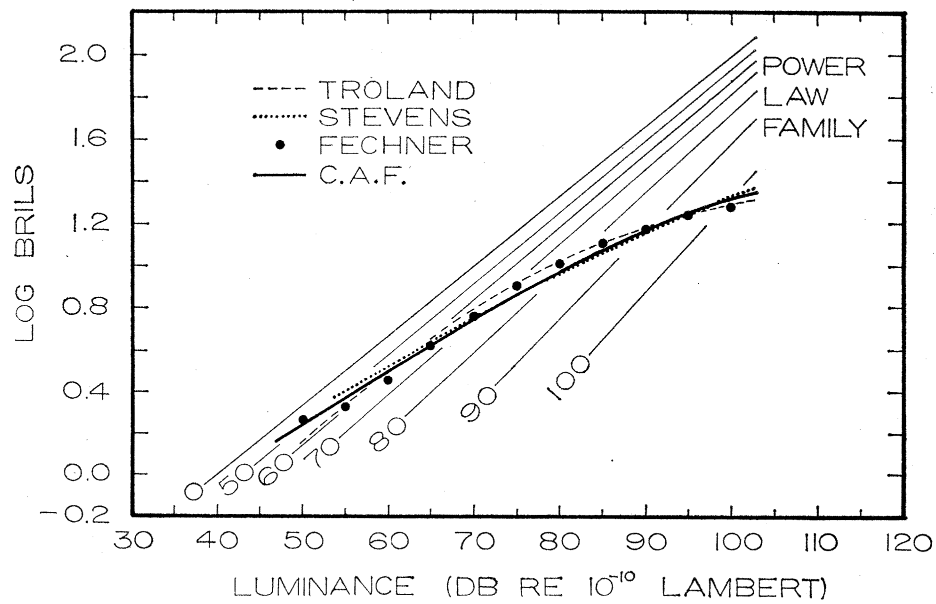

Fig. 1. The experimental subject's brightness sensation (log brils) *before adaptation* to a sudden change in light intensity is shown by the power law family. Pre-trial adaptation level is the family parameter. The other four curves show essentially the brightness sensation *after adaptation* to the intensity level has occurred, and are Troland's jnd summation (allowing 20.3 jnd's per bril), Stevens' terminal brightness function, Fechner's logarithmic sensation law, and my continuous adaptation function (CAF). The curves are arbitrarily tied together near 95 db.

Additional evidence which supports the interpretation that the adaptation curve (terminal brightness function) describes the classical discriminability law was obtained by me during a recent "sensory barrage" experiment (*6*). In this experiment a modification of von Bekesy's method of threshold measurement was used to determine the pain threshold and associated jnd's while other modalities (sensory systems) were simultaneously bombarded for 15 minutes at varying intensity levels. Since in designing the experiment it turned out that the power law could not be used in any *direct* way to partition a physical stimulus dimension so as to produce equal-appearing sensation steps (under conditions of adaptation to the stimulus), an *indirect* method was developed. Suffice it to say that a sensory scale called the continuous adaptation function (CAF) was derived from Stevens' *1960* power law data for vision (*7*) and applied with satisfactory success (and with appropriate scale factors) to three modalities under bombardment: visual, auditory, and tactual. Stevens' numerous cross-modality findings with power functions suggested the cross-modality application of the adaptation function. The continuous adaptation function was developed in answer to the question, "What is the brightness function which would be described if the luminance were increased so slowly that a jnd would never 'appear' on a Bekesy-type paper record?" Or, stated in another way, "What is the visual intensity function to which the subject is completely adapted?" Troland's discriminability curve was found, upon examination, to have a remarkable correspondence to the continuous adaptation function (see Fig. 1), and later, when I became aware of the terminal brightness function (derived by Stevens from totally different power law data), I saw that it and the function were essentially identical, allowing for differences in derivation methods and in the basic data.

In addition to the other curves, a modification of Fechner's equation, represented by a series of filled-in circles, is shown in Fig 1. Fechner was aware of the fact that, at low stimulus intensity, "noise" in the visual system caused a deviation from the simple log law, and he proposed a correction term to be added to the intensity value. If the total inherent and induced "noise" in the visual system at medium and high intensity levels is approximately represented by 0.000133 lam (about 61 db of luminance, physical intensity, relative to 10^{-10} lam) then Fechner's law agrees moderately well with Troland's discriminability function and with the adaptation function and can be written, $\Psi = 0.477 \log(I + 0.000133) - 25.7$. The values of the constants 0.477 and −25.7 represent, respectively, the slope and *y* intercept of the asymptote approached by the function on linear-log paper (sensation units in brils versus luminance in decibels) at high stimulus intensities. It is important to note that since the correction term in Fechner's equation is not actually a constant but is proportional to the stimulus intensity itself, owing to facilitation and other neural and physical factors, the equation can only be an approximation and does not hold at all for stimulus intensities below 50 db (*8*).

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8. Supported by grants to Ward C. Halstead, from NIH and the Wallace C. and Clara A. Abbott Memorial Fund of the University of Chicago. I was an NIH predoctoral fellow and did the work in the medical psychology laboratory, Department of Medicine, University of Chicago.

29 October 1962