

# “ . . . as my eye is part of me ”

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**T**HE EYE, ASIDE FROM ITS OVERWHELMING IMPORTANCE for our continued well-being and existence even, has qualities of very special interest for the clinician and the inquiring researcher. It is, from the physician's standpoint, literally a window to the brain, for the retina, that neural layer at the back of the eye containing the light-sensitive elements, is morphogenically related to the brain itself. With the simplest of hand-held optical devices, it is possible to view directly this complex neural structure and its associated vasculature and in observing learn a great deal about the general state of the body's health. The accessibility of this bed of neural elements is appealing also to physiologists and psychophysicists seeking to learn more about the processes involved in the conversion of photon energy to neural impulses, and neural impulses into the experience we call sight.

Of the many varied and complex avenues to study of the eye none has perhaps been more heavily traveled than that which deals with the eye's ability to resolve time-varying stimuli. This aspect of its function has been investigated from nearly every conceivable angle, and, as a consequence, there is a better understanding of the processes involved, and useful tools for clinical diagnosis have resulted. In what follows, we will describe some early research and theorizing about the eye as a temporal analyzer and relate it to more recent work of our own. Finally, we will discuss some research in progress on the use of a sensitive visual transient response as a clinical indicator.

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*The ability of the eye to resolve time-varying inputs has been a fruitful area of research in the past. Analysis of some recent experiments on a visual transient response demonstrates continued usefulness of the approach both from the standpoint of theory and applications in the clinic.*

## The Eye as a Low Band-Pass Filter

When a light source is switched on and off repetitively at a low enough rate a sensation of flicker ensues. As the rate of switching increases, the sensation of flicker diminishes until at some rate it vanishes altogether and the light source appears steady or fused. This rate is known as the critical fusion frequency—or c.f.f. The frequency at which fusion occurs is dependent upon a host of circumstances, among which a few of the most important are (a) the physical dimensions of the light source, (b) the intensity of the source, (c) the intensity of the background on which the source is viewed, (d) the on-off ratio (or duty cycle) of the source, and (e) the portion of the retina on which the image of the source falls.

Some years ago a Dutch scientist named deLange, in a very carefully devised series of experiments, produced data using the c.f.f. of the normal human eye which has enlarged our understanding of this aspect of visual function. His technique, very simply, was to determine for a small, white, circular light source the percent modulation needed to detect flicker at a given modulation frequency. His modulation was sine-wave and from his results he was able to predict the outcome of many other experiments using different modulation waveforms. In general, he showed that the sensation of flicker was dependent upon the amplitude of the first Fourier component of the modulated light source, and that when the amplitude of this component decreased below some threshold level, the source appeared fused. Figure 1 shows in idealized form the curves he obtained when percent modulation was plotted against modulation frequency for two light intensi-

ties. These have come to be known as “deLange curves.” On the basis of these and similar results, the mechanism by which the eye handles amplitude-modulated light can be described as a linear low-pass filter—at least for frequencies above about 10 Hz.

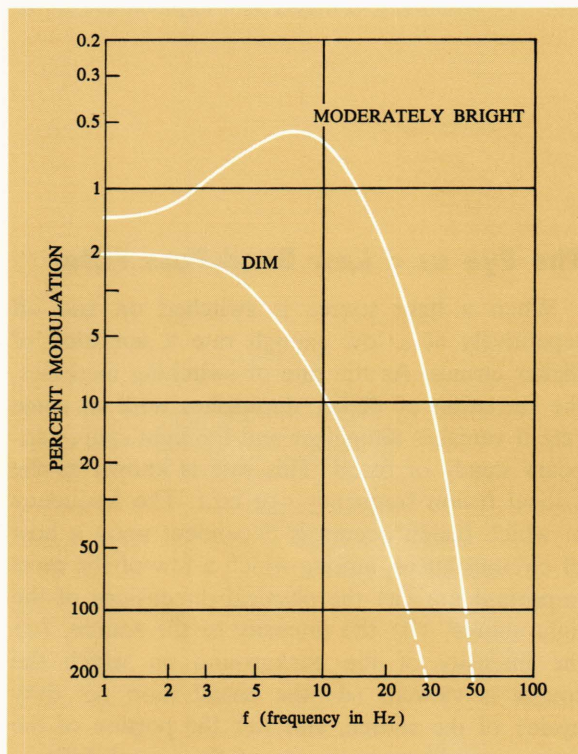


Fig. 1—deLange curves showing the percent modulation needed to detect flicker in a light source for a given modulation frequency.

This demonstration of the essential linearity of this aspect of the visual system turned out to be an open invitation to model builders to ply their trade. As a consequence, largely subsequent to deLange’s important contribution, descriptive analogs proliferated at a great rate. They have varied in kind and complexity. The most popular mechanism employed has been the RC integrator but physiological mechanisms like diffusion and lateral inhibition have also been suggested. And, in an attempt to account for more and more of the eye’s unique characteristics, complications have been added in the form of differentiators and feed-forward and feed-backward circuits.

Coincident with some other work we were doing several years ago, a very unusual type of visual response was noted that seemed to bear directly

on the eye’s temporal analyzing ability. We thought it important enough to pursue.

## Research on a Visual Transient Response

If a light source of moderate intensity is 100% amplitude-modulated with equal on and off periods, it appears as a steady luminance to the normal eye when the modulation rate exceeds a c.f.f. of some 50 Hz. However, consider the stimulus waveform shown in Fig. 2. When  $\tau$  represents a total duration of two seconds,  $T_1$  and  $T_2$  are one second each and  $t_1$  is 1.0 msec, then if the period  $t_2$  is in the neighborhood of 5 msec, a visible transient response is produced. Should the period of  $t_2$  be reduced a slight amount, say to around 3.0 msec, the transient is no longer visible and the stimulus appears as a constant luminance source of 2 seconds duration. On the other hand, should the period of  $t_2$  be extended beyond the 5.0 msec indicated, the transient becomes increasingly easier to see. In appearance the transient seems to be a very brief eclipse, almost as though the light winked its eye. Now, if the pulse train of Fig. 2 is reversed so that the longer period is presented first followed by the shorter period, the transient takes on a different appearance. In precisely what way the transient appears to differ is difficult to describe. The first order appears sharper, clearer, and more definite, but it is only with careful observation that it becomes evident that the order illustrated produces a brightness decrement whereas the reverse order produces a brightness increment.

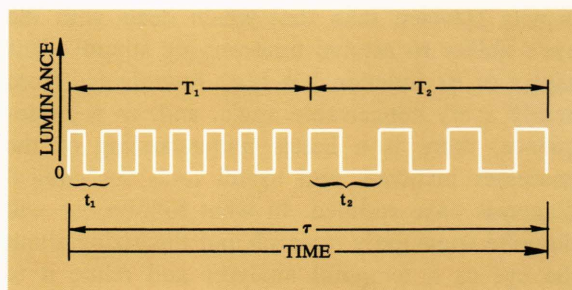


Fig. 2—Modulation pattern for the white light source used in these experiments.

As suggested above, this polarity effect is fleeting at best and not easily observed. In an attempt to gain some objective confirmation two psychophysical experiments were devised.

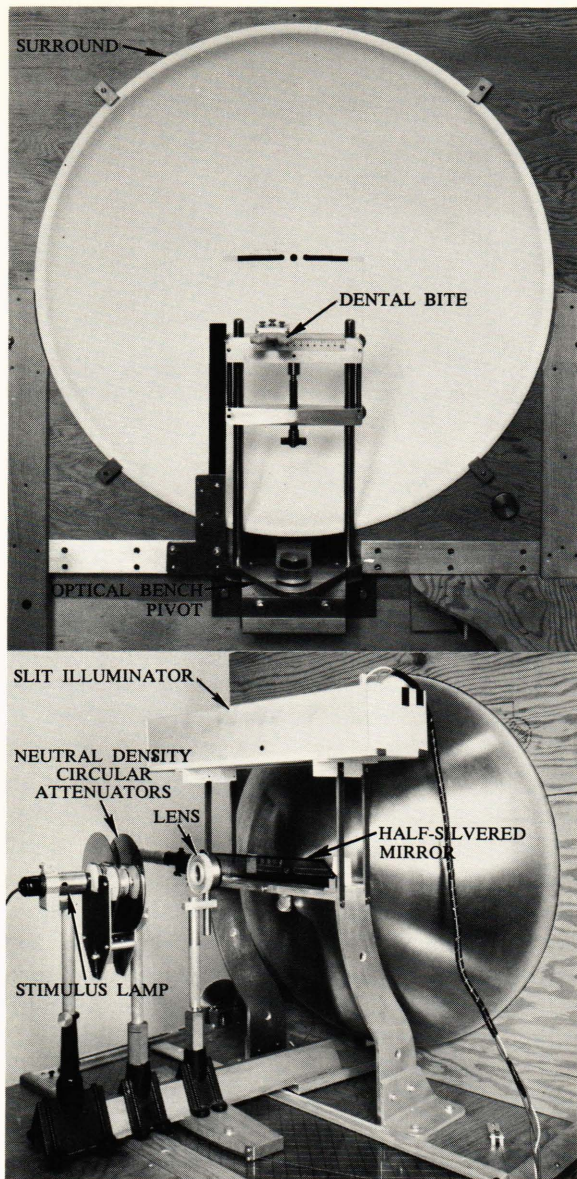


Fig. 3—Views of the experimental apparatus used for presenting the light stimulus.

### A Threshold Test to Determine the Sign of the Transient Response

Some evidence exists to show that the eye is more sensitive at detecting small light decrements than at detecting small light increments. Thus it was reasoned that the same might apply to detection of the transients, and that a smaller frequency separation might be required at threshold for one order of frequencies than for the other.

Standard electronic pulse-generating equipment was used to drive a Sylvania R1131-C glow modulator tube that produces the train of light pulses described. The light source was mounted on an optical bench and the light output directed through appropriate lenses and diaphragm stops to a focus in the plane of the observer's pupil. Conventional measures were taken to ensure that such things as luminance of the stimulus, luminance of the background, and size and position of stimulus on the retina were all carefully controlled throughout the course of the experiment. Figure 3 is a photograph of the equipment used to accomplish these aims.

Frequency-of-seeing functions were obtained experimentally from three normal observers using a procedure that is well known in psychophysics, and will not be described in detail here. It is sufficient to note that in determining the increment and decrement threshold functions one of the two light-flash periods was always held constant at 1.0 msec. This is referred to as the "standard." The other, the "variable," was chosen in exploratory trials so as to provide a range of "percents seen" that extended from near 0% to near 100%. The results of repetitive observations were then

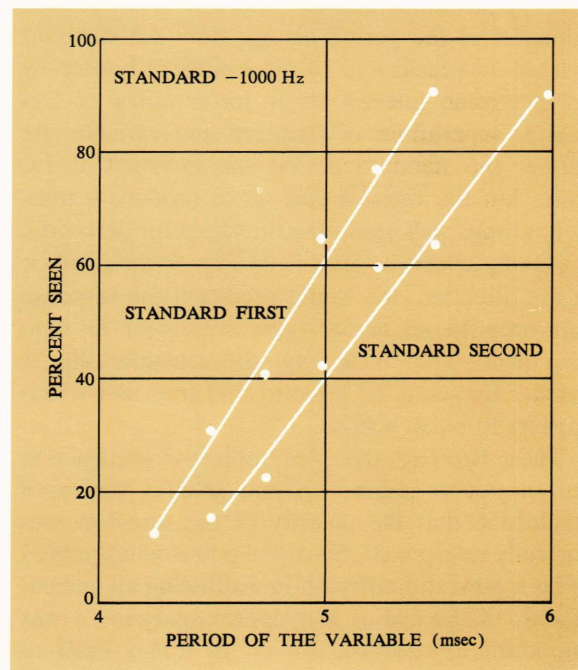


Fig. 4—Transient frequency-of-seeing functions for one observer.

recorded and plotted as frequency-of-seeing functions for the visual transient as a function of the variable period. Figure 4 shows one of these plots for an observer whose thresholds were typical.

Looking at these data there can be no doubt that the "standard first" condition yields the more sensitive threshold, i.e., less frequency separation is required to produce a detectable transient than with the reverse configuration. The more sensitive condition is also the one that produces a transient which to the observer appears as a light decrement, thus giving some objective confirmation to the original subjective evaluation.

### A Reaction-Time Test to Determine the Sign of the Visual Transient Response

Just as there is some evidence that the eye is more sensitive to light decrements than to light increments, there is also some evidence that speed of reaction is similarly influenced. Apparently one can react faster to a decrease in light intensity than to an increase.

Using the same equipment and luminance conditions as in the previous test, the same three observers were set the task of responding as quickly as possible to the appearance of the transient by pressing a microswitch. The time from the initiation of the period change until the observer reacted was measured to the nearest 0.1 msec by an electronic interval timer for a range of frequency separations of standard and variable. As before, the standard period was constant at 1.0 msec, but the variable was set to produce a transient always well above the threshold for detection.

Again, as can be seen from Fig. 5, the result is in the direction one would predict if the response had been to an actual light decrement or light increment. That is to say, the reaction time is quicker by about 20 msec to that transient which appears to be an eclipse.

These two tests then, lend objective credence to the subjective impression and give us increased confidence that the polarity of the transient was correctly interpreted. Since the polarity has proved to be a powerful criterion in evaluating all current models of the eye as a temporal analyzer, it was important to establish this on as firm a basis as possible. With that done, let us demonstrate the theoretical significance of the transient, and in particular, the polarity criterion it imposes.

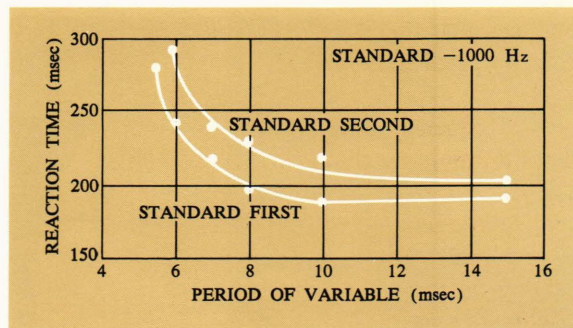


Fig. 5—Mean reaction time to the appearance of the transient as a function of the period of the variable modulation rate.

### An Analytical Look at the Transient

The stimulus is, in essence, an abrupt transition between two steady-states of high-frequency luminance oscillation around a constant mean level. In either initial or final state, the luminance appears of constant brightness equalling that due to the constant mean luminance alone, the familiar observation noted above which has been codified as the "Talbot-Plateau law." The brightness transient produced by the abrupt jump between states is an unusual phenomenon, in the sense that its proper stimulus, a transient luminous energy input, is not present. True, it is reasonable theoretically that the jump should cause an impulse-like response in the brightness system; as we shall see, any model system of interest easily gives some such response. But—just as blithely—that response turns out as a rule to have the wrong sign.

The curious nature of the stimulus is borne out in that the observed polarity of the response is opposite to that predicted by all existing models for brightness vision. This might seem trivial to put aright, by merely reversing the polarity convention in the models. However, that is already fixed by the sensible requirement that a real luminance increase (step) should lead to a brightness increment in the model. Thus, model-systems are caught between the dilemma of a wrong sign either for step (and long flash) responses or for the period-jump response here.

By dint of careful observation, as we said, the polarity of the transient responses can be directly perceived, and has been objectively confirmed. The subjective experience correlated with the period-jump is a brightness increment in the case  $t_1 > t_2$ , and a decrement if  $t_1 < t_2$ . One can easily verify for simple models, e.g., integrators or RC

analog, that the direct perception contradicts the polarity predicted by them.

But the experimental measurements on thresholds, frequency-of-seeing curves, and reaction-times do more than confirm the perceived polarity. They show that the period-jump responses are very reproducible and have a low noise level. Correspondingly, the phenomena show high sensitivity, verging on the hypothetical "neural quantum" of brightness sensation. Thus, the data easily quantify the distinction between the responses of opposite polarity, whereas experiments with real brief luminance impulses have difficulty measuring the differences between light and dark "flashes."

Theoretically, these transient responses have great importance as elemental responses of the brightness system. And they take special interest by contradicting proposed models. It is fortunate, then, that the transients are mathematically tractable. In fact, it is easy to analyze any other related transients of this same elemental class. Thus, the jump stimulus is between two periods ( $t_1, t_2$ ) in most of the experiments, but other waveform discontinuities can be and have been tried (jumps in modulation amplitude and/or phase). Further, the square-wave form of the carrier is inessential and more general waveforms raise no barriers to the analysis. Therefore, we have constructed the following general mathematical apparatus with which to analyze the observations.

## General Theory of the Brightness Transient

The stimulus-response relation we write formally as

$$\mathcal{R}(t) = \mathbf{O} \times \mathcal{J}(t), \quad (1)$$

where  $\mathcal{J}$  is illuminance input to the retinal photoreceptors and  $\mathbf{O}$  a complicated operator transforming illuminance into brightness sensation  $\mathcal{R}$ . The latter is the cortical response which, together with whatever perceptual detection scheme is prescribed by experimental conditions, is presumed to underlie the subjective brightness experience. We display only the time ( $t$ ) dependence, but spatial behavior and parametric variation such as adaptation level effects are to be understood. Thus, since the visual system is multichannel, both  $\mathcal{J}$  and  $\mathcal{R}$  are many-component vectors and  $\mathbf{O}$  a rectangular matrix of operators.

The general relation of Eq. (1) becomes ame-

nable by virtue of the character of the stimuli discussed here. These may be written

$$\mathcal{J}(t) = \mathcal{J}_0 + I(t), \quad (2)$$

where  $\mathcal{J}_0$  is the constant mean illuminance and  $I(t)$  the high-frequency discontinuous modulation. Now, observe that the first operation in  $\mathbf{O}$  in Eq. (1) is the transduction of retinal illuminance via photomolecular reactions, which quantum theory says are strictly linear in  $\mathcal{J}$  and severely time-smoothing. From this one can show that the photomolecular response modulation is linear in  $I$  and relatively small. Then, subsequent visual operations in  $\mathbf{O}$  can process the high-frequency  $I$  linearly, to a good approximation. (This argument explains, and gains support from, the findings that physiological oscillatory responses are surprisingly linear, which has been somewhat of a conundrum since the visual system is not at all patently linear. It also rationalizes the success of deLange's experimental linear analyses, Fig. 1.)

Therefore, although  $I$  is not small—in fact,  $|I/\mathcal{J}_0|$  approaches 100% here—we may nevertheless linearize Eq. (1) with (2) to the form

$$\mathcal{R}(t) \approx \mathcal{R}_0 + \int_{-\infty}^{\infty} G(t, t') I(t') dt'. \quad (3)$$

The first term is the constant Talbot-Plateau brightness  $\mathcal{R}_0 \equiv \mathbf{O} \times \mathcal{J}_0$ . In the second term, the linear operation on  $I$  is here conveniently expressed in terms of the (matrix) Green's function  $G(t, t')$ , which is the response of the visual system to an infinitesimal impulse in the light-adapted state  $\mathcal{R}_0$ . Equation (3) assumes, of course, that the system is linearizable in principle, i.e., that the  $G$  exists.

Now, an arbitrary isolated waveform discontinuity in  $I(t)$ , at  $t = 0$  say, may be written

$$I(t) = I_1(t) + S(t)[I_2(t) - I_1(t)], \quad (4)$$

where  $S(t) = 0$  for  $t < 0$  and 1 for  $t > 0$ . Inserting this into Eq. (3) gives for the deviation from constant brightness  $\mathcal{R}_0$  the

$$\begin{aligned} \text{transient} &= S(t) \int_{-\infty}^0 G(t, t') [I_1(t') - I_2(t')] \\ &\approx G(t > 0, 0) \cdot \sum_{l=1}^{\infty} \frac{1}{2\pi l} [b_2(l) t_2 - b_1(l) t_1]. \end{aligned} \quad (5)$$

The latter approximation is valid for  $t_1$  and  $t_2$  small relative to the system time scales  $\sim G/\dot{G}$ . Any singularities of  $G(t, t')$  at  $t = t' = 0$  are excluded

and  $b_1(l)$  and  $b_2(l)$  are the sine coefficients in Fourier expansions of  $I_1(t)$  and  $I_2(t)$ , respectively.

In particular, for the period-jump square wave-form in Fig. 2,  $b_1(l) = b_2(l) = (2\mathcal{J}_s/\pi l)(1 - \cos \pi l)$ , and Eq. (5) simplifies to

$$G(t > 0, 0) \cdot [t_2 - t_1] \frac{1}{4} \mathcal{J}_s, \quad (6)$$

where  $\mathcal{J}_s \equiv \mathcal{J}_0 - \mathcal{J}_b \approx \mathcal{J}_0$  for small background illuminance  $\mathcal{J}_b$ . Note that in the approximate Eqs. (5) and (6) the system  $G$  and the stimulus parameters appear in separate factors, which facilitates application. For example, Eq. (6) yields at once threshold curves  $t_1$  vs.  $t_2$  that are approximately straight lines, as is observed. Similarly, Eq. (5) predicts the observed dependence of thresholds on the phase at which discontinuity occurs. In principle, as a complete description of experiment with general waveform, Eq. (5) promises a useful analysis of the visual system. Most arresting for now is the polarity of the period-jump responses.

### Polarity Criterion

We saw above that the observed polarity is positive for  $t_1 > t_2$ , negative for  $t_1 < t_2$ . From Eq. (6), that means

$$G(t > 0, 0) \text{ predominantly } < 0 \quad (7)$$

as seen by the perceptual detector. This is strange, since various integrals of  $G$  (step responses, etc.) are detected as positive. Consequently, one might guess that Eq. (7) would afford a strong test for visual models. For example, any model with a monophasic  $G$  is ruled out at once.

We have applied Eq. (7) as a "polarity criterion" to various sorts of models for the temporal behavior of brightness vision. Although all give a transient phenomenon—as the general analysis insists—none gives the correct sign. Of course the criterion Eq. (7) is only a necessary, not sufficient, condition which is of use chiefly in criticizing models. Nevertheless, it can be of some help to building a viable model. For example, among the class of single-channel models made up of integrations and differentiations/or their electrical analogs, the criterion Eq. (7) favors one in particular, two integrators and a second-order differentiator in series. To "save the phenomenon" of strong high-frequency attenuation (Fig. 1) in this model, one must add to it something like a detector that imposes a response duration threshold.

It is interesting that if one interprets this as a "ganglion cell" analog in a retinal model, it fits nicely with physiological data on flicker responses of such cells in the cat. In addition, it could help resolve the psychophysical paradox noted below. Of course, such a simple single-channel model ought not to be taken literally, nor expected to reproduce detailed data.

### A Perceptual Paradox

In vision, as distinct from models of it, the curious nature of the stimulus exhibits itself in a dramatic way. When real, brief luminance changes are made to coincide with the period-jump transient, the perceptual strength of the transient appears attenuated if the objective sign of the luminance change and the subjective sign of the transient are the same. Conversely if the objective and subjective signs are different, then the perceptual strength of the transient appears heightened. Thus the perceived polarity poses a paradox. To the extent that the brightness system operates linearly with the superposed luminance changes, we can only conclude that it fails to conserve polarity somewhere in its transformation of brief flashes. By way of illustration, if the system  $G$  had positive phases that are brief, however strong, then a simple duration threshold such as above could reverse the response polarity for brief flashes while still conserving polarity for long flashes or steps.

### Prospectus

All of this work has been of a psychophysical character. However, studies of physiological responses to the same waveform discontinuity stimuli should give further valuable information about the visual system. Such studies have the advantage of avoiding the purely psychological problems, such as the hypothetical perceptual detector, although no doubt introducing their own difficulties, such as the interpretation of massed responses. Nevertheless, it is encouraging that the above analytical formulation may be applicable generally beyond the initial photomolecular transduction process. Thus, if one can measure the transient responses in the ERG (electroretinogram), the EEG (electroencephalogram), or other signals, one can analyze these also via Eq. (5), only interpreting  $G$  now as the impulse  $G_{\text{ERG}}$ ,  $G_{\text{EEG}}$ , etc. relevant to

that part of the visual system (and its satellites) that produces the signals.

## The Visual Transient in Clinical Applications

Our earliest studies on the visual transient response indicated its high degree of sensitivity and stability. Confirmation of this fact is seen in Fig. 4, where for the most sensitive condition a change of only 1.5 msec in the variable period covers the entire range from not perceiving the transient at all to perceiving it 100% of the time. This result has been repeated many times with ease and with several different observers. Such precision is almost unheard of in visual psychophysics and so quite naturally led us to consider the use of the transient as an early warning device for developing retinal pathology.

The need for sensitive indicators of visual function is continually felt in the ophthalmological clinic. This is particularly true when it comes to detecting degenerative diseases whose onset and development are slow. Simple glaucoma is one such. Developing usually after the age of about forty, it can progress undetected causing irreparable destruction of nerve fibers in the retina. Unchecked, it can lead to total blindness. Several forms of therapy are available for halting the ravages of glaucoma, once detected, and the simplest are those applicable to the disease in its very earliest stages. Obviously then, it is of paramount importance to detect glaucoma as early as possible.

In the clinic one of the earliest warning signs is an increased intraocular pressure, which, if allowed to persist, may be followed by neurological involvement. This latter consists typically of an enlargement of the blind spot which exists in all normal eyes as a consequence of certain anatomical features. Because a blind spot exists normally, and quite unknown to most people, its slow and gradual extension often remains unperceived until it has attained more than a superficial extent. By probing the visual receptive field with small spots of light, a skilled and careful clinician can determine the extent of the damage incurred. This technique also permits evaluation of the efficacy of the therapy applied.

So far so good, but there are complications. For one, it is becoming increasingly manifest that there is a group of people with higher intraocular pressures than the normal population who do not de-

velop signs of neurological involvement which can be detected at present. Studies are presently underway to determine whether these people do, over long periods of time, eventually suffer retinal deterioration. More sensitive measures of retinal function than are currently available would then appear to be an obvious boon to the physician whose responsibility it is to initiate therapy.

## A Normal Population Study

The transient we have been discussing was unknown until a few years ago. Consequently, relatively few data have been collected under standardized conditions which would permit its use in a diagnostic way. Before meaningful clinical trials could be conducted we had to establish reliable population norms for those variables which were considered to be relevant. These were, in the main, age, sex, intensity of the modulated light source, and position of the stimulus on the retina, i.e., whether viewed directly or from the corner of one's eye, so to speak. This latter variable is important for two reasons. First, the eye is generally less sensitive in its periphery under conditions of moderate illumination, but just how much less sensitive was not known in this case. Second, the blind spot in the normal eye is located about  $15^\circ$  from the central fovea in the temporal field of view, along the horizontal meridian. Since this area is implicated in the early stages of glaucoma it seemed important to explore it if possible.

A pool of observers with normal eyes, as determined by complete ophthalmological examination, was drawn from volunteer staff-members of the Applied Physics Laboratory. Examinations were performed at the Wilmer Ophthalmological Institute by Dr. Irvin P. Pollack. A total of 30 volunteers provided five thresholds for each eye, for two different levels of stimulus intensity and at four different positions of the horizontal meridian—a total of 80 thresholds per observer. The 30 observers included 3 males and 3 females for five decade age groups from ages 21–70. The modulation pattern shown in Fig. 2 was used. The observer controlled the onset of the stimulus with a switch, and he also controlled the period of  $t_2$  ( $t_1$  remaining fixed at 1.0 msec), adjusting it until the transient just disappeared. The period of  $t_2$  was then the datum recorded.

Careful analysis of the results from all observers led to the conclusion that the only important

variables affecting transient thresholds were stimulus intensity and retinal position. Table 1 shows the mean threshold periods of  $t_2$  with standard deviations at various retinal positions for all normal observers at one intensity level. Also shown are results from several observers who supplied thresholds at two retinal positions along the 30° meridian.

TABLE 1  
MEAN THRESHOLD SETTINGS  
AND STANDARD DEVIATIONS  
FOR ALL NORMAL OBSERVERS

(Values are periods of the variable rate in msec)

	Retinal Position					
	Horizontal Meridian				30° Meridian	
	0°	3°	6°	10°	3°	6°
Mean	4.62	9.59	11.20	11.59	12.96	15.33
$\sigma$	0.94	2.21	2.61	2.88	2.69	2.59

## The Clinical Study

Volunteer patients from the private practice of Dr. Pollack are being seen and tested at the Wilmer Ophthalmological Institute. The main body of them can be classified by one of three categories, as follows: (a) patients whose intraocular pressures were higher than normal at test, i.e., pressures above 20 mm Hg, but had no neurological involvement insofar as could be determined, (b) patients with no signs of neurological deterioration whose pressures had been higher than normal but due to drug therapy were normal at the time of testing, (c) patients on therapy who had suffered some glaucomatous neurological changes.

The testing procedure in the clinic was identical with that used for the normal population except that it was not as extensive. Experience with testing of the normal observers prompted elimination of the brightest of the two light intensities. While, in general, it yielded lower thresholds, it also was uncomfortably bright to view for long periods of time. Also, to further reduce the tediousness of the testing sessions, no thresholds were obtained in the clinic for retinal areas 10° from the direct line of view.

At this writing, data are still being gathered and will continue to be for quite some time, so it must be emphasized that any results to date are tentative. Table 2 shows the mean threshold periods and standard deviations for the three categories of patients so far completed. Comparing this table with Table 1 leads to the suggestion that patients with raised intraocular pressures yield, in the aggregate, higher thresholds and greater variability than normals, whether their pressures were elevated at time of test or were reduced to normal by drugs. Also, patients who have suffered some visual loss due to simple glaucoma exhibit elevated thresholds in unaffected portions of the retina, when compared with normals.

TABLE 2  
MEAN THRESHOLD SETTINGS  
AND STANDARD DEVIATIONS  
FOR ALL CLINIC PATIENTS

(Values same as Table 1)

	Retinal Position				
	Horizontal Meridian			30° Meridian	
	0°	3°	6°	3°	6°
Hypertensives—Intraocular Pressures > 20 mm Hg					
Mean	6.57	13.70	15.08	14.82	17.23
$\sigma$	2.52	3.68	5.12	3.33	4.09
Hypertensives—Intraocular Pressures < 20 mm Hg					
Mean	6.67	12.36	14.75	16.51	19.02
$\sigma$	2.56	3.69	4.55	5.06	3.02
Patients with Glaucomatous Neurological Involvement					
Mean	10.09	12.25	14.08	11.69	12.71
$\sigma$	4.89	1.87	0.95	4.11	2.45

Of further interest, though not shown by the tables, is the fact that those patients classed as hypertensives, i.e., not exhibiting any neurological involvement, seem to fall naturally into two classes as regards their transient threshold. One of these classes, amounting to about one-third of the total group, produces thresholds at all retinal positions that are completely within the normal range. The other two-thirds of the group all have thresholds that are markedly higher than normal. The crucial question that only follow-up study will answer is whether or not the higher than normal two-thirds are among those who will ultimately develop the deteriorating signs of glaucoma.