and independent manipulation of sets of behaviors from all of the important members of a primate group. Together, these two features should permit many interesting experiments on primate behavior to be undertaken.

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2. A complete technical description of the system is in preparation. We acknowledge the valuable assistance of Mr. Morris Waxler and Mrs. Thelma Galkin.

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Neural Stage of Adaptation between the Receptors and Inner Nuclear Layer of Monkey Retina

Abstract. *The local electroretinogram of the monkey retina is recorded by intraretinal microelectrodes. Observations of the late receptor potential, isolated by selective clamping of the retinal circulation, show that when the retina is light-adapted by repetitive stimulation, the amplitude of the receptor potential is only slightly reduced over a slow time course. The reduction in amplitude of the* b*-wave is much greater and occurs much more rapidly. Thus there is a neural stage of adaptation between the late receptor potential and the generation of the* b*-wave by cells of the inner nuclear layer.*

The existence of neural mechanisms of adaptation within the retina has been reported in several notable papers (*1–3*). These neural mechanisms are little understood, but represent stages of adaptation in addition to photochemical adaptation, which results from the breakdown of photosensitive pigment by light and its regeneration in the dark. In the experiment described here, neural adaptation was demonstrated in the monkey retina by the direct recording of electrical responses from the receptors and from the inner nuclear layer. We show that one stage of neural adaptation occurs between these levels of the retina.

We obtained intraretinal recordings from the cynomolgus monkey (*Macaca irus*), using techniques already described in detail (*4*). The animals were anesthetized by thiopental sodium, relaxed by continuous intravenous infusion of succinylcholine, and given artificial respiration. A specially designed light stimulator was used for stimulation through the normal optics of the unopened eye (*4*). The retinal stimulus spots and the intraocular devices were all positioned under visual control, with the aid of a hand ophthalmoscope. Three needles were inserted into the temporal side of the eye, two of which were used as channels for electrodes. The microelectrode was of the tungsten type, with tip diameter less than 0.5 μ, and the reference electrode was a Ag-AgCl wire in the the vitreous humor. With this position of the reference electrode, it has been shown that an intraretinal microelectrode records almost exclusively a local electroretinogram (LERG) from a small area around the electrode (*5*). All components of this LERG, aside from the *c*-wave, are recorded at inverted polarity with respect to conventional ERG recordings (*5*). A steel rod with a rounded end was inserted into the third channel. This was used to apply pressure upon the optic disc, thus clamping the retinal circulation without affecting the choroidal circulation (*6*). This procedure abolishes ERG components which are generated by cells of the inner nuclear layer, but not the component which has been called PIII in the terminology of Granit (*6*). This component is maintained in a stable condition by the choroidal circulation, and studies of the isolated PIII have shown that it is generated by the receptors (*6, 7*). It is now called the late receptor potential, since an earlier receptor potential has been found which has no detectable latency (*8*). A variety of methods have shown that the *b*-wave of the ERG is generated by cells of the inner nuclear layer (*6, 9, 10*). Hence the comparative effects of light adaptation were observed for the late receptor potential and the *b*-wave, and the results are shown in Fig. 1.

Both series of responses in Fig. 1 were recorded from the same animal and the same area of the peripheral retina. Also, in both series the microelectrode was against the retinal side of the R-membrane, and this position has been shown by electrode marking to be against the retinal side of the pigment epithelium (*11*). Prior to the normal series of responses, the retina was first light-adapted by repetitive stimulation with the stimulus light until the responses were stable in both form and amplitude. Then the eye was adapted to darkness for 15 minutes, after which the time course of light adaptation by successive stimuli was traced. In the response series the stimuli served both to evoke the responses and to light-adapt the retina. After the normal series of responses the electrode was withdrawn from the retina, the retinal circulation was clamped to isolate the receptor potential, and the electrode was reinserted to the original level. The procedure was then repeated for the isolated receptor potential.

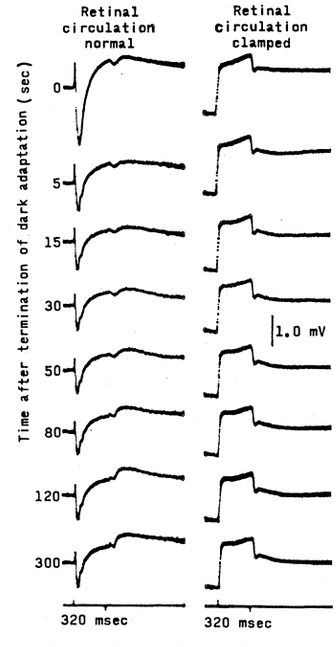

Fig. 1. The effect of light adaptation by successive stimuli upon the normal LERG (left column) and upon the late receptor potential after isolating it by clamping the retinal circulation (right column). Prior to each series of responses the retina was adapted to darkness for 15 minutes. Then the retina was light-adapted by a stimulus of 320-msec duration, repeated every 5 seconds, and each response was recorded. Representative records of this series are shown. The stimulus spot was centered upon the electrode; it had a retinal diameter of 2.72 mm and gave a retinal illumination of 3.28 log lumen/m^2. Direct-coupled amplification. Positive responses displayed as upward deflections, following the convention for ERG work.

The effects of light adaptation upon the normal LERG include a large and rapid reduction in amplitude of both the positive *a*-wave and the succeeding large negative *b*-wave. In the normal LERG the rising phase of the *a*-wave is the leading edge of the late receptor potential (*6*). The *b*-wave is a large response of opposite polarity, the onset of which creates the peak of the *a*-wave. Apparently the onset of the *b*-wave is delayed, with respect to onset of the receptor potential, because of the generation of the *b*-wave at a later stage of the retinal pathway. It is obvious from these considerations that the amplitude of the *a*-wave is not a direct measure of receptor activity; its amplitude is affected not only by amplitude of the receptor potential, but also by the relative latencies of the receptor potential and *b*-wave. Thus the true amplitude of the receptor potential may be obtained only by studying this response in isolation from later responses, as shown in the right column of Fig. 1.

The isolated receptor potential shows a rapid onset. When the stimulus terminates, there is a phase of rapid decay followed by a phase of decay which is so slow that the response does not reach the baseline within the time covered by the records. Since the cone receptor-potential decays rapidly, while the rod receptor-potential decays very slowly (*6, 7*), the response form in the peripheral retina of the cynomolgus monkey appears due to a simple summation of cone and rod receptor-potentials.

Since the amplitude of the isolated receptor potential was little affected by the same stimulus conditions which greatly reduced the *a*-wave, Fig. 1 demonstrates the fallibility of *a*-wave amplitude as an index of receptor activity. But the effect of light adaptation upon *a*-wave amplitude must be explained. It has recently been emphasized that light adaptation decreases the latency of the *b*-wave (*12*), and distinct reductions of *b*-wave latency by light adaptation were noted in this study. Our results indicate that the reduction of *a*-wave amplitude by light adaptation in Fig. 1 is due primarily, if not entirely, to this reduction of *b*-wave latency by light adaptation.

The main data obtained from Fig. 1 are plotted in Fig. 2. The amplitude of the late receptor potential decreased slowly and steadily during the first 80 seconds, after which no clear further decrease of amplitude occurred, and the total decrease in amplitude was only about 16 percent. By contrast, the amplitude of the *b*-wave showed a large and rapid initial drop, followed by a slower decrease of amplitude, and no further decrease in amplitude was evident after about 50 seconds. The amplitude of the *b*-wave decreased 42 percent in the second response, and the total decrease in amplitude was about 60 percent. These findings seem to provide a basis for the observation in the cat that the *b*-wave is more strongly influenced by adaptation than the *a*-wave (*10*).

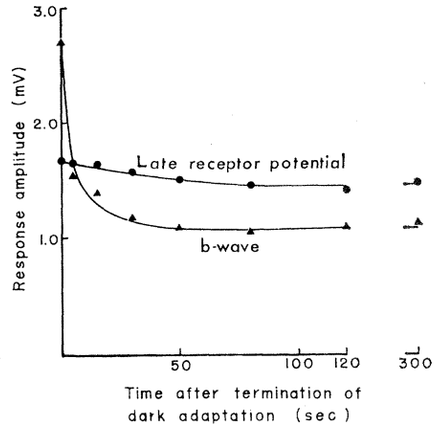

Fig. 2. Changes in amplitude of both the *b*-wave and the late receptor-potential as a function of light adaptation by successive stimuli. This plot was made from the records of Fig. 1. The amplitude of the *b*-wave was measured from the peak of the *a*-wave to the peak of the *b*-wave. The amplitude of the receptor potential was measured from the baseline at a point on the time scale which was just after completion of the rapidly rising phase of the response.

In Fig. 2, the amplitude of the receptor potential was measured from the baseline, just after completion of the rapidly rising phase of the response. Since both the rod and cone receptor-potentials exhibit a rapid rise from the baseline (*6, 7*), this method of measurement gives the combined cone and rod responses. Since the *c*-wave is generated by the pigment epithelium, it is not abolished by clamping the retinal circulation. But the *c*-wave has proved quite small in the cynomolgus monkey, by comparison with the receptor potential, and is not distinctly present in the records of Fig. 1. Also the *c*-wave develops very slowly; thus measurement of the receptor potential just after its rapid rise largely, if not entirely, excludes the *c*-wave.

Since the amplitude of the isolated receptor potential changed very little during light adaptation, the *b*-wave of the normal LERG was superimposed upon a receptor potential of relatively constant amplitude. Also, the receptor potential decreased slowly along an approximately straight line, while the *b*-wave fell very rapidly and then more slowly. Likewise, if the slow decrease in amplitude of the receptor potential had any effect upon measurements of the *b*-wave, it should have increased the measured amplitude of the *b*-wave. Thus the observed decrease of the *b*-wave during light adaptation occurred in spite of, rather than because of, the simultaneous small decreases of the receptor potential.

Since the stimuli of Fig. 1 were spaced at 5-second intervals, the light adaptation which occurred was not as complete as would be attained with continuous light adaptation. The receptor potential should be markedly reduced by light adaptation which is sufficient to produce significant bleaching of the photosensitive pigment, and this has been confirmed. After continuous light adaptation for 12 minutes by light of the same intensity as that used for stimulation in the experiment of Fig. 1, the recovery of the isolated receptor potential was traced by giving brief stimuli every 30 seconds. During recovery from light adaptation, as determined by this procedure, the amplitude of the receptor potential increased by a factor of about 6. Thus continuous and prolonged light adaptation can markedly affect the amplitude of the receptor potential. An accurate comparison cannot be made between recovery of the *b*-wave and receptor potential, following such light adaptation, since the *b*-wave is superimposed upon a receptor potential which is changing greatly in amplitude.

Since the retina of the cynomolgus monkey is very similar to that of the human, our results may be expected to pertain to mechanisms of adaptation in the human retina. Rushton and Westheimer (*2*) showed in human subjects by psychophysical methods that under certain conditions of light adaptation the mechanism is not photochemical but is entirely at some level of the retinal pathway where the response is influenced by stimulating

receptors over a significant area of the retina. The results of Fig. 1 likewise show little photochemical adaptation, and the locally recorded *b*-wave is influenced by convergent pathways from receptors (*10*). Our findings also compare well with those of Dowling (*3*), who showed in the rat that low levels of light adaptation which did not bleach rhodopsin nevertheless caused changes of sensitivity, as demonstrated by recording *b*-waves of threshold amplitude; stronger light adaptation was required to demonstrate reductions in the concentration of rhodopsin. Thus our results confirm, by independent methods, the findings of both of these studies. Our results also define more precisely one of the levels of the pathway through the retina at which a neural mechanism of adaptation occurs.

It was recently found that the late receptor potential is affected by interaction among receptors and, furthermore, that the type of interaction among receptors differs between light- and dark-adapted states (*13*). Hence neural effects of adaptation have also been demonstrated in terms of the late receptor potential. Such effects have been seen only when particular efforts were made to keep the anesthetic as light as possible; they were not seen under similar stimulus conditions in this study, where no such special efforts were made. Thus the interaction among receptors, which is influenced by adaptation, is apparently mediated by synaptic pathways which are particularly sensitive to barbiturate anesthetic. Since the deeper anesthetic used in this study blocks the interaction among receptors, a functional isolation of the receptors from each other seems to have been approximated. This simplifies the interpretation of amplitude of the late receptor potential. Under these conditions the late receptor potential should reflect any photochemical adaptation which occurs, and also any adaptation which may occur in the processes which intervene between absorption of light by the photopigment and generation of the late receptor potential (see *8*). Since our results with the late receptor potential are similar to those obtained by Dowling (*3*) with rhodopsin concentration, there is no indication so far of a stage of adaptation in the mechanism of generating the late receptor potential. The earliest stage of neural adaptation which has been identified is a qualitative change in the type of receptor interaction which affects the late receptor potential. Hence the type of neural adaptation reported here is at least the second stage; this occurs between the late receptor potential and the generation of the *b*-wave by cells of the inner nuclear layer.

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Cesium-137 in Alaskans

Commenting on our report on cesium-137 in Alaskans [H. E. Palmer, W. C. Hanson, B. I. Griffin, L. A. Braby, *Science* **147**, 620 (1965)], S. Novick (*ibid.*, p. 1596) asks for a "bench-mark value" with which the increases we reported can be compared. Although the Federal Radiation Council has not given specific recommendations regarding the allowable radiation dose for cesium-137 as they have for iodine-131, strontium-90, and radium-226, the maximum permissible body burdens of cesium-137 for a population and individuals can be derived from the council's recommendations.

As Novick says, FRC recommendations indicate that the average body burden of cesium-137 for a population should not exceed 1000 nanocuries. This is one-third the amount calculated to deliver 0.5 rem if the amount is constant in the body for one year. The average adult body burden of 1280 nanocuries during the summer of 1964 at Anaktuvuk Pass was the maximum value for that year, and the average burden decreases to about half this maximum value during the winter months, as we indicated. Five measurements of cesium-137 in Anaktuvuk Eskimos during 1964 show that the yearly average adult burden was 940 nanocuries, which does not exceed the RPG for a population. The highest average individual body burden at Anaktuvuk Pass in 1964 was 1620 nanocuries, which is below the RPG for an individual. The person with a 3000-nanocurie burden was not an Alaskan native and was not from Anaktuvuk Pass.

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