

THE SIGNIFICANCE OF ANTIDROMIC POTENTIATION AND INDUCED ACTIVITY IN THE RETINA *

R. GRANIT

FROM THE NOBEL INSTITUTE FOR NEUROPHYSIOLOGY, KAROLINSKA INSTITUTET, STOCKHOLM, SWEDEN

ABSTRACT

It is argued that »The significance of antidromic potentiation and induced activity in the retina» (the title of this article) concerns two identical effects and that both are the outward sign of the existence of a specific organization in the retina. For this reason they can serve as a valuable criterion for identifying activity in this organization. This activity is assumed to be in the nature of a self-excitation by positive feedback in the amacrine circuits of certain Y-cells. Relevant literature has been reviewed. These Y-cells, whose spectral response curve is of the dominator type, play a prominent role in stimulation by intermittent light and in the perception of luminosity. Several properties of intermittent stimulation are mentioned and held to motivate a renewal of the attention of visual experimenters to 'flicker' and its after-effects.

KEY WORDS: RETINA; Y-CELLS; DOMINATORS; LUMINANCE CHANNEL

Our work in the late forties and early fifties on the role of the centrifugal gamma fibres to the muscle spindles made me consider centrifugal fibres to the mammalian eye. Ramón y Cajal (45) had reported the existence of such fibres in the retina of the dog and I thought it very unlikely that he could have been mistaken. Others have since shown less faith in the old Master, but in the laboratory of another highly competent histologist (Powell) centrifugal fibres have again been found in the optic nerve of the cat. I quote: »These electron microscopic observations of the retina following lesions of the central visual pathway may be accepted as valid evidence for the presence of centrifugal fibres to the retina in the mammal» (2).

I mention this to explain why my stereotactic attack on this problem made me in the first instance go for the colliculus superior in the cat, rather than for the lateral geniculate body or the optic tract itself (25).

At the time it was held that only slow fibres pass to the colliculus and so it came as a surprise how very easy it proved to activate the large ganglion cells by antidromic shocks to that region. When the pick-up electrode was shifted from the point of entry of the optic tract toward the periphery, the latent period increased from about 1.2 msec at the lamina cribrosa to between 4 and 6 msec further out. I concluded that, inasmuch as timing has informative relevance, the retina is admirably organized for translating surface coordinates into time coordinates, provided that the eye moves. These relations were then systematically explored by Dodt (13). I was thinking of the familiar Pulfrich effect.

I then tried tetanizing antidromically for some 10 or 20 sec and, to my great surprise, as soon as stimulation was stopped the isolated ganglion cell started firing at a rate greatly exceeding its previous spontaneous activity. Orthodromic potentiation was well known at the time but nobody had yet succeeded in obtaining an antidromic potentiation. The prevailing notion was that the antidromic spike entering its axonal ganglion probably extended its depolarizing action into the dendrites but not any further. In motoneurons the most striking effect known today is that of Decima and Goldberg (8, 9): if an antidromic ventral-root shock is suitably timed

* This Lecture was worked out while the Author was Visiting Professor at the Max-Planck Institute for Physiological and Clinical Research, W. G. Kerckhoff Institute, Bad Nauheim, W. Germany. A copy of it was also sent to the inauguration of the Vision Institute at the University of Houston, Texas, the author himself being prevented from attending.

relative to a conditioning, adjacent root potential, the shock fires a dorsal root spike.

In my experiments not all cells produced a post-tetanic potentiation but all those that did had to be driven by the antidromic shocks. This suggested that the post-tetanic discharge could hardly be a centrifugal phenomenon, even though a centrifugal contribution could not be excluded. Driving of the ganglion spike was a too obvious *conditio sine qua non*. Frequency of tetanization and its duration were decisive in determining the duration and firing rate of the post-tetanic discharge. This sometimes reached values as high as 200—300 per sec, maintained for minutes. As I remember, most of my preparations were Bremer's encephale isolé, though some were on pentobarbitone anaesthesia. The facilitation sometimes lasted for a couple of minutes and active cells often began firing during tetanization — the rate of stimulation permitting. The effect could also be obtained from the geniculate body and the optic tract, but from these structures it was commonly complicated by inhibitory phenomena.

An idea of the degree of post-tetanic facilitation could be gained by translating firing rates into light intensity. Thus, for instance, a test flash of 5 Lux was raised in effectiveness in the post-tetanic state so as to correspond to one of 600 Lux. Dodt (14), later experimenting with rabbits, found the flicker fusion frequency of a given test light raised from 16.5 *before* to 35 flashes per sec *after* antidromic tetanization.

Decisive for my conclusion that the antidromic spikes actually entered the retina were several experiments on interference between tetanization and light stimulation. Thus, for instance, when the antidromic spike failed to enter the ganglion cell during an inhibitory phase of the light test, it could be made to do so by merely increasing the stimulus strength of the shock, thereby bringing in other collicular terminals.

Recent experiments by others have since pushed the study of antidromic potentiation one step further and so I shall not review my old work in greater detail. Sixteen years later the problem was taken up by Fukada (21) who confirmed my findings and connected them with Enroth-Cugell and Robson's (19) important subdivision of the retinal ganglions into X- and Y-cells. Fukada showed that the potentiation only occurred in the

transiently responding Y-cells, which he called Type I, and not in the tonic Type II or X-cells, which to a stationary stimulus, focused on the centre of the receptive field, respond with a sustained discharge. The significant point here is that the post-tetanic effect was confined to an identified cell, even though at that stage the X-Y identification was tentative.

The next step (22) was to demonstrate that a similar long lasting after-discharge followed a flickering stimulus to the Type-I-cell receptive field organization. Fukada proposed the term »induced activity», which from now on I, too, intend to use. Saito and Fukada (46) confirmed the capacity of flickering stimulation to elicit induced activity and studied the responses of Type I and Type II cells to intermittent light. Even when they combined antidromic and flickering stimulation, only the Type I cell proved capable of generating induced activity.

These findings were confirmed by Cleland and Levick (6) who found induced activity only with their transient class of cell, apparently Fukada's Type I. From latency studies of the ganglion spike, combining light and optic tract stimulation, they concluded that the induced discharge »is associated with the appearance of an active spike-generating focus located somewhere along the axis of that cell».

The optic tract loses its myelin sheath at the lamina cribrosa and so the axons in their intraretinal course may acquire the complex properties of dorsal root C fibres. These are known from Gasser's (24, 25) studies of their spikes and after-potentials. This analogy may or may not be valid, but if it is, then one would expect the effect of a long-lasting tetanus to emerge as Gasser's (25) P_2 or second positive after-potential, which is of very long duration. During this hyperpolarization negative after-potentials of spikes are increased. It is not easily understood how a positive after-potential could be conducive to facilitation of the ganglion. If on the other hand after loss of its myelin sheath a fibre retains the original properties of A fibres, a tetanus would probably be followed by a brief hyperpolarization (P_1), rapidly changing into a depolarization, also of relatively brief duration compared with the final, long-lasting, positive P_2 , the only event of a duration long enough to approach that of an induced discharge. However, the polarity of P_2 is of the wrong sign.

In the intraretinal optic tract fibres of the monkey Ogden and Miller (43) noted an »intense negative post-tetanic overshoot». There was little in the way of positive after-potential. While this transient effect may aid the ganglion cell in forwarding Ogden's P-wave into the internal plexiform layer — I shall come to it below — no correlation is thereby established with the long-lasting induced discharges, so far not at all studied antidromically in the monkey retina. The post-tetanic negativity of Ogden and Miller is too brief to explain the long-duration of the induced activity. These problems clearly require more experimentation, such as an attack with microelectrodes on the internal plexiform layer.

At the moment we had better hold on to the two most significant new observations in this field: (i) that the induced activity can be elicited both by flicker from the orthodromic end as well as by repetitive antidromic stimulation; (ii) that both routes of activation presuppose a specific set of large ganglions, apparently those representing the final common path of the synaptic organization that is driving the Y-cells of Enroth-Cugell and Robson. An explanation based on a purely extraretinal axonic focus, not yet demonstrated, suffers from the weakness of not being able to account for the orthodromic effect of flicker and for the restriction of induced activity to merely one type of the approximately 200,000 fibres counted by Hughes and Wässle (36) in the cat's optic tract.

Some of the steadily multiplying studies which are now devoted to cat ganglion cells seem to be of particular interest in the present connection. Boycott and Wässle (1) described three main types of ganglions: large alpha cells with dendritic networks spreading laterally up to 1,000 μm , smaller beta cells with a field diameter of 25–300 μm , and still smaller gamma cells with a dendritic field between 180 and 300 μm . The identification proposed was: Y-alpha, X-beta, and W-gamma. The identification was based on the size of the perikaryon in combination with that of the dendritic network. For all cells the latter expands in size towards the periphery. I shall only be concerned with the Y-alpha type. It is generally accepted that the larger the perikaryon, the greater also the axonal diameter and hence the conduction velocity. The ganglion cells responding with induced activity are found among the large

ones that are provided with extensive dendritic networks.

This identification was fully supported by Hoffmann (34) and by Cleland, Levick and Wässle (7), who added the further specification that the Y-cells are the brisk-transient units of Cleland, Dubin and Levick (4) and Cleland and Levick (5).

According to a suggestion by Ogden (41), the antidromic spikes in the optic tract may enter the inner plexiform layer by mediation of the tight junctions discovered by Dowling and Boycott (15), which for good reasons were held to be electrical in nature; Saito and Fukada similarly assumed these junctions to give access to the internal plexiform layer. The tight junctions are axosomatic ones between bipolar terminals and somata of ganglion cells. Dowling and Boycott did not find them in the all cone portion of the primate retina and suggested that they were characteristic of rod bipolars.

When Ogden endowed them with the role of gate openers to the internal plexiform layer, this was done in order to explain the positive P-wave that he and Brown (42) had found in that layer in response to antidromic shocks. Ogden did not find any P-waves in the cat retina. In similar work Gouras (27) recorded a graded potential at the internal surface of the monkey retina. This potential became positive in the internal plexiform layer, had a shorter latency in the periphery, and longer in the centre where it also was larger and more drawn-out. The views of these two authors on the nature of the P-wave differ, but a more serious difference from the present point of view is that tight junctions were not found in the centre where the positive wave of Gouras had its maximum size.

As such it is of course a plausible notion that an antidromic spike — whatever it does afterwards — is gated into the internal plexiform layer by such apposition contacts. Again, however, we must conclude that there is room for more studies of the microphysiology of this region.

Returning to the question of why the Y-cells, or probably only certain Y-cells, generate induced activity, it stands to reason that a large dendritic network, better than a small one, by chance alone is bound to provide more targets for the output of those amacrine cells that are charged with the task of maintaining lateral spread of excitation. As to them, Dowling and Boycott have pointed

out that »no ganglion cell dendritic spread is large enough to account for these effects (meaning the long-distance McIlwain effect); the only direct pathways in the retina for the peripheral effects are via the amacrine-amacrine synapses» (p. 107).

However, since the explanation of specificity in producing induced activity somehow implicates Y-cells, it is not permissible to neglect their curious property of non-linear summation within the receptive field. To Enroth-Cugell and Robson (19) this was the essential criterion in their definition of Y-cells. I call this property curious, because my own experience with motoneurons, in both intra- and extracellular work, is that, within a large range of firing rates highly complex reflexes add in a strictly linear fashion (summary, see ref. 32). Similarly Enroth-Cugell and Robson found linear summation in the X-cells.

I therefore suggest that the non-linear summation of the Y-cells is a consequence of positive feedback within the amacrine circuits that support their activity. This, at the same time, would explain their proneness to excessive activity, noted also by Enroth-Cugell and Robson (19) when they stated that »the mean discharge of the Y-cells (unlike that of X-cells) was greatly increased when grating patterns drifted across their receptive fields». The nowadays commonly used Y-cell criteria, high conduction velocity, transient response, and a more peripheral location, need not in every case tally with that of non-linearity. In present day usage of the X-Y nomenclature the original Y definition is mostly neglected. If we had had experiments correlating induced activity with non-linearity of summation, we would now be better informed when discussing the nature of Y-specificity.

Of relevance to this line of thinking are some data by Dubin (17) dealing with the serial synapses of Kidd (37). Dubin found them to be characteristic of amacrines and he published a table showing among other correlations the percentages of amacrine synapses in serial configuration in different animals. These are some of his figures: human parafovea 1.9; monkey fovea 2.5, parafovea 7.1, periphery 5.1; cat (2 animals) 8.2 and 7.5 respectively; rabbit (2 animals) 10.0 and 15.2 respectively. With these challenging figures we again come up against questions of correlation, which can be answered only by appropriately designed experiments.

One task of those Y-cells which respond as if they were actuated by positive feedback could be to facilitate the recording of movement in the peripheral visual field and conduct the message at maximum speed to the cortex. This notion presupposes that the X-Y differentiation is maintained up to the central visual stations. For the geniculate body this has been found to be the case, in the cat (23, 35) and in the monkey (16). In this animal the Y-cell projections are found in the magnocellular layer, the X-cells in the parvocellular layer.

In addition to serving as transient fast detectors of movement, the Y-cells also contain information on luminosity. In now forgotten papers and in reviews (Granit, 1962 being the latest) the evidence was summarized that led me long ago to the conclusion that the dominators also in the cat are composite curves carrying a message of luminosity and not one of colour. It was shown that the same, large ganglion cell could serve as both scotopic and photopic dominator, this being true also for the retina of the cat. The destination of a message that has this character could hardly be a specifically colour-sensitive mechanism in the cortex. I had, in fact, postulated that in all animals the dominator originated a luminance channel.

In now proceeding to discuss some results of primate physiology in terms of Y- and X-cells, I am fully aware of gaps in our knowledge that have to be bridged by hypotheses. I defend myself with an enlightening quotation referable to Peyton Rous. »Yet since what one thinks determines what one does in cancer research, as in all else, it is as well to think something» (from Obituary by Dulbecco, 18). And, to begin with, I think that the McIlwain effect (40) and its younger descendant, the »shift-effect» of Fischer and Krüger (20), may well be exponents of the particular Y-cells that give induced discharges. It was pointed out by Werblin and Copenhagen (50) that the McIlwain effect is restricted to the Y-cells.

The relation between spectral sensitivity, conduction velocity, and phasic versus tonic properties has been studied in the monkey by Gouras (26, 27), and later continued in work with De Monasterio and Tolhurst (10, 11, 12). Antidromic stimulation differentiated two main groups of fibres, large ones responding phasically with a conduction velocity of 3.8 m/sec, and small tonically responding fibres conducting at 1.8 m/sec. The small ones

were found everywhere but had their greatest density in the centre. They had opponent colour properties and thus the two opposing regions of the receptive field had different colour sensitivity, e.g. one red, the other green. The large phasic cells represented the same spectral sensitivity in both centre and periphery of the receptive field and so the antagonism between centre and surround did not differentiate wavelength. In this lot would be found the Y-cells with dominator properties or, in other words, the fast luminosity instrument of vision. I shall come to some other papers, psychophysical or based on evoked potentials, that separate luminance from colour channels, but let me, to begin with, consider the flicker phenomenon.

My first question is so obvious that I do not think it has ever been raised in the present era of sophisticated search for detectors: why is it that heterochromatic photometry is possible by the flicker method? My answer is that this is a fairly selective response of fast Y-cells of the dominator type specializing on transients. There would be more of them in the periphery (19), hence more facilitation by interaction in the peripheral retina (28).

In 1929—30, when I was keen to prove that psychophysics could be translated into the kind of neurology that Sherrington's laboratory had pushed into the foreground of research, I used flicker fusion as an index of excitability. Comparisons were made between centre and periphery at 10° , area and intensity of the stimulus being varied. For the photopic fusion frequency as a function of intensity, one had the approximation known as the Ferry-Porter rule

$$f = a \log I + b,$$

It was known at the time that stimulus area played a role for the fusion frequency but until our work (33) there had been no systematic analysis of it. A similar relationship was found to hold for area,

$$f = c \log A + d.$$

By combining these two rules into one, the equation may be formulated as

$$f = \alpha \log I \log A + \beta \log I + \gamma \log A + \delta$$

Tabulating the values of these constants for centre and periphery, they came out as:

	α	β	γ	δ
Centre	0.90	4.76	1.79	15.40
Periphery	1.68	4.87	4.28	14.03

These values show that the constants α and γ which enter the equation in terms containing $\log A$ are the ones that undergo a significant increase from centre towards

periphery. The potent peripheral spatial summation could also be demonstrated with stimuli separated by a portion of the illuminated background. For later contributions to this problem, see Brown (3).

The assumption that in the peripheral retina there are more Y-cells, of the kind that interact by mutual facilitation implicates a cellular substrate whose existence in 1930 could merely be adumbrated. It was not at the time possible to think in terms of a cellular differentiation that today has become the goal of a steadily increasing number of publications dealing with retinal ganglion cells.

For the cat a study by Saito and Fukada (46) differentiates between flicker in Type I and Type II ganglion cells. In the Type I cells the number of spikes per flash increased toward a maximum and then fell off, as repetition rate of stimulation was increased. The Type II cells followed the rate of stimulation over a wide range with low and constant average spike frequencies. As stated above, only the Type I cells were capable of generating induced activity.

The psychophysical study of flicker and flicker fusion is a highly formalized field, accessible to quantification from several points of view, e.g., wave form, stimulus intensity, adaptive changes etc. But today, when our interest is centered on cellular identifications, other properties of the perception of flicker should in the first instance attract our attention. One of them is the peculiarly unpleasant sensation of violent flicker that at a certain rate of intermittent stimulation below the fusion point is such a striking experience. If the Y-cells of man, like those of the cat, possess an optimum of spike frequency at a certain rate of intermittent stimulation (46), it may well be that self-excitation of their amacrine loops also is at an optimum at those same stimulus rates.

On the assumption that intermittent stimulation at certain rates is particularly prone to stir up self-excitation, it would, of course, be interesting to study the visual system immediately after some 10—20 seconds of flicker. From the work by myself, Dodt, Fukada and others, reviewed above, one would expect characteristic facilitatory after-effects to occur. This work, to be sure, was restricted to the cat, but one would like to have psychophysical experiments in man to fill out the picture. A great deal more could

also be done from the point of view of flicker with the cat retina and optic nerve.

When in 1945 I gave up experimental work on colour reception I tried to collect what psychophysical evidence there was in favour of some measure of separation of colour and luminance channels but today this task would be a great deal easier. It is no exaggeration to state that the electrophysiological evidence in favour of spectral information being carried by broad-band dominators and narrow-band curves of the type I used to call modulators has now become so convincing that, if psychophysicists fail to find either or both of these channels, one would be entitled to put down their failure to inadequate methods.

King-Smith and Carden (38) set out to test the idea that visual detection can be based on either channel, depending on which one in a given situation has the lower threshold. They had a white background illumination of 1,000 td on which was presented a 1° test flash, coloured, or a white of the same intensity relative to threshold. When the test flash durations were 200 msec all stimuli except yellow were mediated by the chromatic system. But when the time of exposure was cut down to 10 msec the chromatic peaks disappeared and what remained was a broad-band curve with the maximum in 555 nm. Thus the opponent colour system needed a longer integration time than the luminance mechanism. Flicker was found to give the same effect as shortening of time of exposure.

It is interesting to note in Zrenner's (51) experiments, in which evoked potentials and psychophysical measurements were compared, that against a white background of 30,000 td and a 10 msec exposure of the test stimulus the chromatic effect was strong in the evoked potentials but barely visible in the psychophysical sensory-threshold measurements. A much longer exposure time was needed for demonstration of colour specificity by the psychophysical approach. In monkeys Padmos and Norren (44) using evoked potentials in otherwise very similar experiments found intermittent stimulation merely to trace the well-known heterochromatic flicker curve while single exposures gave the three spectral peaks studied in several papers by Sperling and his coworkers (48). These are in 450, 530—540, and 610 nm with large dips in 480—490 and 570—590 nm. The technique of Sperling et al. was behavioural but also psychophysical inasmuch as it made use of

trained monkeys rewarded for correct responses.

It is not my intention to discuss colour mechanisms. The interest here is focused on the broad-band dominance in the spectral flicker curve by comparison with the prominent peaks and dips in the curves based on single stimuli. The peaks are too narrow and too far removed from the maxima of the three retinal photopigments to represent simple projections of the latter. The nature of the interactions involved has been analyzed by Sperling and Harwerth (48).

We need not fall back on psychological interpretations in making our comparison between the two curves. The results of Padmos and Norren (44) and those of Zrenner (51) show that the difference between 'flicker curves' and 'colour curves' also holds for the recording of evoked potentials from monkey and from man, who on the evidence of Sidley and Sperling (47) has the same receiving apparatus as the monkey. Rather interesting is the fact that the psychophysically determined colour peaks and dips do not come out at short exposures while they do so in the records of evoked potentials. This is not the first experiment in which conscious awareness is shown to be time-consuming. Libet (39), stimulating the somatosensory area in patients, found each repetitive shock to produce an evoked potential but mobilization of conscious awareness required maintained, iterative stimulation for about half a second.

The gist of my argument should now be clear enough; there is a luminance channel taking its retinal origin in Y-cells with a dominator distribution of spectral sensitivity. Intermittent stimulation, as employed also in heterochromatic photometry with fusion frequency as an index of brightness, favours this channel of information. The chromaticity channel is likely to be based on the more slowly conducting fibres of X-cells but at the moment it is not possible to conclude that the two channels are wholly independent and incapable of interaction. The degree of their segregation and conditions for their interaction must be established by further experimentation. I have referred above to the work on these lines commenced by Gouras and his colleagues.

The evidence in favour of self-excitation in Y-cells should not be construed to imply that all Y-cells necessarily have this capacity developed to the degree found in those which

in the cat are capable of induced activity. As pointed out above, this antidromic potentiation has not yet been studied in primates. But I have drawn attention to the similarity of the induced effects by flicker and by antidromic stimulation (21) because it suggests means of approaching the related problems of luminance specificity, Y-cells, their self-excitation, distance effects of the McIlwain type and antidromic potentiation. Intermittent light may well be a good substitute for antidromic stimulation.

REFERENCES

1. Boycott BB, Wässle H: The morphological types of ganglion cells of the domestic cat's retina. *J. Physiol (Lond)* 240: 397—419, 1974
2. Brooke RNL, Downer J de C, Powell TPS: Centrifugal fibres to the retina in the monkey and cat. *Nature (Lond)* 207: 1365—1367, 1965
3. Brown JL: Flicker and intermittent stimulation. In: *Vision and visual perception*, p. 251—320. Ed. C. H. Graham. Wiley, New York 1965
4. Cleland BG, Dubin MW, Levick WR: Sustained and transient neurones in the cat's retina and lateral geniculate nucleus. *J Physiol (Lond)* 217: 473—496, 1971
5. Cleland BG, Levick WR: Brisk and sluggish concentrically organized ganglion cells in the cat's retina. *J Physiol (Lond)* 240: 421—456, 1974
6. Cleland BG, Levick WR: The nature of the 'induced' discharge of cat retinal ganglion cells. *J Physiol (Lond)* 244: 60—61 P, 1972
7. Cleland BG, Levick WR, Wässle H: Physiological identification of a morphological class of cat retinal ganglion cells. *J Physiol (Lond)* 248: 151—171, 1975
8. Decima EE, Goldberg LJ: Centrifugal dorsal root discharges induced by motoneurone activation. *J Physiol (Lond)* 207: 103—118, 1970
9. Decima EE, Goldberg LJ: Antidromic electrical interaction between alpha motoneurons and presynaptic terminals. *Brain Res* 57: 1—14, 1973
10. De Monasterio FM, Gouras P: Functional properties of ganglion cells of the Rhesus monkey retina. *J Physiol (Lond)* 251: 167—195, 1975
11. De Monasterio FM, Gouras P, Tolhurst DJ: Trichromatic colour opponency in ganglion cells of the Rhesus monkey retina. *J Physiol (Lond)* 251: 197—216, 1975
12. De Monasterio FM, Gouras P, Tolhurst DJ: Trichromatic colour opponency in ganglion cells of the Rhesus monkey retina. *Vision Res* 16: 674—678, 1976
13. Dodt E: Geschwindigkeit der Nervenleitung innerhalb der Netzhaut. *Experientia* 12: 34, 1956
14. Dodt E: Erregung und Hemmung retinaler Neurone bei intermittierender Belichtung. *Documenta Ophth* 18: 259—274, 1964
15. Dowling JE, Boycott BB: Organization of the primate retina: electron microscopy. *Proc R Soc B* 166: 80—111, 1966
16. Dreher B, Fukada Y, Rodieck RW: Identification, classification and anatomical segregation of cells with X-like and Y-like properties in the lateral geniculate nucleus of old-world primates. *J Physiol (Lond)* 258: 433—452, 1976
17. Dubin MW: The inner plexiform layer of the vertebrate retina: a quantitative and comparative electron microscopic analysis. *J Comp Neurol* 140: 479—505, 1970
18. Dulbecco R: Francis Peyton Rous. *Nat Acad Sci Biographical Memoirs* 48: 275—289, 1976
19. Enroth-Cugell C, Robson JG: The contrast sensitivity of retinal ganglion cells of the cat. *J Physiol (Lond)* 187: 517—552, 1966
20. Fischer B, Krüger J: The shift-effect in the cat's lateral geniculate nucleus. *Exp Brain Res* 21: 225—227, 1974
21. Fukada Y: Receptive field organization of cat optic nerve fibres with special reference to conduction velocity. *Vision Res* 11: 209—226, 1971
22. Fukada Y, Saito H: The relationship between response characteristics to flicker stimulation and receptive field organization in the cat's optic nerve. *Vision Res* 11: 227—240, 1971
23. Fukada Y, Stone J: Retinal distribution and central projections of Y- and X-, and W-cells of the cat's retina. *J Neurophysiol* 37: 749—772, 1974
24. Gasser HS: Unmyelinated fibers originating in dorsal root ganglia. *J Gen Physiol* 33: 651—690, 1950
25. Gasser HS: The postspike positivity of unmyelinated fibers of dorsal root ganglia. *J Gen Physiol* 41: 613—632, 1958
26. Gouras P: Identification of cone mechanisms in monkey ganglion cells. *J Physiol (Lond)* 199: 533—547, 1968
27. Gouras P: Antidromic responses of orthodromically identified ganglion cells in monkey retina. *J Physiol (Lond)* 204: 407—419, 1969
28. Granit R: Comparative studies on the peripheral and central retina. I. On interaction between distant areas in the human eye. *Am J Physiol* 94: 41—50, 1930
29. Granit R: Centrifugal and antidromic effects on ganglion cells of retina. *J Neurophysiol* 18: 388—411, 1955
30. Granit R: The visual pathway. In: *The eye*, vol. 2, p. 537—763. Ed. H. Dawson. Academic Press, New York 1962
31. Granit R: Sensory mechanisms of the retina. Oxford University Press, 1947; Hafner, New York 1963
32. Granit R: The basis of motor control. Academic Press, London 1970
33. Granit R, Harper P: Comparative studies on the peripheral and central retina. II. Synaptic reactions in the eye. *Am J Physiol* 95: 211—228, 1930
34. Hoffmann KP: Conduction velocity in pathways from retina to superior colliculus in the cat: a correlation with receptive field properties. *J Neurophysiol* 36: 409—424, 1973
35. Hoffmann KP, Stone J, Sherman SM: Relay of receptive-field properties in dorsal lateral geniculate nucleus of the cat. *J Neurophysiol* 35: 518—531, 1972
36. Hughes A, Wässle H: The cat optic nerve: fibre total count and diameter spectrum. *J Comp Neurol* 169: 171—184, 1976

37. *Kidd M*: Electron microscopy of the inner plexiform layer of the retina in the cat and the pigeon. *J Anat (Lond)* 96: 179—187, 1962
38. *King-Smith PE, Carden D*: Luminance and opponent-color contributions to visual detection and adaptation and to temporal and spatial integration. *J Opt Soc Am* 66: 709—717, 1976
39. *Libet B*: Brain stimulation and the threshold of conscious experience. In: *Brain and conscious experience*, p. 165—181. Ed. J. C. Eccles. Springer-Verlag, New York 1966
40. *McIlwain JT*: Receptive fields of optic tract axons and lateral geniculate cells: peripheral extent and barbiturate sensitivity. *J Neurophysiol* 27: 1154—1173, 1964
41. *Ogden TE*: On the function of efferent retinal fibres. In: *Structure and function of inhibitory neuronal mechanisms*, p. 89—109. Ed. C. von Euler, S. Skoglund and U. Söderberg. Pergamon Press, Oxford 1968
42. *Ogden TE, Brown KT*: Intraretinal responses of the cynomolgus monkey to electrical stimulation of the optic nerve and retina. *J Neurophysiol* 27: 682—705, 1964
43. *Ogden TE, Miller RF*: Studies on the optic nerve of the rhesus monkey: Nerve fibre spectrum and physiological properties. *Vision Res* 6: 485—506, 1966
44. *Padmos P, Norren DV*: Increment spectral sensitivity and colour discrimination in the primate, studied by means of graded potentials from the striate cortex. *Vision Res* 15: 1103—1113, 1975
45. *Ramón y Cajal S*: *Die Retina der Wirbeltiere*. Bergmann, Wiesbaden 1894
46. *Saito H, Fukada Y*: Repetitive firing of the cat's retinal ganglion cells. *Vision Res* 13: 263—270, 1973
47. *Sidley NA, Sperling HG*: Photopic spectral sensitivity in the Rhesus monkey. *J Opt Soc Am* 57: 816—818, 1967
48. *Sperling HG, Harwerth RS*: Red-green cone interactions in the increment-threshold spectral sensitivity of primates. *Science* 182: 180—184, 1971
49. *Sperling HG, Sidley NA, Dockens WS, Joliffe CL*: Increment-threshold spectral sensitivity of the rhesus monkey as a function of the spectral composition of the background field. *J Opt Soc Am* 58: 263—268, 1968
50. *Werblin FS, Copenhagen DR*: Control of retinal sensitivity. III. Lateral interaction at the inner plexiform layer. *J Gen Physiol* 63: 88—110, 1974
51. *Zrenner E*: Influence of stimulus duration and area on the spectral luminosity function as determined by sensory and VECF measurements. *Documenta Ophth Proc Ser* 13: 21—30, 1977

Address: R. Granit, Prof. emeritus
 The Nobel Institute for
 Neurophysiology
 Karolinska Institutet
 S-104 01 Stockholm
 Sweden