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PATHOLOGY OF THE X-WAVE OF THE HUMAN ELECTRORETINOGRAM*

1. RED-BLINDNESS AND OTHER CONGENITAL FUNCTIONAL ABNORMALITIES

BY

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MOTOKAWA and Mita (1942) discovered a subsidiary positive deflection preceding the *b*-wave of the ERG in a moderately light-adapted human eye. They called it "*x*-wave", but gave no interpretation of it.

Independently of these Japanese authors, Adrian (1945) rediscovered the phenomenon. He established that the *b*-wave (which he called "scotopic response") is absent in red light and in a state of light adaptation, and that it can be isolated in blue light; it is augmented considerably by dark adaptation. On the other hand, the *x*-wave (called "photopic response") is absent in blue light and can be isolated in red light; it should not increase by dark adaptation. The *x*-wave is more rapid than the *b*-wave so that both may be recognized together in orange light.

Adrian (1946) showed that the *x*-wave may be demonstrated in animals with a rich cone-population (monkey, pigeon) and not in animals with few or no cones (cat, rabbit, guinea-pig).

Amongst the few contributions concerning the *x*-wave which have appeared in recent years, those of Schubert and Bornschein (1952), Armington (1952), Armington and Schwab (1954), Armington and Thiede (1954), and Auerbach and Burian (1955) are the most important. Schubert and Bornschein showed that, whereas the culmination time of the *b*-wave increases with the wave length of the stimulus, that of the *x*-wave remains constant and equal to 50–70 millisec.; the latency time is equal to 25–30 millisec. Armington (1952) demonstrated that the *x*-wave is augmented by dark adaptation, but that the maximum amplitude is already reached after 1 minute; its spectral sensitivity does not correspond to the subjective scotopic or photopic curves, but has a maximum for a wave length of 630 mμ. Armington and Thiede (1954) showed that either the *x*-wave or the *b*-wave may be selectively reduced in amplitude if the eye is adapted to light of which one electrical component or the other possesses greater sensitivity. Auerbach and Burian (1955) emphasized the relationship

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between the x-wave and the a_1-wave, already described by previous authors; the modifications of the x-wave and of the other components of the ERG during dark adaptation are precisely described.

Technique and Normal Appearance of the X-Wave

We used a frontal electrode and Karpe's contact-lens as the corneal electrode. They were connected to an ink electro-encephalograph. We used three time-constants (1·0 sec., 0·3 sec., and 0·1 sec.) with very similar results. The records were obtained after sufficient dark adaptation to ensure a scotopic b-wave of constant amplitude. A neon lamp provided constant light-flashes of very short duration (<0·02 sec.) and regulatable frequency. This light contains only wavelengths larger than 570 mμ and has an orange hue.

The distance of the eye-lamp is 18 cm. and the angular field-diameter subtended by the light-source is 45°; the patient looks at the centre of this field. Each flash has an energy value of about 0·1 joule. As measured with the slow-reaction Gossenluxmeter (which has a spectral sensitivity similar to that of the photopic human eye), the mean pupillary illumination E (lux) is related to the frequency of stimulation n (flashes per second) according to the approximate formula: $E=4n$.

With this technique and with normal subjects (Fig. 1, opposite) the b-wave of an isolated response has an amplitude of 125–250 μV and an average culmination time of 80 millisec. In some cases a duplication of that positive deflection can be seen: the subsidiary, most rapid component has a culmination time of 40 millisec. However, in most cases, the x-wave becomes distinct only for stimulus frequencies of 2–4 cs. The amplitude of that x-wave lies between 25 and 60 μV at 2 cs. At a higher frequency, namely in the vicinity of the objective flicker fusion rate, two types of records can be obtained according to the predominance of the photopic or the scotopic responses.

Protanopia and Protanomaly

Schubert and Bornschein (1952) and Armington (1952) have already reported the absence of the x-wave in protanopia, the former in two cases, and the latter in three cases. Protanomaly has not hitherto been studied in this respect.

We have studied six cases of protanopia and six cases of protanomaly.* For investigating these subjects, the pseudo-isochromatic tables of Ishihara, Polack, and Stilling were used and further study of the cases was done with Nagel's anomaloscope and, subsidiarily, with Farnsworth's panel D–15. The depression of the spectral sensitivity in the long wave-end was estimated as follows:

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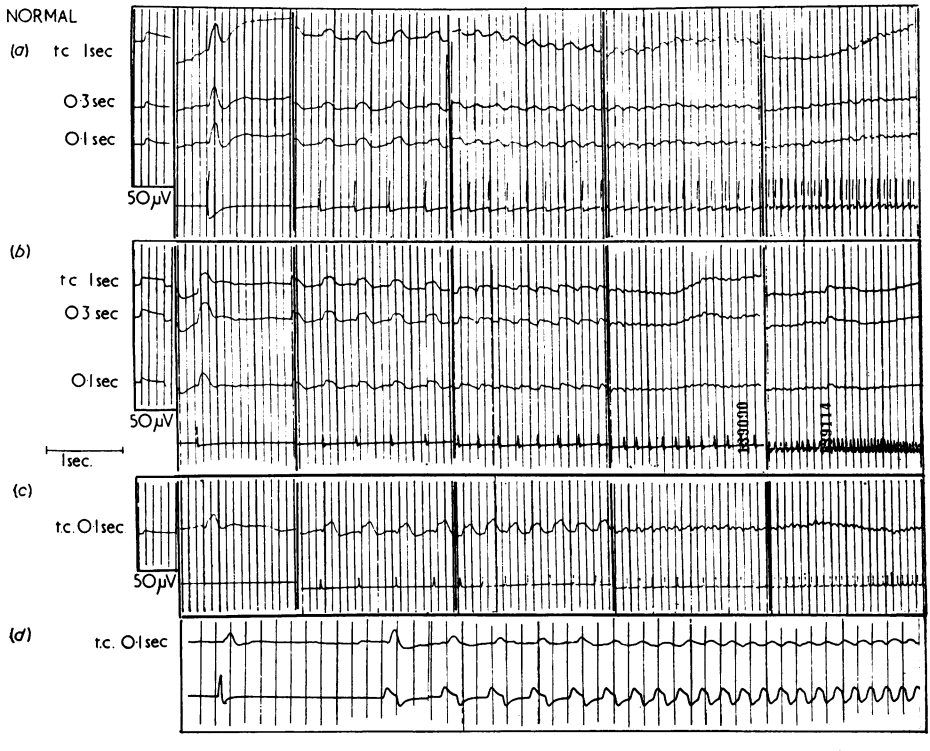

FIG. 1.—Dark-adapted normal subjects.
(*a–c*) Electroretinographic responses to constant flashes of orange light, isolated (left) or of increased frequency (right).
(*a*) No demonstrable *x*-wave in an isolated response; the *x*-wave is apparent for frequencies of 2, 4, and 6 cs.; the fluctuating response to high-frequency stimulation is of the scotopic type.
(*b*) No demonstrable *x*-wave in an isolated response; clear-cut *x*-waves are apparent for frequencies of 2, 4, and 6 cs.; the fluctuating response to high-frequency stimulation is of the photopic type.
(*c*) *X*-wave apparent even in an isolated response; photopic type of response to high-frequency stimulation.
(*d*) Comparison, in the same subject, of the response to an isolated flash of orange light (left, *x*-wave demonstrable) and of the responses to white light-stimuli of increasing frequency (right, no appearance of *x*-wave; Karpe's lamp).

From the luminance-level needed to read letters corresponding to a visual acuity of 0·3 in monochromatic light of 660 mμ was subtracted the luminance-level needed to read the same letters in white light. The result was further corrected by subtracting the average value of the results obtained from subjects with normal colour-vision.

All the protanopes showed characteristic and more or less identical features in all these experiments; the results for the protanopes are given in the Table (overleaf). All the subjects were males; the normal Rayleigh-equation with our anomaloscope is 35·5/17; the results with Farnsworth's dichotomous test are obtained by reference to the number of "protan-parallels".

TABLE
COLOUR-VISION OF SIX PROTANOPES

Case No.	Age (years)	Anomaloscope		Farnsworth's Panel D–15		Depression Spectr. Sensib. 660 mμ (log–log)
		Mean Position of Green-Red Screw	Quotient of Anomaly	Test	Retest	
1	14	42	0·70	1 (?)	0	1·5
2	12	55	0·31	0	0	0·95
3	17	57	0·27	1	0	0·8
4	15	62·5	0·16	4	1	0·5
5	17	64	0·14	1	1	0·75
6	16	accepts from 65 to 35	"extreme protanomaly"	4	4	1·2

In all twelve cases of protanopia and protanomaly, similar electroretinographic records were obtained, which were distinctly different from the normal: no appearance of the *x*-wave could be demonstrated, whatever the frequency of the stimulus used, in even the mildest cases of protanomaly (Fig. 2*a*, *b*).

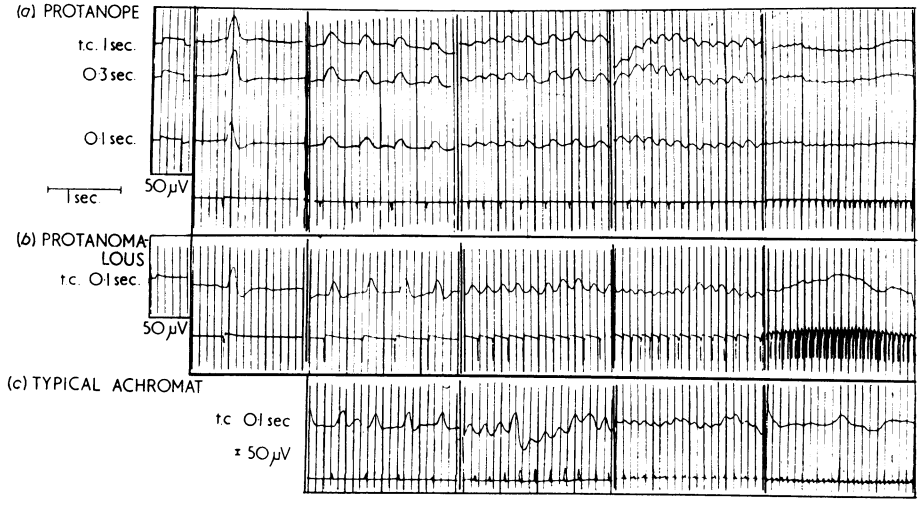

FIG. 2.—Electroretinographic responses to flashes of orange light in a protanope (*a*), a protanomalous subject (*b*), and a typical achromat (*c*). The subjects were dark-adapted. Not the slightest appearance of the *x*-wave for all frequencies. Scotopic type of response to high-frequency stimulation.

Other Congenital Functional Abnormalities

Schubert and Bornschein (1952) found a normal *x*-wave in a case of deuteranopia. In a case of congenital hemeralopia, the characteristics of the *x*-wave were also normal (culmination time 50–60 millisec.; latency time 25–30 millisec.), but the *b*-wave was absent. Armington and Schwab (1954)

obtained similar results. Other types of electrical responses have been described in congenital hemeralopia, but the exact diagnosis of these cases is doubtful.

Armington (1952) noted a normal *x*-wave in cases of deuteranopia and congenital tritanopia.

Vukovich (1952) found the *x*-wave totally absent in a typical case of achromatopsia.

We shall refer only very briefly to our findings, because their essential features have already been published (François, Verriest, and De Rouck, 1955, 1956). Like Vukovich, we noted the lack of *x*-wave in three typical cases of congenital achromatopsia (Fig. 2*c*). The electrical response for an isolated stimulus was normal, but the rate of objective critical flicker fusion was lowered.

In three cases of congenital essential hemeralopia, and in one case of Oguchi's disease, we obtained characteristic electroretinographic records; the scotopic *b*-wave is not apparent, so that the *x*-wave is the only positive deflection; its culmination time (70–80 millisec.) is in accordance with that of the *x*-wave in normal subjects (Fig. 3).

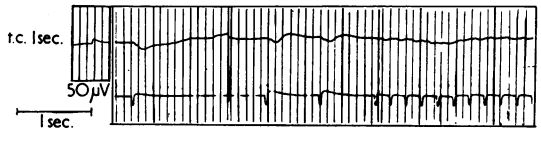

FIG. 3.—Electroretinographic responses to flashes of orange light in a subject with Oguchi's disease. Essentially electro-negative response with a positive inflection after 70 millisec. *x*-wave.

Summary

(1) A technique for the clinical study of the *x*-wave of the human electroretinogram is described and its normal characteristics noted.

(2) The *x*-wave seems to be absent in protanopia and in protanomaly, even in very slight cases.

(3) The *x*-wave is not demonstrable in typical achromatopsia.

(4) The *b*-wave was not demonstrable, but the *x*-wave was present in our cases of essential hemeralopia and Oguchi's disease.

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