New Facts on Neutralization of Retinal Induction

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INTRODUCTION

A physiological effect remaining within a retinal area, after exposure to any colored light, is called "direct induction." Against this, an effect set up around the retinal area pre-illuminated is called "indirect induction." Retinal induction was shown by Motokawa to be a basic physiological process underlying a variety of psychological phenomena such as contrast, optical illusion, apparent movement, etc. It has been established by Motokawa and by Nakagawa and Kohata that the indirect induction caused by any colored light is extinguished when a remote retinal region is exposed to a patch of complementary color. In the present experiment we became aware that the indirect induction can be extinguished on exposure of a remote retinal region to a stimulus patch of the same color under special conditions. The following investigation was undertaken to specify experimental conditions under which indirect induction is extinguished, and to elucidate the mechanism underlying this phenomenon.

EXPERIMENTAL

Method

Method, procedures and precautions are fully described in other papers, so that only a brief résumé will be mentioned here. After a preliminary dark adaptation of about 20 minutes the electrical sensitivity of the eye was measured at varying moments after the end of pre-illumination. The electrical sensitivity was expressed in terms of $\zeta$ which is defined as $\zeta = 100 \frac{(E-E_o)}{E_o}$, when $E$ and $E_o$ are reciprocals of electric thresholds determined with and without pre-illumination.

The retinal induction effect was determined by the difference between the $\zeta$ value for white test-light alone and the $\zeta$ value for successive stimuli:
any colored light and white test-light, and it was denominated the contrast effect (C. E.).

In the present experiment the spectral light (equal energy) and color-filtered light were used. The intensity of the latter was given in terms of the illumination measured without the filter by a luxmeter on the stimulating surface. The white test-light was always 10 lux in intensity, if not otherwise stated, and its size was about 1 mm. in diameter.

The distance from the stimulating surface to subject’s eye was always 30 cm. The eye used for the experiment was the left one and the right eye was shielded.

The details of the arrangements and procedures will be mentioned together with the results.

Results

At first, it was investigated, how the indirect induction established around a retinal area pre-illuminated was affected by subsequent illumination of the same area with lights of various wave-lengths.

![Fig. 1. Neutralization of direct induction caused by red light (R) and by yellow light (Y). Patches used and temporal sequence of stimuli are given in inset, where λ, W, S and t denote spectral light, white light, electric stimulus, and interval between W and S respectively. Cross is fixation point. Continuous curves refer to indirect induction, and broken curves to direct induction. Circular and triangular symbols refer to induction caused by red light and by yellow light respectively.](image)

A patch of 12 mm. in diameter was presented on a vertical screen in front of the subjects. The eye was exposed to red (R) or yellow (Y), spectral light (λ) and white test-light (W) in succession, as is shown in the inset of Fig. 1, and then an electric stimulus (S) was applied just at
1.0 (R) or 1.5 (Y) seconds after termination of the white test-light. The time of 1.0 or 1.5 seconds corresponds to the crest time of the ζ-time curve which would be obtained for successive stimuli: red or yellow and white.

The results are shown in Fig. 1. The broken curves connecting solid symbols indicate the neutralizing effect of spectral light upon the direct induction set up by colored light. The detail of this effect is described in our previous paper. The full curves marked by empty symbols refer to the indirect induction around the same retinal area. As can be seen in this figure, the two kinds of curves almost coincide with one another. This fact indicates that the indirect induction around the retinal area pre-illuminated disappears simultaneously when the direct induction within the same retinal area is neutralized.

Then, the question arises as to whether or not the indirect induction established around the retinal image shows a parallel change with the direct induction under other experimental conditions. In the following experiment the direct induction was modified by strong white light applied to the retinal area pre-illuminated by any colored light, and the effect of this procedure upon the indirect induction was measured.

![Fig. 2. Effects of strong white light upon indirect induction.](image)

Abcissa: intensity of white light applied prior to white test-light. Intensity of white test-light is 40 lux. In insets S. W. denote strong white light.

The inducing lights used were of wave-lengths 650 mμ, 590 mμ, 550 mμ and 450 mμ. The interval between the white test-light and the electric stimulus was different according to the kind of inducing light, as is shown on top of Fig. 2. In the previous paper we showed that the direct induction is reduced by extremely strong white light applied subse-
quently to the area pre-illuminated with colored light. As is illustrated in Fig. 2, a similar effect can be seen on the indirect induction, although the strong white light was restricted to the retinal area pre-illuminated by colored light. This is another evidence that the disappearance of direct induction is accompanied by that of indirect induction.

In order to see how the indirect induction caused by one patch was affected by another patch presented subsequently at a distant part of the retina, the following experiments were performed. A detector, D, consisting of two parallel bars was used to detect the effect of the spreading induction from the inducing patch, I, presented farther away from D.

The patches used and the order of application of stimuli are shown in the inset of Fig. 3. The color of the detector was red, and that of the inducing patch was varied. The Data obtained are illustrated in Fig. 3.

![Fig. 3. Relationship between neutralization of direct induction and change of indirect induction as function of wave-lengths of neutralizing spectral lights.](image)

Detector: red horizontal parallel bars. Size of bar is $2 \times 10 \text{ mm}^2$. Distance between parallel bars is 6 mm. Intensity of red light is 20 lux without filter. Inducer: vertical bar of spectral light. Its size is $2 \times 10 \text{ mm}^2$. Distance between detector and inducer is 20 mm. Solid symbols refer to direct induction measured at points 3 and 4. Empty symbols refer to indirect induction measured at points 1 and 2.

When the indirect induction was measured at point 2 between the red bars, neutralization of indirect induction occurred only at 490 m$\mu$ (curve marked by empty triangles). This agrees with Motokawa's finding, and based upon the complementary relation between D and I, this kind of neutralization can easily be accounted for. When measured
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at point 1, the indirect induction was found to be neutralized not only at 490 m\(\mu\), but also at 650 m\(\mu\), as is shown by the curve connecting empty circles. In other words, neutralization of indirect induction occurs also with an inducer of the same color as the detector under this special condition. In this case the vanishing of the indirect induction around the detector can not be considered as due to a direct action of the spreading induction from the inducer, because the former and the latter are identical in character.

In the preceding section we observed that the disappearance of indirect induction follows that of direct induction. Then, it is likely that the vanishing of indirect induction at 650 m\(\mu\) is a secondary effect of the neutralization of the direct induction, because the direct induction and the spreading induction from a red inducer are complementary in character. In order to confirm the neutralization of the direct induction, the measurement of direct induction was carried out at points 3 and 4 with a red inducer, and it was found that the direct induction was missing at point 3, but remaining intact at point 4 (cf. curve connecting solid symbols). The fact that the induction at the left part of the detector remained unaffected is probably due to the circumstance that the spreading induction from the inducer could not reach the point because its energy had been used up for neutralization of direct induction on the way.

This interpretation is supported by the following experiments. The red patches, D and I, used are shown in the inset of Fig. 4. The intensity of the detector was graded in four steps in order to examine the permeating effect of the spreading induction into the field of direct induction caused by the detector. The results are shown in Fig. 4, in which the intensity of direct induction (C.E.) is plotted against the distance from the left end of the detector. All continuous curves indicate that the direct induction decreases as the right end of the detector is approached, and this means that neutralization is easiest at the right end nearest to the inducer and becomes progressively more difficult toward the opposite end. This is because the spreading induction from the inducer loses its energy as it is propagated through the field of direct induction caused by the detector. It is to be noted that neutralization occurs more extensively at the detector of weaker intensity, and this fact may be interpreted in terms of lower resistance against the permeation of the spreading induction. The set of broken curves in the same figure represents the distribution of indirect induction between the two bars of the detector. From these curves it is obvious that the indirect induction changes parallel to the direct induction.

Generally speaking, the indirect induction around the detector can not directly be extinguished with the spreading induction from the inducer of the same color, because the indirect induction is the same character
as the spreading induction. Nevertheless, the indirect induction can be extinguished indirectly in association with the neutralization of the direct induction. It seems as if the neutralization of direct induction is always connected with the disappearance of indirect induction. However, we have succeeded in separating both phenomena by means of a special device. White parallel bars, BL, were presented in the interval between the detector and the inducer in such a manner that the inner margins of the detector were lined with the white bars (see the inset of Fig. 5 A). The indirect induction remained intact in this arrangement, while the direct induction underwent the same change as mentioned above. (Fig. 5 A). The white bars lining the inner margins of the detector are obviously effective in keeping the indirect induction unaffected which would otherwise be reduced together with the direct induction. The field of direct induction and that of indirect induction are separated by the blocking white bar. It may be supposed that this separation has caused independent changes of the direct and the indirect induction.

In the following experiment the right edges of the bars of the detector were lined with blocking white bars, as is shown in the inset of Fig. 5 B, and similar experiments were carried out. In this experiment both kinds of induction suffered from no change, as is illustrated in Fig. 5 B. The white blocking bars are known to be effective to check the propagation
Fig. 5. Experiment on blocking effect of white bar on neutralization of indirect induction

D: red detector, I: red inducer. BL: blocking white bar of 10 lux. W: white test-light. Abscissa: distance from left end of D. Continuous curves refer to direct induction, and broken ones to indirect induction. Numbers on curves indicate intensities of D.
of spreading induction. The direct induction is protected by the white bar from neutralization by the spreading induction. The field of indirect induction is open to the spreading induction, but no neutralization will occur, because the spreading induction is the same character as the indirect induction. This experiment is further evidence that the indirect induction remains intact if the direct induction is unaffected. The reverse is, however, not always true, as has been demonstrated by the experiment in Fig. 5 A.

The latter experiment seems to be explained with such a working hypothesis as will be mentioned below: Some propagating process is initiated at the site of neutralization of direct induction. If this hypothetical process reaches the field of indirect induction, the latter is neutralized (secondary neutralization). When the propagating process is blocked by the blocking white bar, no secondary neutralization of indirect induction occurs, as has really been shown above. It is to be noted that the secondary neutralization occurs only when the detector and the inducer are of the same color.

DISCUSSION

Direct induction is a kind of after-effect surviving a photic stimulus at the site of stimulation. This after-effect is extinguished when the second stimulus of the same color is applied elsewhere in the retina. This phenomenon was ascribed by Motokawa to the neutralizing action of the spreading induction initiated by the second stimulus. The neutralization occurs, because the direct induction caused by the first stimulus is in character complementary to the spreading induction initiated by the second stimulus. The indirect induction around the optical image of the first stimulus is, however, in character the same as the spreading induction caused by the second stimulus. So there is no reason to suppose a phenomenon like neutralization between the indirect induction and the spreading induction. But for the secondary neutralization of indirect induction mentioned above, the indirect induction would survive the first and the second stimulus. In reality the indirect induction disappears with the direct induction because of the secondary neutralization. Thus the after-effect of the first stimulus is wiped out by the second stimulus, unless the first is too strong and long-lasting. The after-effect of a sufficiently strong stimulus is, however, so strong that neither direct induction nor indirect induction caused by it can completely be extinguished by the second stimulus. In such cases a group of psychological phenomena called "figural after-effects" can be seen. In short, the secondary neutralization is a natural device to wipe out the after-effect of a preceding stimulus and to avoid unnecessary interaction and confusion between
the effects of successive stimuli.

As has been shown by Motokawa and Ebe, the secondary neutralization does not take place when the interval between two successive stimuli is so short that apparent movement occurs. The secondary neutralization can be observed only in the stage of succession in which two stimuli are perceived as successive ones.

**SUMMARY**

Physiological effects remaining within a retinal area and around it after exposure to colored light are designated direct induction and indirect induction respectively.

1. The indirect induction was shown to disappear when the same area was illuminated subsequently with colored light complementary to the pre-illuminating light.
2. The indirect induction was reduced or extinguished also when the direct induction was modified by an illumination with strong white light restricted to the pre-illuminated area.
3. The indirect induction pre-established by the first patch was extinguished when the direct induction was neutralized with the spreading induction from the second patch of the same color presented at a distance subsequently.
4. This fact cannot be accounted for in terms of the neutralization described by Motokawa, because Motokawa's effect could be observed only between two patches complementary to each other. Therefore, it was proposed to distinguish the present phenomenon from Motokawa's and to designate it "secondary neutralization." It was meant by this term that the effect occurs secondarily following the neutralization of direct induction.
5. Some experiments supporting this interpretation were presented.

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