References and Notes

1. A. C. Greiner and K. Berry, *Can. Med. Assoc. J.* **90**, 663 (1964).
2. A. S. Zelickson and H. C. Zeller, *J. Am. Med. Assoc.* **188**, 394 (1964).
3. More than 90 patients with this syndrome have been observed at the Provincial Mental Hospital, Essondale, British Columbia. The majority have exhibited corneal and lens changes; unexplained sudden death occurred in 12 of these patients.
4. H. S. Posner, R. Culpan, J. Levine, *J. Pharmacol. Exptl. Therap.* **141**, 377 (1963).
5. V. Fishman and H. Goldenberg, *Proc. Soc. Exptl. Biol. Med.* **112**, 501 (1963).
6. H. Goldenberg and V. Fishman, *Biochem. Biophys. Res. Commun.* **14**, 404 (1964); S. Price, H. F. Martin, B. J. Gudzinowicz, *Biochem. Pharmacol.* **13**, 659 (1964).
7. We thank Albert A. Manian, Psychopharmacology Service Center, National Institutes of Health, for a gift of 7-hydroxychlorpromazine, and Guy Marier, Poulenc, Ltd., Montreal, for gifts of several nonphenolic chlorpromazine metabolites.
8. C. F. A. Culling, *Handbook of Histopathological Technique* (Butterworth, London, ed. 2, 1963), p. 310.
9. R. D. Lillie, *J. Histochem. Cytochem.* **5**, 346 (1957).
10. L. K. Whitten and D. B. Filmer, *Australian Vet. J.* **23**, 336 (1947); N. T. Clare, *ibid.*, p. 340; N. T. Clare, L. K. Whitten, D. B. Filmer, *ibid.*, p. 344.
11. Supported by a grant from the Medical Research Council of Canada.

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Visual Evoked Potentials as a Function of Flash Luminance and Duration

Abstract. *Computer-averaged evoked potentials were recorded to visual stimuli of constant duration and varying luminance, as well as to flashes whose luminance and duration varied reciprocally. With constant duration, the latency, amplitude, and waveform of the evoked response varied as a function of luminance. The effects of decreasing the luminance on amplitude and waveform of the responses can be balanced by increasing the duration of the flash. This reciprocity between luminance and duration suggests a relationship between apparent brightness and evoked potentials.*

The data from several studies of visual evoked potentials in humans, in which light flashes of constant duration were used, suggest that the waveform of the potentials varies as a function of stimulus luminance (*1*). The use of flashes of constant duration, however, makes it difficult to separate the effect of the physical parameter, luminance, from that of the psychological parameter, apparent brightness, since the latter may vary as a function of both luminance and duration (*2*). It is therefore of interest to relate these physical and psychological dimensions to electrophysiological data.

One method of holding brightness constant while changing physical parameters is suggested by Bloch's law, sometimes referred to as the Bunsen-Roscoe law (*2, 3*). According to this law, the apparent brightness of flashes shorter than some critical period C depends on both luminance and duration. In other words, flashes which vary in these physical parameters can be made to have the same apparent brightness as long as the product of their luminance and duration remains constant, and C is not exceeded. The exact value of the critical period, C, varies with the conditions of observation, but it is usually given at about 100 msec. Using this method, we have investigated the average visual evoked potentials elicited by light flashes varied in both luminance and duration and thereby related to apparent brightness.

Two different stimuli were presented to the fovea of the right eye in Maxwellian view: a semi-circle of 1° 22′ visual angle along its diameter, and a full circle of 2° 6′ visual angle. The light sources were Sylvania R1131C glow modulator tubes, whose luminous intensities were initially equated by means of a photomultiplier display on a cathode ray oscilloscope. The maximum luminance of the circular stimulus and that of the semicircular stimulus was 9000 mlam. Flash duration was controlled by two Grass-S4B stimulators monitored by an electronic counter. The subjects fixated four dim red lines converging upon the stimulus area and pressed a key to trigger each flash arhythmically about once every 2 seconds (*4*). When sufficient stimulations had accumulated, the experimenter terminated that series. Electrical potentials were amplified by a Grass model 6 electroencephalograph and recorded on magnetic tape. The average evoked potentials were obtained with a Mnemotron Computer of Average Transients, a 1-second epoch being used, with a sampling rate of 400 per second. All records presented here are from the scalp over the visual area, 2.5 cm above the inion and 2.5 cm to the right of the midline, with reference to the left ear lobe.

Figure 1 shows the average evoked potentials obtained from one of seven subjects exposed to flashes of constant duration (10 msec) and varying luminance [see Donchin (*5*) for further details]. As flash luminance was reduced over a range of 4 log units, changes occurred in the number, amplitude, and latency of the components of the average evoked potential as well as in the overall waveform. With the stimulus of greatest luminance, namely 9000 mlam, two diphasic waves appear in the average evoked potential (*abc* and *cde* in Fig. 1). Negative peak latencies occur at about 80 and 175 msec (*b, d*); positive peak latencies, at about 120 and 210 msec (*c, e*).

In the average evoked potentials elicited by the circular stimulus, the peak-to-trough amplitude of the first diphasic component (*b–c*) decreases as the luminance is reduced and eventually disappears into the background activity. The peak-to-trough amplitude of the second diphasic component (*d–e*) initially increases as luminance is decreased and reaches a maximum approximately when the first diphasic wave disappears. With further reduction in luminance, the amplitude of this component sharply diminishes, and a long positive wave of 200 to 400 msec develops when the luminance approaches threshold values. The negative peak latencies of both diphasic waves increase with reduced luminance, by approximately 40 msec over 5 log units.

These same trends are apparent when the luminance of the semicircular stimulus is reduced. The waveforms tend to be similar when the

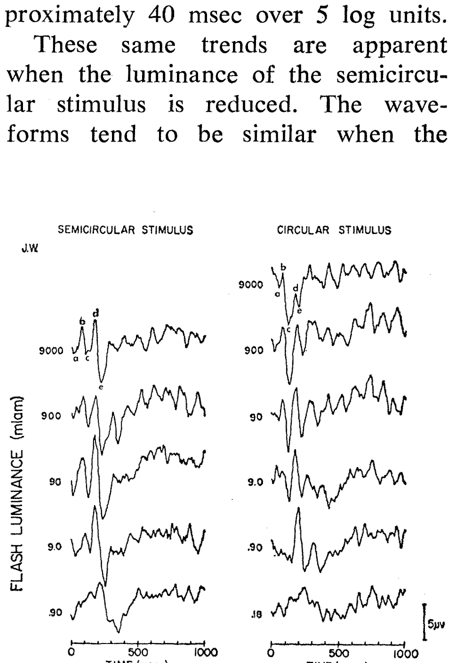

Fig. 1. Effect of flash luminance on average evoked potentials for subject J.W., with semicircular and circular stimulus flashes of constant duration (10 msec). Flash onset occurs at the start of each trace. Each average is based on 100 stimulations. Negativity at visual area in this and subsequent figures is upward. The bottom traces in both columns are responses to stimuli just above subjective threshold; areal differences account for their different luminance values.

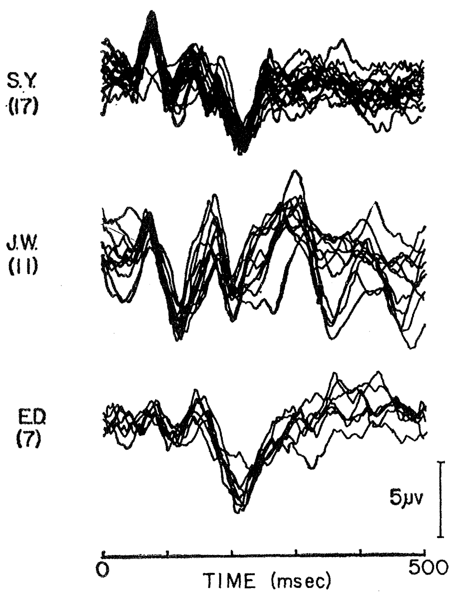

Fig. 2. Reliability of average evoked potentials for given stimulus conditions for subjects S.Y., J.W., and E.D. The number of superimposed traces, each of which is based on 100 stimulations, is indicated below the subject's initials. Circular stimulus: 9000 mlam, 10 msec.

stimuli are approximately the same number of log units above threshold. Thus the differences in contour and retinal area play a small role in determining the waveform of the average evoked potential for these stimuli. Confirming a previous suggestion (*6*), we may conclude that stimuli of relatively high luminance (at least 3 log units above threshold) elicit average evoked potentials with at least two diphasic components, whereas dimmer flashes evoke a response in which only the second diphasic component is apparent.

An indication of the stability of the evoked potential patterns (general form, amplitude, and latency of components) is shown, for three of seven subjects, in Fig. 2. Here, the average evoked potential tracings, resulting from a number of replications in which the same stimulus was employed, have been superimposed to show that the intra-subject variability is small. Intersubject variability is greater but there is sufficient similarity in the pattern, and latency of the component peaks, to identify them relative to the stimulus parameters. Similar results in terms of intra- and inter-subject variability are reported by Dustman and Beck (*7*). In this connection, it would appear to be better to study the evoked potentials of a few individual subjects intensively rather than many subjects more superficially.

To determine the extent to which the waveform is related to the apparent brightness of the flashes, the luminance and duration of the semicircular stimulus were varied reciprocally so that their product (mlam × msec) was constant. Three such product-values were investigated, 900, 9000 and 90,000: stimulus duration varied from 1 msec to 150 msec. Figure 3 shows the results for two of three subjects.

Two general trends are apparent. Within rows, where luminance is varied for flashes of constant duration, changes in the form, amplitude, and latency of the evoked potentials are seen. These changes correspond with those indicated in Fig. 1, where luminance was varied over 5 log units for a 10-msec flash. On the other hand, the waveform and amplitude of the average evoked potentials within most columns, where the luminance-duration product is constant, show a striking similarity. In other words, increased duration of the flashes compensates for decreased luminance. These data indicate that the waveform and amplitude of the average evoked potentials depend on the total luminous energy of apparent brightness, in accordance with Bloch's law.

It will be noted within a given column that the latency of the negative peaks of both diphasic waves increases as luminance is decreased to compensate for increasing duration. A similar increase in latency as a function of luminance is shown in Fig. 1. Thus the latency of the evoked potential components appears to be determined largely by the luminance of the flash. Prolongation of the flash tends to preserve the pattern of the response but has no appreciable effect on the latency of its components.

The data presented here suggest that the waveform and amplitude of average evoked potentials recorded from

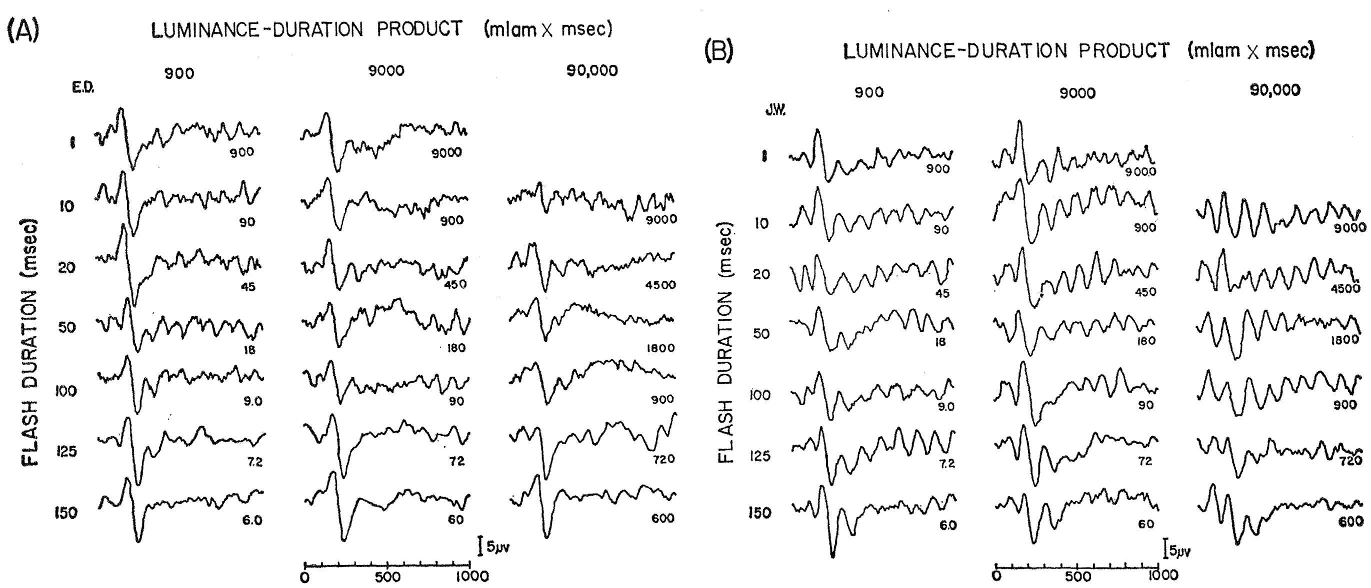

Fig. 3. Average evoked potentials from visual area for subjects E.D. (*A*) and J.W. (*B*) for different luminance-duration products, with the semicircular stimulus. Each trace is based on 100 stimulus flashes; onset of flash at start of trace. Number beneath each trace indicates flash luminance in millilamberts.

the occipital area of the cortex are systematically related to the luminance-duration product and therefore to the apparent brightness of the eliciting flashes. In addition, the latency of the response to the flashes appears to be related to the luminance of the flash independently of its duration.

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References and Notes

1. D. I. Tepas and J. C. Armington, *Vision Res.* **2**, 449 (1962); M. Ebe and T. Mikami, *Tohoku J. Exptl. Med.* **78**, 17 (1962); F. Contamin and H. P. Cathala, *Electroencephalog. Clin. Neurophysiol.* **13**, 674 (1961).
2. Y. LeGrand, *Light, Colour and Vision* (Wiley, New York, 1957) .
3. G. S. Brindley, *Physiology of the Retina and Visual Pathway* (Arnold, London, 1960), p. 177.
4. For a detailed description of apparatus used in stimulus presentation and control, see R. C. Boyle, "An investigation of perceptual interference resulting from successive visual presentations," dissertation, University of California, Los Angeles (1963).
5. E. Donchin, "Cortical evoked potentials and retroactive masking and enhancement effects with brief paired flashes of light," dissertation, University of California, Los Angeles (1964).
6. E. Donchin, J. D. Wicke, D. B. Lindsley, *Science* **141**, 1285 (1963).
7. R. E. Dustman and E. C. Beck, *ibid.* **142**, 1480 (1963)
8. Supported by Army contract DA-49-007-MD-722 and aided by Navy contract Nonr 233(32). We gratefully acknowledge use of facilities and equipment of the Data Processing Laboratory of the Brain Research Institute, UCLA. We thank Gary Galbraith and Stephen Young for their assistance.

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Nystagmus as a Criterion of Hypnotically Induced Visual Hallucinations

Abstract. *Hypnotized subjects who report hallucinating a visual situation which would ordinarily elicit optokinetic nystagmus demonstrate nystagmus under these conditions. They and control subjects are unable to feign nystagmus in the waking state, either by imagining the situation or by direct efforts to simulate the eye movements. Thus an objective criterion is provided for the presence of visual hallucinations.*

Many hypnotized subjects report visual hallucinations on appropriate suggestion (for example, seeing a bowl of fruit on a table when none is actually present). However, there are obvious limitations in relying on the subject's verbal report alone as evidence that he has indeed experienced such an hallucination. For this reason there have been many efforts, dating back to at least 1888 (*1*), to develop objective criteria to determine the genuineness of hypnotically induced perceptual changes. However, as pointed out recently (*2*), none of these procedures has offered conclusive evidence that hypnotic visual "hallucinations" are more real than "imagining" in the waking state.

Optokinetic nystagmus (rhythmical oscillations of the eyes with a slow and fast component) can be elicited in normal individuals by having them gaze steadily at a rotating drum which contains alternate, vertical, black and white stripes (optokinetic drum). It is considered an involuntary reaction to an appropriate visual stimulus (*3*). In human beings the presence of the striate cortex is necessary for its elicitation, and lesions of many areas of the cortex affect its characteristics (*4*). If hypnotized subjects are made to hallucinate such a situation, and their perceptions are similar to those that result from viewing the actual drum, they might be expected to demonstrate optokinetic nystagmus during such an hallucinatory experience.

From a large pool of volunteers, five subjects were selected who reported visual hallucinations on appropriate hypnotic suggestion and who ascribed a realness to their hallucinatory experiences that approached or equaled the realness of perceptions which result from viewing actual objects. Eye movements were recorded on these subjects under the following conditions. (i) The subject was instructed to watch the rotating drum for 1 minute. (ii) Hypnosis was induced and the subject was instructed to watch the rotating drum for another minute. (iii) The subject was instructed to close his eyes and was told that on reopening them, 30 seconds later, he would be able to see the rotating drum again. However, the drum was actually removed while his eyes were closed. Movements were recorded for 1 minute after he reopened his eyes. (iv) Finally the trance was terminated and eye movements were recorded for 5 minutes while the subject attempted to feign nystagmus in various ways. This included having the subject imagine the rotating drum with his eyes opened and closed. The subject was also instructed on the nature of the eye movements of nystagmus and he was permitted to observe nystagmus in a laboratory assistant who was watching the rotating drum. After this he made a direct effort to feign nystagmus.

Figure 1 shows samples of the electrooculogram of one subject (*5*). The top record is a random sample of the subject's eye movements in condition (i)—that is, watching the rotating drum. Clear nystagmus is seen during the entire 8-second sample, regular oscillation occurring with alternating slow and fast components. Condition (ii), watching the drum after the induction of hypnosis, gave the same result. The middle record is a random sample of the tracing during condition (iii), while hallucinating the rotating drum. Unmistakable nystagmus is present during 80 percent of the sample. The frequency of the nystagmus is similar to that obtained in condition (i) (three per second) but the average amplitude of the eye excursions is smaller and there is a reversal in the direction of the slow and fast components (the hallucinated drum seemed farther away and moved in the opposite direction to the actual drum). The bottom tracing, condition (iv), represents an effort of the subject to feign nystagmus in the waking state. Many different patterns of eye movements were seen in various attempts of the subject to simulate nystagmus (such as imagining the rotating drum, or imitating the eye movements). However, as in Fig. 1, nystagmus was seen in none of these tracings.

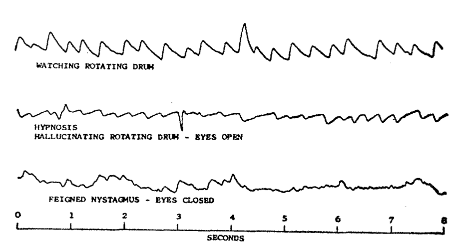

Fig 1. Eight-second samples of an electrooculogram of a subject under three different conditions.