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Effect of Differential Binocular Adaptation on Scotopic Acuity

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Monocular scotopic acuity thresholds were determined for three observers when both eyes were dark adapted and also when only the observing eye was dark adapted while the nonobserving eye was exposed to a brightness of 100 ft-L between the target presentations. Although the observers reported that the targets looked quite different under the two conditions, acuity remained substantially the same under both conditions, and it was concluded that light adapting one eye does not affect the scotopic acuity of the other eye.

1. INTRODUCTION

BINOCULAR interaction has long been a subject of study. In 1921, Dunlap[1] presented evidence for what he called "central inhibition" or central "fatigue" and Crook[2] shortly agreed that "there is a real decrease in the sensitivity of a point on one retina when the corresponding point on the other retina has just been previously stimulated." But with succeeding work, it has proved extremely difficult to settle interaction questions relating to thresholds. Duke-Elder[3] and Cook[4] have given the early history of this problem indicating that from the beginning, the experimental results have been divided on the question. Indeed, complete confusion persisted until quite recently.[4,5] In the last few years, however, there have been new approaches to the problem. Pirenne[6] has examined the matter from a statistical point of view and concluded that "summation" is really what might be termed a statistical artifact. He points out that doubling the brightness of the stimulus increased the monocular frequency of seeing from 0.38 to 0.86 while the binocular frequency of seeing for the initial brightness was only 0.56 and concludes that the results are the same as would be expected if the two eyes belonged to different people.

Collier[7] also treats the problem statistically and concludes that the binocular "probability of responding" is greater than the monocular probability of responding, but once again, this does not necessarily imply summation or interaction.

The apparent resolution on statistical grounds of the binocular threshold results still leaves us with another closely related problem, the effect of differential adaptation of the eyes. Duke-Elder[8] and Cook[4] have summarized the early work on this problem also. These studies, dealing with the effect of light adapting only one eye on the absolute threshold of the dark adapted eye appeared to culminate with Crawford's work[9] showing that the threshold remained relatively constant while the other eye was subjected to a wide range of adapting luminances. Crawford suggested that in previous work where binocular interaction had been found, there may have been light leaks into the dark adapted eye. In his discussion of the topic, LeGrand[10] concluded that "the dark adaptation of one eye may be preserved by keeping it closed when in the light."

Evidence that the problem may still not be completely settled, however, has since appeared. Wolf and Zigler[11] showed that dark adaptation curves obtained when the two eyes are stimulated with different luminosities and tested simultaneously are not identical with curves obtained independently with the same luminances. Bouman[12] has recently reported that contrast and difference thresholds are essentially unaffected by steady stimulation of the other eye, but fluctuating stimulation does produce disturbances which he attributes to such factors as eye dominance, rivalry, etc. But Helms and Prehn[13] have just published results showing that the sensitivity of the dark adapted eye is altered when the other eye is light adapted, and Helms and Raeuber[14] have reported that the amount of change is a function of the color of the adapting light, with 570 mμ producing the greatest change. The latter is interesting in comparison with Allen's old reports[15,16] that the CFF of one eye, whether light or dark adapted, may be affected by the stimulation of the other eye, but only by red, green, and violet, and not by a series of other spectral lights, among them 570 mμ.

Although LeGrand, as noted, claimed that the absolute threshold is unaffected by the state of the other

[1] K. Dunlap, Am. J. Psychol. 55, 206 (1921).
[2] M. Crook, J. Gen. Psychol. 3, 313 (1930).
[3] W. Stewart Duke-Elder, *Text-Book of Ophthalmology* (The C. V. Mosby Company, St. Louis, 1944), Vol. I, p. 1050.
[4] T. Cook, Psych. Monog. 45, 86 (1934).
[5] C. Graham, J. Gen. Psychol. 3, 494 (1930); 5, 311 (1931); D. Shaad, J. Exptl. Psychol. 18, 391 (1935); R. Lythgoe and L. Phillips, J. Physiol. 91, 427 (1938); W. Crozier and A. Holway, J. Gen. Physiol. 23, 101 (1939); N. Bartlett and R. Gagne, J. Exptl. Psychol. 25, 91 (1939).
[6] M. Pirenne, Nature 152, 698 (1943).
[7] G. Collier, J. Exptl. Psychol. 47, 75 (1954).
[8] W. Stewart Duke-Elder, reference 3, p. 964.
[9] B. Crawford, Proc. Roy. Soc. B128, 552 (1940).
[10] Y. LeGrand, *Light, Colour and Vision* (John Wiley & Sons, Inc., New York, 1957), p. 244.
[11] E. Wolf and M. Zigler, J. Opt. Soc. Am. 45, 696 (1955).
[12] M. Bouman, *Problems in Contemporary Optics* (Istituto Nazionale di Ottica, Florence, 1956) pp. 511–518.
[13] A. Helms and R. Prehn, Arch. Ophthalmol. Graefe's 160, 290 (1958).
[14] A. Helms and J. Raeuber, Arch. Ophthalmol. Graefe's 160, 285 (1958).
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[16] F. Allen, J. Opt. Soc. Am. 7, 583 (1923).

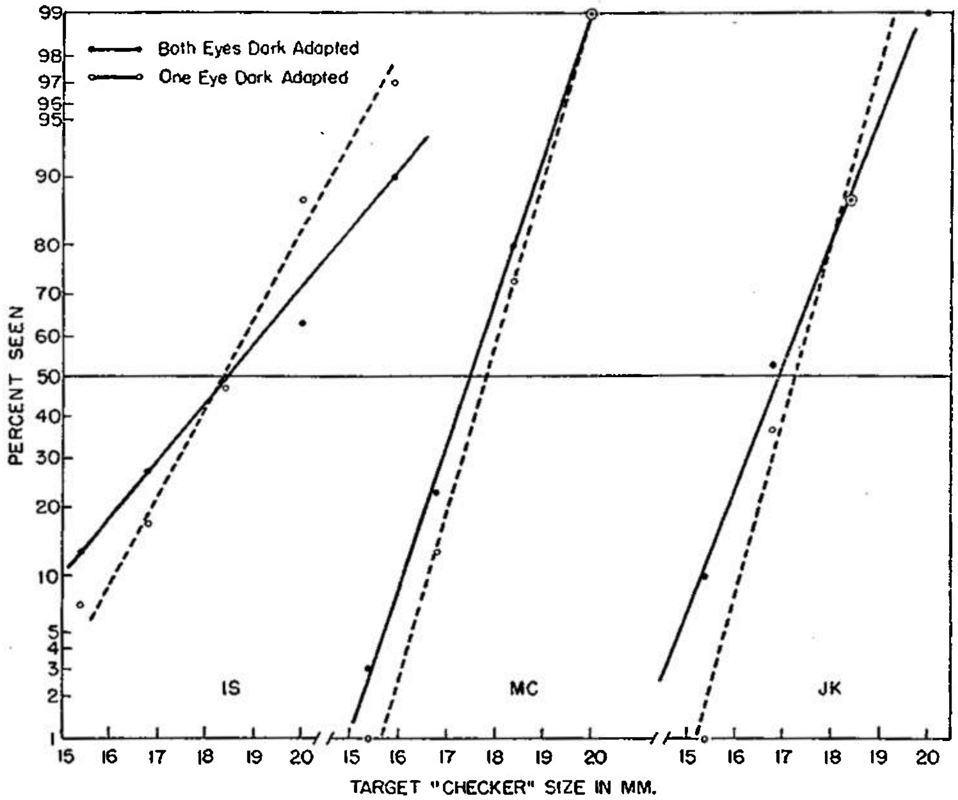

FIG. 1. Frequency of seeing curves of three Os for both eyes dark adapted and for only one eye dark adapted. Each point is based on 30 observations. The differences for each O are not significant.

eye, he has written elsewhere[17] that there is some evidence by Aguilar and Solis that the state of adaptation of one eye can somewhat alter the *difference* threshold of the other. Judging from the evidence so far, this may well be true and, if so, would be of importance in considering the relation of the sensitivity findings in acuity. If difference thresholds are affected, we would expect scotopic acuity to be altered when the other eye is light adapted. Almost no work has been done in this area with acuity aside from a series of experiments dealing with photopic acuity[18] which raise different questions. Fry and Ihring[19] have found visual acuity to be unaffected by a high intensity flash in the other eye, but their target illumination was not quite in the scotopic range and it is uncertain how much adaptation is affected by a three second flash; but it is certainly not excessive.[20]

For these reasons, and since it is a matter of some practical importance, the effects on scotopic acuity of adapting the nonobserving eye to a fairly high illumination have been tested.

2. APPARATUS AND PROCEDURE

The acuity limens were obtained with a set of checkerboard targets which, at 10 ft from the observer, subtended an over-all visual angle of 10 deg. The targets, at a brightness of 4.17 log$\mu\mu$L, were centered 10° to the left of the fixation light. The "checker" squares on the targets ranged from 73 to 10 mm in size. The background wall was illuminated to a brightness of 3.9 log$\mu\mu$L.

A shutter was placed before O's right eye and a white screen, which could be illuminated to a brightness of 100 ft-L, in front of the left eye. The shutter concealed the target from the right eye but permitted O to view the fixation point, a dim red cross, beyond its right edge; when the shutter was raised, the target was also visible.

At the beginning of each session, O was dark adapted for 15 min and then both eyes were adapted to the background light level of 3.9 log$\mu\mu$L (referred to as the "dark adapted" threshold) for 5 min. In the first half of the session, the monocular "dark adapted" acuity threshold was determined by presenting each target in the series five times in random order. The exposure time was always 3 sec. During the second half of the session, the so-called "light adapted" threshold was determined with the following procedure: The O's right eye was occluded and the screen before the left eye illuminated to 100 ft-L. The left eye was exposed for five minutes, at which time it was assumed to be about 85% light adapted.[20] Then the adapting light on the screen was extinguished and O was told "fixate the red cross"; O uncovered his right eye and found the

[17] Y. LeGrand, reference 10, p. 266.
[18] G. Hartmann, J. Exptl. Psychol. 16, 383 (1933); S. Kravkov, J. Exptl. Psychol. 17, 805 (1934).
[19] G. Fry and N. Ihring, WADC Tech. Rept. Pt. I, 53–159 (March, 1953).
[20] S. Smith and F. Dimmick, J. Opt. Soc. Am. 47, 391 (1957).

fixation light; the shutter was raised; *O* made his judgment; *E* gave the order to cover the right eye; the screen light was turned on while the target was being changed.* The timing cycle was such that the adapting light was on for 20 sec and off for 10 sec during this procedure. The targets were presented randomly five times each with 3 sec exposures. There were six sessions for each *O* resulting in 30 judgments for each target in both parts of the experiment.

3. RESULTS

The frequency of seeing curves for the three *O*s are shown in Fig. 1. For the first *O*, the limens are identical; for the other two *O*s the limen for the "light adapted" condition is slightly higher than the limen with both eyes dark adapted. To determine the significance of these differences, standard errors of the 50% points were computed by the formula devised by von Schelling.[21] These are listed in Table I. The differences between the limens, based on these standard errors in a *t*-test, are not significant. For all *O*s the standard deviations of the distribution are smaller for the "light adapted" condition. This may be a practice effect since these judgments were all made during the latter half of a session.

The *O*s reported that the targets appeared much different during the "light adapted" condition, one saying the targets appeared to be seen through a fog and another reported seeing black spots on white while there were white spots on black in the dark-adapted condition.

4. DISCUSSION

The present results indicate that for target exposure times of about 3 sec, scotopic acuity is not significantly altered by light adapting the nonobserving eye. This experiment, however, will not settle the interaction controversy outlined in the introduction. There is no reason to assume that sensitivity and acuity are identical functions, and it is quite possible that experimental conditions may affect sensitivity and leave acuity undisturbed or vice versa. It should be noted that most studies have used very short exposure times, less than 100 msec, which are unusual for measuring acuity. But exposure time may be a decisive factor. We have noted Bouman's contention that the disturbances in threshold values, when they occur, may be due simply to the effects of eye dominance. This idea seems to be supported by a recent study by Kelsey[22] showing that reaction times to visual stimuli are shorter when the dominant, rather than the nondominant, eye was stimulated. If we conceive eye dominance and retinal rivalry to be attention factors, then we would expect threshold disturbances to diminish with increasing exposure time since there will be an increasing opportunity for the target to be seen during some fraction of that time. Indeed, it appears that most of the studies reporting no interaction used relatively long exposure times; for example, Crawford's was 1 sec and Fry and Ihring's was 3 sec. Most studies finding interaction—however it was explained—used short exposure times; Helms used 0.1 sec, Pirenne, 0.004 sec, Bouman 0.03 sec. But there are too many exceptions for this to be conclusive; for example, Shaad used an exposure time of 2.5 sec and found an interaction while Bartlett and Gagne did not with an 0.008 sec flash. Whether an interaction effect would be obtained with acuity thresholds if short exposure times were used remains to be seen, but it would be of little practical value if acuity measurements require long exposures to be meaningful.

TABLE I. Summary of the experimental results.

O	Target size (mm) at "dark adapted" threshold	σ_L	Target size (mm) at "light adapted" threshold	σ_L
IS	18.4	0.62	18.4	0.39
MC	17.5	0.25	17.8	0.23
JK	16.9	0.27	17.2	0.21

* It should be noted that this "covering" procedure was also carried out during the "dark adapted" half of the session as a matter of routine and to equalize the effects of darkness and pressure on the right eye for both parts of the session, but, in fact, there still remained this difference between the two conditions: when the "dark adapted" threshold determination was begun, *O*'s eye was adapted to the ambient illumination of 3.9 log $\mu\mu$L; when the "light adapted" threshold determinations were begun, the eye, which had been occluded for 5 min, was thus a little more dark adapted. A separate investigation showed, however, that this slight difference produced no change in the acuity threshold.

[21] S. Smith *et al.*, J. Opt. Soc. Am. 45, 502 (1955).

[22] P. A. Kelsey, Master's thesis (University of Connecticut, Storrs, Connecticut, 1959).