Interocular non-independence¹

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Binocular interaction was studied by presenting a different letter form to each eye via a dichopic tachistoscope. The two dissimilar letters were presented simultaneously or at short delay intervals of 0-200 msec and were either presented on corresponding or non-corresponding retinal areas. At delay intervals of less than 100 msec stimulation of corresponding areas resulted in identification performance below that to be expected on the basis of independent chances to perceive. Stimulation on non-corresponding areas resulted in both presented letters being identified at the accuracy level predicted by an independence assumption.

The exact interrelationship between the two eyes in man has been the subject of much experimental research over the last three decades. Although binocular vision is conceded to be more sensitive than monocular, the question of whether or not this is due to a simple combination of independent detectors has been hard to answer. Crawford (1940) and Pirenne (1943) believed that the binocular detection threshold was lower than the monocular only because the O had two independent chances to detect. Collier (1954) and Collier and Kubzansky (1958), in rigidly controlled experiments, found that binocular summation exceeded predicted independence levels.

The latter view, that the two eyes are not independent, has been largely substantiated in two ways. First, the model typically used in demonstrating independence has been shown by Eriksen (1966) to be inappropriate and to overestimate in its predictions. Second, data from areas other than brightness detection has had interesting implications. Thomas (1954, 1955), Lipkin (1962) and others have found interocular interactive effects in flicker discrimination. Hubel and Wiesel (1959, 1962) have demonstrated summative and inhibitory interactions between homologous loci in the receptive fields of the two eyes. These data show that in cats 80-85% of fifth-order neurons in the striate cortex are binocularly driven when appropriate (patterned) stimuli are used.

An interocular brightness balancing model was suggested by Levelt (1965) in accounting for brightness perception and certain contour phenomena. Martin (1962) demonstrated summation by showing not only that performance exceeded predicted independence levels, but that it also decreased as a temporal separation was introduced between stimuli to each eye. Finally, Eriksen, Greenspon, Lappin, and Carlson (1966) and Eriksen and Greenspon (1967) studied form perception at brief exposure durations and found that summation above independence levels exists when identical let-

ters are presented to corresponding retinal areas and within a short time interval.

The electrophysiological, but not the behavioral studies have attempted to evaluate performance in each eye when they are stimulated simultaneously to answer questions about interaction. The present paper utilizes a similar approach. The Os are required to identify two dissimilar form stimuli, one to each eye. Monocular accuracy should be unaffected by whether or not a form appears in the other eye if the two eyes are independent. Furthermore, if independent, the product of the two monocular hit rates (HR) should be identical with accuracy on identifying both letters on a single trial. Departures from these predictions over any temporal or spatial relationships between the stimuli would indicate non-independence.

METHOD

Subjects

Six University of Illinois students, three female, served as paid volunteers. All had participated in a previous dichopic form recognition experiment.

Apparatus

The optical system and the Scientific Prototype tachistoscopic timer and lamp driver unit have been described in detail elsewhere (Eriksen, et al, 1966). The S viewed a circular adapting field in each channel of the tachistoscope. The diameters of the channels were of angular subtense 2 deg. These fields were a diffuse white of 0.3 ft-L. In the center of each was a glowing "X", subtending 0.12 deg visual angle which remained on constantly and served as a fixation point. These circular fields and the Xs were fused. Stimulus letters were located at the corners of an imaginary 1 deg square centered on the X. The stimulus fields were both of 0.3 ft-L.

Stimuli consisted of the letters A, T, U, and H. "Paratype" 18-point futura bold (No. 11316) letters were used on white vinyl cards. Each letter subtended 0.12 deg of visual angle. As in previous experiments in which these materials were used (Eriksen et al, 1966), the letter-to-background contrast was about 96%. Small circular holes were cut into the stimulus cards so that X was continuously visible.

Procedure

The Ss were first given a practice session during which a basic exposure duration was established allowing for a HR of 85-90% in each eye. The two eyes were similar enough in all Ss to allow the use of a

single exposure duration for both. This duration was used for each stimulus exposure in the experimental sessions. There were 18 experimental conditions, randomly arranged into nine sessions, each with four blocks of 24 trials. The Ss were to identify the letters which could appear at 2, 4, 8, or 10 o'clock with respect to the X. There were 12 blocks of monocular trials in which a letter was presented to one eye (half the time the right and half the left) and a blank field (of the same luminance as the stimulus field) to the other, and 12 blocks each of dichopic presentation on corresponding areas (fused) and on noncorresponding areas (unfused) of two letters. These three basic kinds of trials were further subdivided into two blocks, each block having six different temporal relationships between stimuli to each eye. Stimuli occurred simultaneously, successively, or with interstimulus intervals (ISI) of 10, 50, 100, or 200 msec. Two further subdivisions were made. In the fused and unfused trials half the stimuli presentation was left eye to right eye and half the reverse. For the unfused condition another division was made between homolateral and heterolateral trials, the former having both letters on the same side of the X and the latter having them on opposite sides.

When a stimulus was presented to either eye the other eye received darkness, except during simultaneous presentation. Delay intervals were formed by returning to the adapting field luminances. The simultaneous condition consisted of presentation of the letters to each eye followed by an equal duration of darkness in both eyes.

After the original nine sessions each S received two final four-block sessions, one at the originally determined exposure duration and one at twice this value (2T). For these sessions either the right or the left eye was presented a stimulus card upon which two different letters were superimposed.

There were six possible pairings of the four letters. The same letter never appeared twice on any one trial.

Fig. 1. Percent correct identifications of both letters as a function of ISI and whether the letters were or were not on corresponding retinal areas.

The Ss were required to answer on every trial and controlled timing of the trials by a triggering device after E gave a ready signal.

RESULTS

The per cent of trials on which both letters were correctly identified was analyzed in a three-way analysis of variance (fused-unfused conditions, ISI, and Ss). Significant effects ($p < .01$) were obtained for the fused-unfused conditions and the interaction of these conditions with ISI. The nature of these effects can be seen in Fig. 1 where the mean per cent of trials in which both letters were correctly identified is shown as a function of ISI and the fused-unfused conditions. The horizontal line in Fig. 1, 67%, represents the level of performance to be expected if the eyes were operating independently. This value is calculated by multiplying each S's average monocular HR for right and left eyes and averaging these products over Ss.

For the unfused condition where the letters are presented on non-corresponding retinal areas, both letters are reported correct at the level to be expected from two independent chances, irrespective of the ISI between the different letter presentations. However, when the different letters fall on corresponding retinal areas as in the fused condition, identification accuracy for the two letters is markedly impaired if they are presented simultaneously. It isn't until the two letters are separated by an ISI of 100 msec or more that performance approximates that to be expected from two independent chances to identify.

Control observations were obtained for the condition where both letters were superimposed one on top of the other on the same stimulus card and presented monocularly. The average identification was 32% when the exposure duration of this condition was the same for each S as was used for that S in the other experimental sessions. When the exposure was twice the duration (2T), identification was 34%. If these two values are compared with performance at the simultaneous ISI for the fused condition, it is seen that dichopic presentation of the two letters on corresponding retinal areas is not identical to monocular presentation of the superimposed letters even when the total light energy entering the visual system is constant as for the 2T condition. Dichopic stimulation permits somewhat better separation of the composite stimulus than does the monocular stimulation.

In the next analysis right and left eye performance for Ss was compared under the condition where a letter was presented monocularly and the other eye was stimulated by an empty illuminated field at the various ISI values. A three-way analysis of variance (right and left eye by ISI by Ss) gave no significant main effects or interactions, indicating that for all Ss both eyes were of similar monocular accuracy and that the delay between the letter and the empty flash had no effect on identification performance.

Fig. 2. Percent correct monocular form identifications as a function of ISI, kind of stimulation to the other eye, and whether corresponding retinal areas were involved.

The accuracy in identifying the letter presented to a given eye when the other eye was also presented a letter for identification was analyzed for the fused-unfused conditions and the different ISI values. A significant interaction between conditions and ISIs was again obtained ($p < .01$) and also the S effect was significant.²

Figure 2 shows the mean per cent accuracy in identifying one of the two letters as a function of conditions and ISI. Figure 2 also shows the results from the previous analysis where the letter was presented to only one eye and the other eye received an empty flash at the designated ISI values. For the unfused condition identification accuracy for a single letter is essentially the same for a given eye when the other eye receives a different letter as when the other eye receives an empty flash stimulation. However, if the stimulation to the other eye is a letter on corresponding retinal points, performance is impaired at ISI values out to 50 msec and perhaps longer.

One further breakdown of the single eye accuracy data was made in order to examine more closely the interaction between the two eyes. In Fig. 3, data for single eye accuracy when two different letters are dichopically presented is shown as a function of ISI conditions and whether the identified letter was first or second in order of presentation. The horizontal line in Fig. 3 (82%) is the average monocular identification accuracy achieved when only one

letter was presented and the other eye received an empty light flash.

An ISI by condition by order by Ss analysis of variance was carried out. The interaction of fused-unfused conditions with ISI is again significant and there is also an ISI by order interaction. For the fused condition interocular interference is greatest in the recognition of the first of the two presented letters at ISI values of 50 msec or less. However, at ISI values of 100 and 200 msec, identification accuracy of the first of the two presented letters is superior to that for the second presented letter. Under the unfused condition no order effect is apparent. Both first and second occurring letters are identified, irrespective of ISI value, at the level obtained for monocular single letter stimulus accuracy (82%).

DISCUSSION

The above results provide clear-cut evidence that the two eyes do not operate independently when stimulation falls upon corresponding retinal points. If two different stimuli are presented on corresponding areas of the two eyes within somewhat less than 100 msec of each other, the identification of both stimuli is impaired. Maximum impairment occurs if the presentation is simultaneous and is comparable though not identical to the performance effects obtained if both stimuli are superimposed on the same stimulus card and presented monocularly. The monocular stimulation of a composite of the two forms produces greater impairment in identification of either form than is obtained with the simultaneous dichopic presentation. This result is consistent with the previous finding (Eriksen et al, 1966) where incomplete summation was found for dichopic presentation of the same form. The greater the summation the more the two forms are intertangled in a composite perception and therefore the greater the difficulty in identifying either one.

The data in Fig. 3, however, show that this identification impairment is not equal for the two forms. At short ISIs the form presented first has its identification impaired more than the second presented form. At ISI values of 100 msec or more the reverse situa-

Fig. 3. Percent correct monocular form identifications as a function of order of stimulation, ISI, and whether corresponding retinal areas were involved.

tion obtains. This reversal at longer ISI values is the result of improved identification of the first presented form rather than a further loss in identification of the second presented form. Actually, the data in Fig. 3 show that identification of the second form remains essentially constant over ISI values of 0 to 200 msec. This may be due to new variables entering the task at longer ISI values.

The failure of the second presented form to gain in identification accuracy at these longer values may be due to a drift in accommodation of the eye over time so that the image is not as clearly focused on the retina. Also, when the average exposure duration of the stimulus (35 msec) is added to the 200 msec ISI, the total time interval from the advent of the first stimulation is now in the region of the latency for eye movements. The second stimulus may then be occurring on some trials at or during a change in fixation on the part of the S occasioned by the occurrence of the first stimulus in one of the quadrants of the field. Latour (1962) and Volkmann (1962) have shown impairment in visual perception at and even slightly before the occurrence of saccadic eye movements. Drifting of accommodation and saccadic eye movements might then be responsible for the failure of the second presented letter to achieve the performance level for monocular stimulation. It is also possible that at the longer ISI values the latency for binocular rivalry is exceeded. The 200 msec ISI may be sufficient to have produced an inhibitory response on some trials in the eye receiving the second stimulation.

The stimulation sequence employed in this condition is identical with the backward and forward dichopic masking paradigm (Smith & Schiller, 1966). The identification of the first presented form would represent backward masking and identification of the second form preceded by the first would represent forward masking. The greater impairment found for the first form identification at short ISI values is in agreement with the results of Smith and Schiller (1966) who found that backward dichopic masking was greater than forward.

No temporal effects were found if the stimulation to the separate eyes did not fall on corresponding retinal points. Under the unfused condition performance was at the level to be expected from independent chances to perceive irrespective of the ISI between the test stimulations. This result is consistent with previous findings of dichopic stimulation (Eriksen et al, 1966) and it also agrees with the finding that error components in the visual system

are temporally uncorrelated for retinal areas separated by approximately a degree or more (Eriksen, 1966).

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Notes

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2. The condition by S interaction attained significance at the .05 level. This was due primarily to one S who followed the general slope trends of the curves but gave a saw-toothed plot varying over a wide range.

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