Amblyopic eyes have longer reaction times

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The RT (reaction time) to a 0.25° spot of light was measured monocularly on 25 normal subjects and 36 strabismic patients. The overall mean RT and the ΔRT (difference in RT between the right and left eyes) for the 19 strabismic patients without amblyopia did not differ significantly from that of the normal subjects. The overall mean RT of the dominant eyes of the 17 amblyopic patients did not differ significantly from that of either the faster or slower eyes of the normal subjects. The overall mean RT of the amblyopic eyes was significantly longer than that of the normal subjects. The ΔRT was significantly larger in the amblyopic patients. A regression analysis of the visual acuity of the amblyopic eye and the ΔRT showed that the data was best fit by a linear equation. The coefficient of correlation was +0.82. Additional experiments showed that the longer RT of the amblyopic eyes was not caused by eccentric fixation or by the reduced visual acuity.

Key words: amblyopia, strabismus, reaction time, suppression

Earlier studies on a limited number of amblyopic patients have shown that the visual reaction time (RT) of the amblyopic eye was significantly longer than that of the dominant eye.1, 2 More recently it has been reported that the RT for detecting a low contrast grating was longer when the amblyopic eye was used3 and also that saccadic latencies were longer when the stimulus was presented to the amblyopic eye.4 In these studies there was some suggestion that the degree of delay might be related to the depth of amblyopia, but the small number of patients prevented these investigators from determining how strong this relationship might be. The small number of subjects also did not allow the authors to examine how other factors such as the fixation behavior might contribute to the longer RT of the amblyopic eyes. It was thus decided that a more extensive examination of the RT of strabismic subjects was necessary. We have tested 25 normal subjects and 36 heterotropic subjects with and without amblyopia. We shall show that the RTs are significantly longer when the amblyopic eyes are used and that the difference in the RT of the two eyes is highly correlated with the visual acuity of the amblyopic eye.

Materials and methods

Subjects. RT was determined for 25 normal subjects and 36 strabismic subjects. All the normal subjects had normal binocular vision and visual acuity (corrected or uncorrected) of 20/20 or better. Their ages ranged from 11 to 54 years. Some of the subjects had had experience in performing visual psychophysical experiments, but the majority were inexperienced observers.

The patients were classified as having amblyopia if the visual acuity of the two eyes differed by

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This investigation was supported in part by Public Health Service Grant EY-00376 from the National Eye Institute, National Institutes of Health, Bethesda, Md.

Submitted for publication Nov. 5, 1980.

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more than two Snellen acuity lines. Seventeen of the patients were amblyopic and 19 were not amblyopic. The ages of the strabismic subjects ranged from 11 to 49 years, and all had had a complete eye examination within 3 months of the RT measurements. The best corrective lenses were used during the measurements, and natural pupils were used.

**Stimulus.** The stimulus was a 0.25° spot of light that was flashed in the center of a continuously present annulus. The stimulus was visible to all subjects. The luminance of the spot was 35.1 cd/m², which was approximately 1.5 to 2.0 log units above threshold for the normal subjects.

The inner diameter of the annulus was 2.5° and the outer diameter was 5°. The luminance of the annulus was 27.2 cd/m². The background was diffusely illuminated and had a luminance of 1.0 cd/m².

**Procedure.** The subject sat 114 cm away from a translucent screen on which the stimulus was projected. One of the eyes was covered by a plastic occluder, and the subject was asked to fixate the center of the annulus. The subject was given a pushbutton switch and was instructed to push the switch as soon as the stimulus was seen. Several practice trials were given before the measurements were begun.

For the measurements, the experimenter gave an alerting audio signal and, after a variable time delay, opened the shutter to expose the stimulus for 1.0 sec. The subject then pushed his switch, which determined the RT for that trial. After 3 to 5 sec the alerting signal was given and another trial was begun.

A total of 40 or 50 measurements of the RT were made for each eye. These measurements were divided into two blocks so that 20 (or 25) measurements were taken for the right and left eyes; after a 1 to 2 min rest period, another 20 (or 25) measurements were taken from the two eyes. The entire testing time required about 20 min.

**Recording and analysis of the data.** A Texas Instrument 960A minicomputer was used to record the RT. The pulse used to open the shutter was sent in parallel to the computer to begin the timing period, and the pulse elicited by the subject pushing the switch stopped the timing period. The time period was divided into 5 msec bins, and the computer stored each RT measurement in the appropriate bin. After the 40 or 50 measurements of the RT had been obtained from each eye, the RT values were printed out in digital form, and further analysis and statistics were done from these data. RT shorter than 150 msec (usually less than 2% of the trials) were discarded.
Results

Normal subjects. From the individual RT measurements a mean RT was calculated for each of the eyes of the 25 normal subjects. The distribution of the mean RT for the 50 eyes is shown in Fig. 1 by the open bars. The overall mean RT was 242.7 ± 37.1 msec (mean ± S.D.) for the right eyes and 247.6 ± 38.1 msec for the left eyes, with a range from 192.1 to 343.4 msec.

The absolute difference in the RT between the two eyes (ΔRT) was calculated for each pair of eyes, and the distribution of the ΔRT is shown in Fig. 2 by the open bars. The mean ΔRT was 12.5 ± 9.3 msec, with a range from 1.6 to 40.1 msec. There were two subjects with ΔRT of 30.1 and 40.1 msec.

Strabismic subjects without amblyopia. There were 19 strabismic patients who were classified as nonamblyopic. The distribution of the mean RT for the squinters without amblyopia is compared with that of the normals in Fig. 1. The overall mean RT was 273.6 ± 66.9 msec for the right eyes and 270.7 ± 72.9 msec for the left eyes. Both of these means were not significantly different from that of the normal subjects (right eye, t = -1.95, p > 0.05; left eye, t = -1.36, p > 0.05). The higher mean RT of these heterotropic subjects was greatly influenced by one esotrope whose mean RT was 528.4 msec for the right eye and 552.9 msec for the left eye.

The distribution of the ΔRT for the squinters without amblyopia is compared with that of the normals in Fig. 2. As with the mean RT, the distribution of ΔRT is quite comparable for the two groups. The mean ΔRT for the squinters without amblyopia was 9.9 ± 7.7 msec, which is not significantly different from that of the normals (t = 0.95, p > 0.05).

Patients with amblyopia. There were 17 strabismic subjects with amblyopia whose visual acuity in the amblyopic eye ranged from 20/30 to 20/400. Their ages ranged from 12 to 49 years. The overall mean RT for the subjects with amblyopia is compared with that of the normal subjects in Fig. 3. Some of the RT values were quite comparable to that of normal subjects, but there were a large number of RT values that were significantly longer than those of the normal subjects. The overall mean RT was 254.9 ± 45.8 msec for the preferred eyes and 298.3 ± 78.0 msec for the amblyopic eyes.

To compare the RT values of the amblyopic patients with those of the normals, the RT values of the normal subjects were separated...
Fig. 3. Comparison of the distribution of the mean RT of the normal subjects with that of the amblyopic patients.

Fig. 4. Comparison of the distribution of the $\Delta$RT of the normal subjects with that of the amblyopic patients.

into the slower and faster eyes. The overall mean RT of the dominant eye of the amblyopic subjects did not differ significantly from either the faster eye of the normal subjects ($t = -1.26$, $p > 0.05$) or the slower eye of the normal subjects ($t = -0.27$, $p > 0.05$). The amblyopic eye, on the other hand, was significantly slower than even the slower eye of the normals ($t = 2.60; 0.05 > p > 0.01$).

The distribution of the $\Delta$RT for the amblyopes is compared with that of the normal subjects in Fig. 4. Some of the $\Delta$RT values were comparable to those of the normal subjects but there were many $\Delta$RT values that were considerably larger. The mean $\Delta$RT for the amblyopes was $44.1 \pm 50.0$ msec, which was
Fig. 5. Relationship between ΔRT and MAR of the amblyopic eye. The coefficient of correlation is +0.82.

significantly longer than that of the normals. The range of ΔRT for the amblyopes was 1.1 to 156.3 msec, which was larger than that for the normals (1.6 to 40.1 msec).

A comparison of the ΔRT with the visual acuity of the amblyopic eye showed that the larger ΔRT was seen in the patients with the deeper amblyopia. To determine whether there was a correlation between visual acuity and ΔRT, a regression analysis was carried out between the minimum angle of resolution (MAR) of the amblyopic eye and the ΔRT for the 17 amblyopic patients (Fig. 5). The analysis showed that the best-fit curve (least square deviation and highest coefficient of correlation) was obtained with a linear equation:

\[ \text{MAR} = 2.4 + 0.10 \times \Delta \text{RT} \]

This equation is represented by the solid line in Fig. 5. The coefficient of correlation was +0.82, which is highly significant.

The data were also fitted to the exponential equation:

\[ \text{MAR} = e^{0.6 \times \Delta \text{RT}} \]

The coefficient of correlation was slightly lower (+0.75) and the residual deviation larger than those with the linear equation.

A regression analysis was also carried out between MAR and the RT of the amblyopic eyes. The coefficient of correlation was slightly lower (+0.68) but still highly significant.

Regression analysis was also done for the nonamblyopic patients. The coefficient of correlation between MAR and RT and between MAR and ΔRT were both statistically insignificant.

The question then arises whether the longer RT and large ΔRT in the amblyopic patients could be related to other changes usually found in amblyopes, e.g., eccentric
Fig. 6. Distribution of RT measurements for a patient with deep amblyopia. With the 0.25° stimulus the mean RT was 228.9 msec for the preferred eye and 385.2 msec for the amblyopic eye. Increasing the stimulus size to 0.50° reduced the RT of the amblyopic eye to 302.7 msec, but the RT was still significantly longer than that of the right eye.

fixation or unstable fixation. With reference to eccentric fixation, we found that of the four amblyopes with visual acuity less than 20/100 and ΔRT greater than 100 msec, two had eccentric fixation, one had foveal fixation, and one had nystagmus.

Since two of the amblyopes showed eccentric fixation, we measured the changes in RT for eccentric retinal loci in two subjects. One of these subjects had normal binocular vision and the other was an exotrope without amblyopia. In both cases there was no systematic change in the mean RT with eccentricities up to 10°. These results are in good agreement with the more extensive observations of Haines et al. 5 (see below).

Can the longer RT in the amblyopes be merely a result of the difficulty in detecting the 0.25° stimulus because of decreased visual acuity? To answer this question, the RT was measured in two of the amblyopes with larger targets. In the first patient, who had deep amblyopia, the mean RT was 228.9 msec for the dominant eye and 385.2 msec for the amblyopic eye when the standard 0.25° target was used (Fig. 6). With a 0.5° target the mean RT for the amblyopic eye was reduced to 302.7 msec, which was still significantly longer than the RT for the preferred eye. In the second amblyope (20/70) the ΔRT was 55.4 msec with the standard 0.25° target and 29.2 msec when the 0.5° target was used. The first amblyope had eccentric fixation, whereas the latter had foveal fixation. We also tested two subjects (who had been used in the eccentric fixation experiment) for the effect of blurring the eyes on RT. In both cases, blurring the eye with frosted lenses (to approximately 20/100) did not change the RT in any systematic way.

Discussion
The results of this study have shown that the overall mean RT of the amblyopic eyes and the ΔRT of the amblyopic patients are significantly longer than those of the normal subjects. We have also found that there is a high correlation (r = +0.82) between the
MAR of the amblyopic eye and the ΔRT. For the strabismic subjects without amblyopia the RT and ΔRT were not significantly different from those of normal subjects, and the coefficient of correlation between these measures and the MAR were not significant. These findings are in good agreement with the results of previous studies on a limited number of amblyopic patients.\textsuperscript{1-4}

We have also shown that the delay in the visual signal when the amblyopic eye is used cannot be accounted for by eccentric fixation. Haines et al.,\textsuperscript{5} in an extensive study of the RT at different retinal loci, have shown that the RT does not change by more than 10 msec for eccentricities up to 30° along the horizontal meridian and up to 10° in the vertical meridian. In none of the amblyopic patients was the eccentric fixation of this magnitude. These findings would indicate that even if an eccentric point was being tested in these amblyopes, the RT of that region was also significantly longer than that of normal subjects.

We have also shown that the ΔRT of the amblyopic patients is maintained when larger targets are used and also that blurring the stimulus in subjects with good visual acuity does not alter the RT in any systematic way. These observations demonstrate that the longer RT of amblyopic eyes was not caused by a difficulty in detecting the small stimulus and that the RT measures are not merely a reflection of the reduced visual acuity of the amblyopic eye. This could have been predicted from the results of Haines et al.,\textsuperscript{5} who showed that at retinal eccentricities (up to 30° in the horizontal meridian) where visual acuity would have been greatly reduced, the RT was not altered. This does not mean that the mechanisms or the sites for the longer RT and reduced visual acuity are necessarily different.

With reference to the site for the delay in the visual signal, the use of the same hand and finger when the preferred and amblyopic eyes were tested would eliminate the motor side of the RT pathway as the site for the delay. Where the delay is occurring on the sensory side is more difficult to state. Earlier studies on the RT of normal subjects during binocular rivalry might offer a clue. It has been shown that when an eye is suppressed,\textsuperscript{6} the RT of that eye is significantly longer than the RT of the dominant eye (unpublished observation). If amblyopia can be considered an extension of suppression from the binocular to the monocular condition,\textsuperscript{7} then the results of experiments dealing with the site of suppression might be considered. Bárány and Hallđén\textsuperscript{8} have reported that a pupillary constriction was less likely to occur if the suppressed eye (during binocular rivalry) is stimulated. In a study involving a patient with alternating esotropia, Doesschate and Alpern\textsuperscript{9} reported that the pupillary response was weaker when the nonfixing eye was stimulated. This was found whether the dominant or amblyopic eye was fixating. Brenner et al.,\textsuperscript{10} also showed that the degree of pupillary constriction was less when the nonfixing eye was stimulated. This was found in normal subjects and in patients with strabismus. It should be noted that Lowe and Ogle\textsuperscript{11} have not been able to repeat the observations of Bárány and Hallđén.\textsuperscript{8}

In any case, if the pupillary response is depressed when an eye is suppressed, then it might be expected that similar changes could be found when the amblyopic eye is stimulated. Indeed, both Harms\textsuperscript{12} and Brenner et al.,\textsuperscript{10} have reported that the degree of pupillary constriction is significantly less when the amblyopic eye is stimulated. And pertinent to the present study, Dolenek et al.\textsuperscript{13} have reported that the latency of the direct and consensual pupillary response is significantly longer when the amblyopic eye is stimulated. These observations would then indicate that the site of delay is peripheral to the lateral geniculate nucleus.

We wish to thank Mr. O. Navarro for his assistance with the experiments.

REFERENCES
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