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DISPARITY INDUCED VERGENCE RESPONSES IN
NORMAL AND STRABISMIC SUBJECTS

DISSERTATION

Presented in Partial Fulfillment of the
Requirements for the Degree Doctor
of Philosophy in the Graduate
School of The Ohio State
University

by

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* * * * *

The Ohio State University
1971

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INTRODUCTION AND OBJECTIVES

When a normal observer is told to look at a point in space (the object of regard), the images of this point fall on the two foveas. Both images are seen in the same direction. This basic fact of binocular directional localization is called the law of identical visual directions.

In general for each retinal element of one eye there is a retinal element in the other eye which when stimulated separately gives rise to the same primary visual direction. By definition these elements are said to be corresponding.

Normal retinal correspondence is defined as retinal correspondence in which the foveal image of the two eyes are seen in the same direction.

In some strabismus patients, however, the foveas of the two eyes do not give rise to impressions which are seen in the same direction. When the fovea of one eye corresponds with a non-foveal point in the other eye, the correspondence is said to be anomalous.

Anomalous correspondence is associated with strabismus. Strabismus is defined as a motor anomaly in which the primary lines of sight of the two eyes fail to intersect the object of regard.

The angle of deviation in strabismus is defined as the angle subtended at the sighting intersect of the deviating eye by which

the line of sight of the deviating eye fails to intersect the object of regard. See Fig. 1.

Most cases of anomalous correspondence are found in subjects with comitant strabismus. Comitant strabismus is non-paralytic and results from a defect in the vergence mechanism producing a strabismus in which the amount of deviation remains essentially the same in all fields of gaze no matter which eye is fixating.

In a squinter the correspondence can be normal but also may be anomalous. The line of sight in the deviating eye that corresponds to the primary line of sight in the fixing eye deviates from the point of fixation through an angle, called the subjective angle of squint. This angle is measured at the center of the entrance pupil. See Fig. 2. The angle between this line of sight and the primary line of sight of the deviating eye is the angle of anomaly.

Typically the subjective angle is the angle through which first degree targets in an amblyoscope must be set for subjective superimposition to occur.

The difference between the angle of deviation and the subjective angle is the angle of anomaly. If the subjective angle and the angle of deviation are equal then the angle of anomaly is zero and the subject is said to have normal correspondence.

Four types of anomalous correspondence have been classified:

1. Harmonious anomalous correspondence in which the subjective angle of squint is zero.

Figure 1

The objective angle of squint (the angle of deviation).

Figure 2

The subjective angle and angle of
anomaly.

2. Unharmonious anomalous correspondence in which the subjective angle is greater than zero but less than the objective angle.
3. Paradoxical anomalous correspondence in which the subjective angle is greater than the objective angle or is in the opposite direction.
4. Suppression anomalous correspondence in which the subjective angle cannot be accurately measured due to an existing suppression.

Four types of horizontal vergence have been classically described by Maddox¹:

1. Initial (tonic) vergence which is the vergence required to bring the eyes from the anatomical position of rest to the physiological position of rest.
2. Accommodative vergence which is the vergence associated with changes in accommodation.
3. Fusional vergence which is the vergence required to eliminate disparity in the localization of the two visual fields.
4. Proximal vergence which is the vergence evoked by other stimuli such as instrumentation which may lead to an "awareness of nearness".

If the capacity for fusional movements is present in subjects with strabismus, then changes in the angle of deviation should be

noted with the introduction of lateral prisms. This has been reported by Hofstetter² and again by Alpern and Hofstetter³. These investigators found much similarity between the type of vergence produced in strabismic subjects wearing prisms and in fusional vergence in the non-strabismic subject, although Hofstetter originally proposed a new type of vergence different from the classical type.

Morgan⁴ presented a motor theory of anomalous correspondence which states that anomalous correspondence results from a defect in eye movement innervation involving "registered" eye movements. This theory accounts for the phenomenon of anomalous correspondence by the type of innervational pattern associated with strabismus. Morgan feels that the egocentric direction of objects is dependent on the vergence innervation as well as the eye position itself. Thus he says that there are both motor and sensory factors involved in the egocentric localization of objects in space. Movements or innervational patterns which result in a change of egocentric direction are called "registered", and those eye movements or innervational patterns that do not alter egocentric localization are called "non-registered". Morgan feels that comitant strabismus with anomalous correspondence is due to an innervational problem. If the innervational pattern producing the squint is "registered", then anomalous correspondence would result.

Kerr⁵ has investigated correspondence changes in strabismic patients with anomalous correspondence by changing the stimulus

to two of the four possible types of vergence movements. Kerr found that the introduction of prisms to his subjects resulted in associated changes in the angle of deviation and the angle of anomaly, whereas no change in the angle of anomaly was noted with the use of accommodative stimuli to induce vergence.

Kerr measured three subjects with constant esotropia and anomalous correspondence and one subject with esotropia and normal correspondence. All four subjects responded to changes in accommodative stimuli with approximately equal changes in angle of deviation and subjective angle with essentially no change in the angle of anomaly (which was zero in the case of the anomalous responder). Responses by the subjects to lateral prisms were clearly different from the responses to accommodative stimuli since there were essentially equal changes in the angle of deviation and angle of anomaly with little or no change in the subjective angle. The conclusion, then, from this work is that changes in correspondence are associated with changes in fusional vergence. Kerr's results substantiate Morgan's theory and specifically name the anomalously registered mechanism as the fusional vergence component.

Kerr points out that if changes in retinal correspondence result only from changes in the non-accommodative vergence component, then it would seem that orthoptic treatment of anomalous correspondence should be directed toward altering this component.

That stimulation of fusional movements can be an effective procedure for orthoptic treatment of anomalous correspondence is seen from Gibson's treatment procedures⁶. His method consists of using simple fusion targets to stimulate the fovea of the fixating eye and, in the case of esotropia and anomalous correspondence, temporal to the fovea on the retina of the deviating eye. With exotropia and anomalous correspondence the stimulation would be nasal to the fovea of the deviating eye. He cites an example of his success with this type of procedure.

Flom⁷ also seems to have had some success with stimulation of fusional movements to eliminate anomalous correspondence.

The problem then is to discover an effective means of stimulating this movement in subjects with anomalous correspondence and to find out the nature of the eye movements as the stimuli are placed on various regions of the retina.

In normal subjects horizontal disparity is the basis for stereopsis and can be the stimulus for vergence movements. Mitchell⁸ has found that for subjects with normal binocular vision, disparate images, even if different in form, spatial position, and temporal characteristics, provide the stimulus for vergence movements. In his study the disparate targets were presented for 200 msec. which did not allow time for completion of a fusional movement thus leaving disparity alone as the only eye movement cue. He was able

to record the amount and direction of the eye movement response electronically. His results indicate that stimuli presented to give either a convergent or divergent disparity will initiate the appropriate eye movement response.

Jones⁹ has recently substantiated this along with giving insight into the process operating in the initiation and completion of a fusional movement. He finds that disparity and image similarity are both important features for completion of fusional vergence movements.

It would seem that if subjects with strabismus and anomalous correspondence have some type of disparity detection mechanism (and there is evidence for this as cited previously) then one could, by a technique similar to that used by Mitchell and Jones, induce eye movements by means of a disparity cue falling off the fovea of the deviating eye.

The aim of this investigation is to determine the nature of disparity induced eye movements in strabismus and to compare them with those in normal subjects. The results of this work should have some bearing on the design of an effective orthoptics procedure to eliminate anomalous correspondence in strabismus.

APPARATUS AND METHODS

Two different designs of apparatus were used to present stimuli to the subjects. Each design will be discussed separately.

HAPLOSCOPE ARRANGEMENT

The mirror haploscope was used in some cases for presentation of the stimuli. The schematic of this arrangement is shown in Fig. 3. For subjects with normal binocular vision the arms of the haploscope were set at the phoria position and for subjects with strabismus the arms were set at the subjective or objective angle depending on the conditions.

In most cases the initial stimulus used consisted of a self luminous broken vertical line placed in front of the deviating eye and a self-luminous star or asterisk pattern in front of the fixating eye. The asterisk target could be replaced by a vertical line target in the same position while the target in front of the deviating eye was able to be changed in order to present the disparity target (also a vertical line). Figure 4 shows what was initially seen by the subject who was instructed to move the arm of the haploscope so that the star was in the center of the broken vertical line. For normal subjects this resulted in setting the arms of the haploscope at the phoria position. For strabismic subjects the arms of the haploscope were placed at the subjective angle.

Figure 3

Design of the mirror haploscope used
to present disparate stimuli.

Figure 4

Representation of stimuli presented to the subject initially for alignment. The total length of the broken vertical bar was 4 degrees and the width was 10 minutes of arc. The gap in the vertical bar subtended 2 degrees.

SEEN BY
FIXATING EYE

SEEN BY
DEVIATING EYE

AFTER SUBJECTIVE ALIGNMENT

The target disc before the deviating eye could be rotated to change the stimulus target so that varying amounts of disparity could be introduced.

The disparity target (seen by the deviating eye) was a vertical line exactly duplicating the one which replaced the asterisk and seen by the fovea of the fixating eye. This stimulus target could be momentarily presented by a rotation of the stimulus disc (see Fig. 5 for a description of the disc) by use of a rotating stepping motor (Sigma Cyclonome, Series 9AG4Ja.18) that was attached to the haploscope arm. The motor steps through an angle of 18 degrees for each impulse it receives. Thus by alternating the aligning target (broken vertical line) with the disparity target (vertical line) one could present a maximum of ten different stimulus conditions per disc. The disc itself was made photographically so that stimulus conditions were alternated with the subjective alignment conditions.

The discs used to present the targets to the two eyes were illuminated from behind by a transilluminated piece of milk glass. The targets were masked by a black rectangular mask so that the subject saw the stimulus targets in an otherwise dark or gray field. Examples of the stimulus discs for the two eyes are shown in Fig. 5. The stimulus targets were of varying amounts of disparity and randomly arranged on the disc. For example, on presentation of the momentary stimulus, the subject would not know the amount or direction of the disparity.

Figure 5

Stimulus discs used to present stimuli to the fixating and deviating eye. The length vertical bars used for the disparity condition was $2\frac{1}{2}$ degrees and the width was 10 minutes of arc.

The stepping time was short enough (1 msec.) so that the subjects could not detect actual target changes that were occurring. The target presentation interval and the stepping motors were controlled by an Iconix, model 6010, time controller with a time interval generator, Iconix model 6255. With this device one can control the sequence of events in presenting the targets. The Iconix is capable of operating on ten separate channels. Thus the experimenter can control the time intervals for target presentation by presetting the controller to the desired specifications. The pulse output by the Iconix was used to step the motor controlling the variable target. The Iconix was also used to provide the stimulus mark for recording purposes. This was accomplished by feeding the impulses from the Iconix into a flip-flop which provided an adequate signal that could be picked up by the recorder for marking the stimulus.

The subject's eye movements were monitored by using a Biometrics Modulated I.R. Eye Movement Monitor (model SGV-2). Using this device, eye movements can be detected photoelectrically. Eye movements were detected by two photo field effect transistors (photo FETS) which were aimed at the temporal and nasal limbus. Each eye was illuminated by an infra-red emitting diode which was placed below the line of sight so as not to interfere with the subject's view. As already noted, the photo FETS are aimed at the limbus so that as the eye turns, more energy is detected by the photo FET on

the side opposite to the direction of the eye movement since the sclere reflects more of the energy than the iris. Less energy is detected by the photo FET on the side toward the eye movement. The difference in output of the two transistors is amplified giving a voltage which is proportional to the amount of the eye movement. This principle was first described by Richter.¹⁰ The schematic for this arrangement can be found in Fig. 6.

The output of the eye marker is linear over eye movement ranges of ± 15 degrees. The infra-red diodes have a pulse frequency of 10 kHz. to which the photo FET amplifiers are locked. Thus slight changes in ambient illumination caused by the stimulus target are essentially eliminated.

The Biometrics eye marker comes mounted on a spectacle frame. The haploscopic arrangement used in this experiment made use of a frame mounted eye marker impossible and thus the photo FETS and the I.R. diodes were mounted on a stereotaxic device independent of the haploscope to allow for more exact positioning. This arrangement is shown in the photograph in Fig. 7.

Recording was accomplished by means of a two channel Beckman type RS Dynograph. Eye movements were not recorded directly. The output of the eye marker was fed into the recorder such that one channel of the recorder was used to monitor vergence response of the subject and the other channel was used to monitor either the deviating or the fixating eye.

Figure 6

**Diagrammatic representation of the eye
movement monitoring device.**

Figure 7

Photograph of eye monitoring device and
arrangement for manipulation.

USE OF POLARIZED LIGHT

It became apparent that for proper investigation of eye movement responses to stimuli, a more flexible apparatus had to be designed. The haploscope did not provide enough disparity or choice of stimuli to meet all the requirements of this investigation.

For some experiments, then, an arrangement was devised taking advantage of plane polarized light to present the stimuli. With this arrangement plane polarized stimuli were presented on a silvered cylindrical screen of approximately 2 meters radius. The stimuli were presented by means of 2 Carousel projectors placed one above the other on the axis of the cylindrical screen. The projectors were mounted so that their axes could undergo changes in both latitude and longitude.

The plane of polarization of one projector was 90 degrees to that of the other. On each of the projectors there was a shutter arrangement to control time of presentation of the disparity target. The shutters were operated manually. A photograph of this apparatus is shown in Fig. 8.

To monitor eye movements, the Biometrics Modulated I.R. Eye Movement Monitor was again used. This time, however, the eye marker was mounted on a spectacle frame and fitted to the subject's head by means of an adjusting strap (Fig. 9). The eye movements responses were recorded in the same manner as previously described.

Figure 8

Photograph of apparatus using polarized
light to present stimuli.

Figure 9

Photograph of frame mounted eye
movement monitor.

The subject was seated 1-1/2 meters from the screen. Polaroid material was attached to the spectacle frame in front of the line of sight of each eye and at 90 degrees to each other so that one eye could view the stimulus from one projector while the other eye would see only the stimulus from the second projector. The stimulus targets were generally vertical lines produced by a slit in a 2 in. by 2 in. mounting and placed in the projector and focused on the screen. The length and width of the vertical bars were 2-1/2 degrees and 10 minutes respectively.

In the usual experiment one projector remained fixed in position and its projected slit target served as the fixation target for the fixating eye. The second could be rotated about the vertical axis of the cylindrical screen. The target could therefore be imaged on the retina of the deviating eye at points relative to the anomalous retinal point (which corresponded to the fovea of the fixating eye).

The shutter device was equipped with a photocell which was fed into one or both channels of the recorder to provide information as to the onset and duration of the stimulus.

PROCEDURE

HAPLOSCOPE ARRANGEMENT

Subjects were seated comfortably in the apparatus and the chin rest was adjusted so that the eye was at the correct height and so that the center of rotation of the eye coincided with that of the haploscope. A chin and head rest arrangement was used to keep the head steady. Each subject was instructed to keep his head as steady as possible during the experiment. Each experimental run lasted only a few minutes and it was found that subjects had no difficulty with this. Only with one subject (10 years old) did head movements seem to be a problem. A bite bar would have been preferable. However, since most of the subjects used were taken from the strabismus clinic and could only be seen for a limited amount of time, not enough time was available to make a bite bar for each subject.

Subjects generally were picked who had low refractive errors in each eye and good monocular acuity. Corrective lenses were placed before the eyes for those subjects who had moderate refractive errors. No subject used in this experiment had an acuity below 20/30.

Normal subjects were asked to set the arm of the haploscope containing the variable target disc to the phoria position. This was accomplished by having the subject place the asterisk target

seen by one eye between the two vertical lines seen by the other eye.

Strabismic subjects performed the same task with the result being that the arm was set at the subjective angle. The objective angle was obtained by alternate flashing of targets until no eye movement was observed. Vertical line stimuli were presented to the deviating eye in a random fashion to either side of the anomalous retinal point, by means of the rotating target disc, the duration of stimulation generally being 500 msec. After a wait of about 5 sec. following the flash, the subject was asked to reset the subjective angle. When this was accomplished the subject received another flash of the stimulus target. The interval between stimulus conditions was generally between 10 and 15 seconds. The subjects received 6 to 10 flashes of each stimulus condition.

POLAROID ARRANGEMENT

Subjects were seated comfortably in front of the screen in a head and chin rest and wearing the spectacle mounted eye movement monitors. With normal subjects the phoria position was obtained by the experimenter moving the projected broken vertical line target seen by one eye of the subject until it was lined up with the dot seen by the subjects other eye. A dot was used in this arrangement rather than an asterisk as with the haploscope. The subject indicated this position by means of a hand signal. A similar procedure was used with strabismic subjects to obtain the subjective angle. The objective angle was noted when the eye movement record

showed no eye movements after alternate flashing of targets to each eye.

Vertical line stimuli could then be flashed by the examiner to the non-fixing eye on either side of the retinal point in the non-fixing eye which corresponded to the fovea of the fixating eye. This was done in a random fashion. A vertical line stimulus was flashed to the fovea of the fixing eye. Eye movement responses were then recorded through the eye marker recording system.

SUBJECTS

Nine subjects were used in this investigation, four subjects with normal binocular vision and five subjects with strabismus. Of the five patients with strabismus, four had anomalous retinal correspondence and one had normal correspondence.

Of the four subjects with normal binocular vision, three of them (T.D., A.U., and M.S.) were slightly myopic and required corrective lenses for the experiment and the fourth subject (A.L.) was emmetropic. All of these subjects had 20/20 corrected visual acuity in both eyes. One of the subjects (M.S.) had a past history of exotropia and anomalous correspondence. Table 1 summarizes the refractive error, ACA ratio, and distance blur, break, and recovery findings for each of the subjects with binocular vision.

The strabismic subjects differed considerably in the amount of strabismus and in the length of treatment procedures, (orthoptic training and surgery). ACA ratios were calculated using the distance-to-near method.¹¹

Subject J.W. is an alternating exotrope of 6 prism diopters with normal correspondence. He has no refractive error and 20/20 visual acuity O.U. His past history indicates that he originally was an alternating esotrope of about 35^A prior to surgery which produced the exotropia. At the time of this investigation he was

TABLE 1

VISUAL DATA FOR SUBJECTS WITH BINOCULAR VISION

SUBJECT	REFRACTIVE ERROR		STIMULUS	DISTANCE
			ACA RATIO	BLUR/BREAK/RECOVERY
A. U.	R. E.	-2.50 -0.50 x 175	4.8/1	B. I. X/10/7
	L. E.	-2.75 -0.50 x 175		B. O. 22/40/33
A. L.	R. E.	-0.25 sph	2.5/1	B. I. X/7/6
	L. E.	-0.25 sph		B. O. 6/7/5
T. D.	R. E.	-2.25 -0.50 x 08	4.0/1	B. I. X/6/4
	L. E.	-1.50 -0.75 x 05		B. O. 10/32/30
M. S.	R. E.	-2.25 -1.00 x 180	-	B. I. X/18/4
	L. E.	-1.00 -1.00 x 02		B. O. X/24/10

undergoing orthoptic treatment. The ACA ratio was found to be 4.7/1.

Subject D.T. is an alternating esotrope of 16^{Δ} with unharmonious anomalous correspondence of 6^{Δ} . He has a moderate amount of myopia with vision correctable to 20/20 with spectacle lenses. He had no history of surgery or orthoptics. The ACA ratio was calculated to be 7.1/1.

Subject W.H. is a unilateral right esotrope and showed harmonious anomalous correspondence. Previous treatment included orthoptics. There was no history of strabismus surgery. W. H. was emmetropic in both eyes with 20/20 visual acuity.

Subject R.M. exhibited right unilateral esotropia at 20^{Δ} with unharmonious anomalous correspondence of 6^{Δ} . He was slightly myopic in both eyes and his corrected V.A. was O.D. 20/30, O.S. 20/20. The calculated ACA ratio was 6.4/1. Previous therapy included spectacle correction and orthoptics.

Subject R.D. was a high alternating esotrope with unharmonious anomalous correspondence prior to strabismus surgery, after which he displayed 20^{Δ} of esotropia with paradoxical anomalous correspondence. Orthoptics treatment was carried on for quite some time with no apparent success. His visual acuity through his spectacle correction for hyperopia was 20/30 O.U. and his ACA ratio was 9.0/1.

RESULTS

Vergence responses to disparate stimuli were obtained for all subjects. True responses were taken to be those which appeared to be associated with the stimulus. On some vergence records (for example see Fig. 19, on subject M.S.) this would appear to be a rather difficult task as the entire record seems to show random vergence movements. Those vergence movements following the stimulus were taken to be the response. Most of the other vergence movements on records such as this were caused by having the subject reset the subjective angle after each presentation of the stimulus.

The direction and latency of the response were measured. Those responses for which it was impossible to tell direction were labeled "no response". Data for which a blink occurred either during the stimulus or the response were discarded. Blinks usually show up on vergence records as long spikes. Blinks are labeled in Figs. 11 and 13.

SUBJECTS WITH NORMAL BINOCULAR VISION

Fig. 10 shows a schematic of the two eyes and the arrows indicate the various points of stimulation on and to either side of the fovea of the eye that was receiving stimulation from the variable vertical line target. The other eye received a stationary vertical line stimulus on the fovea. These points of stimulation

Figure 10

Schematic diagram indicating the position of the stimulus in degrees across the horizontal meridian of the retina of the right eye. The right eye received a stimulus identical to the stimulus imaged on the fovea of the left eye. F indicates the position of the fovea. These stimuli were used for subjects A.U. and T.D.

L.E.

R.E.

indicated in Fig. 10 were used for subjects A.U. and T.D.

A typical vergence record to random stimuli for subject A.U. is shown in Fig. 11. The arrows indicate the onset of stimulation. Convergent responses are toward the top of the record. Divergent responses are toward the bottom. It can be seen from the record that responses to the disparate stimuli were always in the correct direction to eliminate the disparity. It can also be seen that the latency of responses was of the order of 200-400 msec. Fig. 12 indicates the frequency of response for subject A.U. The percentage of convergent responses, (circles), divergent responses (open circles), and no response (squares) are plotted against retinal position of the stimulus. It is seen from the graph that the subject always responded correctly to divergent stimuli and nearly perfectly to convergent stimuli. The percentage of the "no response" category was 100% with foveal stimulation and was seen to increase again when stimuli were 8° temp to the fovea. Table 2 shows the summary of the average latency of the vergence responses for subject A.U. for the various stimuli positions on the retina and for three different stimuli durations. All of the latencies (whether for convergence or divergence) are between 295 and 388 msec. It can be seen from the table that convergent responses show a slightly lower latency than divergent responses.

Subject T.D. is also a subject with normal binocular vision.

Figure 11

Vergence record to various stimuli for subject A.U. Convergence is an upward displacement on the record while divergence is a downward displacement. The arrows indicate the onset of the stimulus (500 msec duration) and the degree values indicate the location of the stimulus relative to the fovea of the right eye. Each mm of vertical displacement represents about 0.25 degree of vergence response.

N = nasal
T = temporal
O = on the fovea

Chart speed = 5 mm/sec.

Figure 12

Frequency of response for the three response categories for subject A.U. The percentages are for 6 to 12 responses for each stimulus location. Data were taken on the polaroid apparatus.

TABLE 2

VERGENCE RESPONSE LATENCIES (IN MSEC.) FOR VARIOUS STIMULUS
LOCATIONS AND STIMULUS DURATIONS FOR SUBJECT A. U.

DURATION	1°N	2°N	5°N	8°N	1°T	2°T	5°T	8°T
300 msec.	350	340	330	400	320	300	380	400
500 msec.	356	361	370	317	322	320	380	348
800 msec.	325	313	388	350	340	340	320	295
All durations	345	346	370	355	328	325	360	352

Ave. latency for divergent responses to nasal stimulation
366 msec.

Ave. latency for convergent responses to temporal stimulation
341 msec.

Ave. latency for all vergence responses
354 msec.

A typical vergence record for subject T.D. is shown in Fig. 13. It can be seen from this record that no response was obtained for the condition in which the stimulus was placed 8° nasally to the fovea thus requiring a divergence movement to overcome the disparity. It was typical of subject T.D. not to respond to large degrees of disparity as can be seen from Fig. 14 which shows the frequency of the three possible responses (convergence, divergence, no response) plotted as a function of stimulus placement. All data collected on subject T.D. and subject M.S. were from the haploscope arrangement while for subjects A.U. and A. L. the polarizing arrangement was used. Table 3 indicates the latencies of response observed for subject T.D. The stimulus duration was 500 msec. exclusively. No data were taken for other durations. It should be noted that stimuli near the fovea evoked shorter response latencies than ones further in the periphery of the retina. In fact for the 8° stimuli subject T.D. only responded 50% of the time. There is no statistical difference in the mean response times for divergence and convergence although, as for subject A.U., convergence gives a shorter latency. T. D. shows a mean latency for all responses of 391 msec as compared to the previous subject who showed 354 msec.

Data were collected for subject A.L. exclusively on the polarizing arrangement. Fig. 15 indicates the stimulus points on the retina for this subject. A typical vergence record for this subject is found in Fig. 16. The frequency of responses is shown in the

Figure 13

Vergence record for subject T.D. Convergence is indicated as an upward displacement while divergence is a downward displacement. The degree values indicate the location of the stimulus relative to the fovea of the non-fixating eye. Stimulus duration is 500 msec.

N = nasal

T = temporal

O = on the fovea

Chart speed = 5 mm/sec.

Figure 14

Frequency of response for the three response categories for subject T.D. The percentages are for 6-12 responses for each stimulus location. Data were taken on the haploscope.

SUBJECT: T. D.

TABLE 3

LATENCY OF RESPONSE (IN MSEC.) FOR VARIOUS STIMULUS
POSITIONS AND DURATION TIMES FOR SUBJECT T.D.

DURATION	1°N	2°N	5°N	8°N	1°T	2°T	5°T	8°T
500 msec.	326	412	412	446	306	312	540	446

Ave. latency for divergent responses to nasal stimulation
393 msec.

Ave. latency for convergent responses to temporal stimulation
388 msec.

Ave. latency for all vergence responses
391 msec.

Figure 15

Schematic diagram indicating the position of the stimulus, in degrees, across the horizontal meridian of the retina of the non-fixating eye of subject A.L. F indicates the position of the fovea.

SUBJECT: A.L.

L. E.

R. E.

Figure 16

Vergence record of subject A.L. to various disparity stimuli. Convergence is an upward displacement on the record while divergence is a downward displacement. The degree values indicate the location of the stimulus relative to the fovea of the non-fixing eye. The slight rise at the beginning of each vergence response is the stimulus artefact. The artefact is very evident in the divergent responses. Stimulus duration = 800 msec.

N = nasal
T = temporal

graph in Fig. 17. It is seen that A. L. made perfect responses to all stimuli except those beyond 3 degrees temporal to the fovea at which time convergent responses fell off rapidly to zero at 5° . Table 4 is a summary of the latency of response data for A. L. Except for the 1° convergent stimulus all of the other convergent stimuli evoke much longer latencies than the divergent. This is somewhat unusual and will be discussed later.

The data for subject M.S. were taken exclusively on the haploscope. The stimulus disc used allowed only certain points on the retina to be stimulated. These points on the retina are diagrammatically illustrated in Fig. 18.

A typical vergence record for subject M.S. is shown in Fig. 19. It was typical for this subject to exhibit spontaneous vergence movements at the times that the stimuli were not being presented. This may be due to her past history of strabismus and anomalous correspondence. Post surgically, clinical tests indicated normal binocular vision. Unlike the other subjects with normal binocular vision, however, M.S. tended to make random vergence movements as is evident in the record. Some vergence movements were closely allied with the stimuli presented and made in the proper direction to eliminate the disparity and it was felt that these were the true vergence responses to the stimuli. Some of the "spontaneous" vergence movements were undoubtedly changes in vergence when the subject reset the subjective angle before presentation of the next

Figure 17

Frequency of response for the three response categories for subject A.L. The percentages are for 6-12 responses for each stimulus location. Data were taken on the polaroid apparatus.

TABLE 4

VERGENCE RESPONSE LATENCIES (IN MSEC.) FOR SUBJECT A.L.
FOR VARIOUS STIMULUS LOCATIONS AND A
DURATION OF 500 MSEC.

DURATION	1°N	2°N	3°N	4°N	5°N	1°T	2°T	3°T	4°T	5°T
500 msec.	370	440	420	400	400	300	556	600	530	-

Ave. latency for divergent responses to nasal stimulation
405 msec.

Ave. latency for convergent responses to temporal stimulation
518 msec.

Ave. latency for all vergence responses
467 msec.

Figure 18

Schematic diagram indicating the stimulus position, in degrees across the horizontal meridian of the retina of the non-fixing eye of subject M.S. F indicates the position of the fovea.

SUBJECT : M.S.

L.E.

R.E.

Figure 19

Vergence record for subject M.S. to various disparity stimuli. Convergence is an upward displacement on the record. Divergence is a downward displacement. The arrows indicate the onset of the stimulus (500 msec duration) and the degree values indicate the location of the stimulus relative to the fovea of the non-fixating eye.

N = nasal

T = temporal

O = on the fovea

Chart speed = 5 mm/sec.

stimulus.

The frequency of response for subject M.S. to the various types of stimuli is shown in the graph in Fig. 20. The category of no responses for this subject had a greater percentage for temporal stimulation than for most normal subjects but otherwise the graph resembles those of the three previous subjects with normal binocular vision.

Table 5 gives the latency of response for the various stimulus conditions for subject M.S. In general it can be noted that the latencies for convergent responses were longer than for the divergent responses and that the latencies in general were longer than for the other subjects with normal binocular vision.

SUBJECTS WITH STRABISMUS

Subject J.W. is a 10 year old boy with 7^{Δ} of exotropia and normal correspondence. The stimulation of eye movements in this subject was carried out on both the haploscope and on the polaroid arrangement. Fig. 21 indicates the points in the deviating eye which were stimulated by the disparity target.

Fig. 22 shows a record of vergence responses of J.W. to the vertical line stimuli. It can be noted from the record that the responses to divergent stimuli are more well defined than for convergent stimuli. In fact there is no response to the 8° T stimulus. It can also be generally noted from the vergence record in Fig. 22 (chart speed 5mm/sec) and the record in Fig. 23 (chart speed 25mm/sec) that the vergence responses for this subject had longer

Figure 20

Frequency of response for three different response categories for subject M.S. The percentages are for 6-12 responses for each stimulus location. Data were taken on the haploscope.

TABLE 5

VERGENCE RESPONSE LATENCIES (IN MSEC.) FOR SUBJECT M.S. FOR
VARIOUS STIMULUS LOCATIONS AND DURATION TIMES

DURATION	1°N	5°N	8°N	1°T	5°T	8°T
500 msec.	460	320	400	450	400	500
800 msec.	420	320	410	400	380	420
All durations	437	320	406	428	391	463

Ave. latency for divergent responses to nasal stimulation
401 msec.

Ave. latency for convergent responses to temporal stimulation
469 msec.

Ave. latency for all vergence responses
437 msec.

Figure 21

Schematic diagram indicating the stimulus location, in degrees across the horizontal meridian of the retina of the deviating eye of subject J.W. F indicates the position of the fovea.

SUBJECT: J.W.

L.E.

R.E.

Figure 22

Vergence responses of strabismic subject J.W. to various disparity stimuli. Convergence is an upward displacement; divergence is a downward displacement. Arrows indicate the onset of the stimulus (500 msec. duration) and the degree values indicate the location of the stimulus relative to the fovea of the right eye.

N = nasal
T = temporal
O = on the fovea

Chart speed = 5 mm/sec.

Figure 23

Vergence record of subject J.W. to
various disparity stimuli. Chart speed
= 25 mm/sec.

latencies than those observed in normal subjects. Subject J.W., although he was diagnosed as having normal correspondence did not always give the appropriate vergence response for the stimulus. This is evident from the graph in Fig. 24 which plots frequency of response against stimulation position on the retina (similar to what was done with normal subjects). Although there were some responses that were not appropriate for the stimuli and perhaps higher number of "no responses", the graph closely resembles those of the subjects with normal binocular vision.

Table 6 indicates the response times (latencies) for the various stimulus conditions. The response times for the inappropriate responses are also included. It is readily seen that the latencies for this subject are much longer than for normal subjects and that the convergent responses have slightly longer latencies than the divergent.

Subject W. H. has right esotropia of 18^{Δ} (10.3°) and harmonious anomalous correspondence. The subjective angle measured 0 giving an angle of anomaly of 18^{Δ} (10.3°). Stimulation of eye movements was accomplished on both apparatus arrangements. Fig. 25 indicates the angle of strabismus and the points in the deviating eye which were stimulated by the vertical line targets. Figures 26, 27, and 28 show typical vergence responses of this subject to various disparity situations. Note that the responses are not as clear cut as those found in normal subjects and frequently there are biphasic and

Figure 24

Frequency of response for three different response categories for subject J.W. The percentages are for 6-12 responses for each stimulus condition. Data were taken on both the polaroid apparatus and the haploscope.

SUBJECT: J. W.

TABLE 6

VERGENCE RESPONSE LATENCIES (IN MSEC.) FOR SUBJECT J.W. FOR
VARIOUS STIMULUS LOCATIONS AND DURATION TIMES

DURATION	1°N	2°N	5°N	8°N	1°T	2°T	5°T	8°T	0
Div. responses 500 msec.	460	520	680	720	-	-	-	-	580
Con. responses	800*	-	300*	-	670	740	860	880	820
Div. responses 1000 msec.	520	760	740	700	-	800*	800	900*	530
Con. responses	-	-	-	-	760	400	900*	920	900
Div. responses All durations	487	640	713	711	-	800*	800	900*	555
Con. responses	800*	-	300*	-	724	627	866	883	847

Ave. latency of all divergent responses to nasal stimulation
643 msec.

Ave. latency of all convergent responses to temporal stimulation
796 msec.

Ave. latency of all divergent responses
663 msec

Ave. latency of all convergent responses
785 msec.

Ave. latency of all vergence responses
721 msec.

*only one response recorded

Figure 25

Schematic diagram indicating the stimulus location, in degrees, across the horizontal meridian of the retina of the deviating eye of subject W.H. F indicates the position of fovea. A indicates the point in the deviating eye which corresponds to the fovea of the fixating eye.

SUBJECT: W.H.

Figure 26

Vergence record of subject W.H. to various disparity stimuli. Convergence is an upward displacement; divergence is a downward displacement. The arrows indicate the onset of the stimulus and the degree values indicate the location of the disparate stimulus relative to the fovea of the deviating eye.

N = nasal

T = temporal

0 = on the fovea

Chart speed = 5 mm/sec.

Figure 27

Vergence responses of subject W.H. to various disparity stimuli. Chart speed = 5 mm/sec.

Figure 28

Vergence record of subject W.H. to
various disparity stimuli. Chart speed =
25 mm/sec.

multiple responses. Also there were a number of instances where no response was obtained to the disparate stimulus. Fig. 29 illustrates the frequency of vergence responses to the various disparity conditions. It should be noted that stimuli temporal to the anomalous point (labeled A) in the deviating eye generally evoked convergence responses even though some of the stimuli were nasal to the fovea of that eye. Divergence responses to stimuli placed in the nasal retinal region between the fovea and the anomalous point were almost never seen.

Table 7 presents the latency times for the vergence responses of W. H. to stimulus durations of 500 msec. and 1.0 sec. It is readily seen that the divergent responses were of much longer latency than normal. Convergent response latencies to stimuli temporal to the fovea were relatively short (550 msec). It can be seen from the table that convergent responses to nasally placed stimulation were longer than this. Fig. 30 indicates the points in the deviating eye of subject R. M. which were stimulated by the vertical line targets.

Typical vergence responses for subject R.M. are found in Fig. 31. This subject showed an objective angle of 20^{Δ} (11.5°) of esotropia and a subjective angle of 14^{Δ} (8°) giving an angle of anomaly of 6^{Δ} (3.5°) showing unharmonious anomalous correspondence. As seen in Fig. 32 response form is similar to that found for W. H. and definitely different from those found in normals.

Figure 29

Frequency of responses for three different response categories for subject W.H. The percentages are for 6-12 responses for each stimulus location. Data were taken on the haploscope.

SUBJECT: W.H.

TABLE 7

VERGENCE RESPONSE LATENCIES (IN MSEC.) FOR SUBJECT W.H. FOR
VARIOUS STIMULUS LOCATIONS AND DURATION TIMES

DURATION	2.3°N	5.3°N	8.3°N	9.3°N	10.3°N	11.3°N	12.3°N	15.3°N	18.3°N	3.0°T	0
Div. responses 500 msec.	700*	-	520*	1050	900*	1300*	1175	1480	1325	-	900*
Con. responses	660	737	700	1600	780	-	1040	1550	1080*	550	760
Div. responses 1000 msec.	-	-	400*	700*	-	550	500*	1400	800	-	-
Con. responses	1500*	800	800	-	400*	-	1200*	-	-	550	-
Div. responses All durations	700*	-	460	990	900*	800	1020	1460	1153	-	900*
Con. responses	933	746	725	1600	650	-	1020	1500	1080*	550	760

Ave. latency of all divergent responses to nasal stimulation: 1082 msec.

Ave. latency of all convergent responses to temporal stimulation: 550 msec.

Ave. latency of all divergent responses: 1072 msec.

Ave. latency of all convergent responses: 896 msec.

Ave. latency of all vergence responses: 965 msec.

*only one response recorded

Figure 30

Schematic diagram indicating the stimulus location, in degrees across the horizontal meridian of the retina of the deviating eye of subject R.M. F indicates the position of the fovea. A indicates the point on the retina of the deviating eye which corresponds to the fovea of the fixating eye.

SUBJECT: R.M.

L.E.

R.E.

Figure 31

Vergence record of subject R.M. to various disparity stimuli. Convergence is an upward displacement on the record and divergence is a downward displacement. The arrows indicate the onset of the stimulus and the degree values indicate the location of the stimulus relative to the fovea of the deviating eye.

N = nasal

T = temporal

Chart speed = 5 mm/sec.

Figure 32

Vergence record of subject R.M. to
various disparity stimuli. Chart speed
= 5 mm/sec.

Frequency of vergence responses for this subject is seen in Fig. 33. This subject, like W.H., showed a large percentage of convergent responses for stimulation in the nasal retinal region of the deviating eye between the anomalous point (labeled "A" in the figure) and the fovea.

Table 8 lists the latencies of the various vergence responses to a stimulus duration of 500 msec. latencies are much longer than those found in normals.

Subject D. T. was found to have alternating esotropia of 16^{Δ} (9.2°) with unharmonious anomalous correspondence. The subjective angle was found to be 10^{Δ} esotropia (5.7°), giving an angle of anomaly of 6^{Δ} (3.5°). Stimulus conditions are illustrated in Fig. 34. Typical vergence responses are shown in Figures 35 and 36.

The form of these responses is similar to those encountered with other subjects with strabismus.

Response frequencies for D. T. can be obtained from the graph in Fig. 37. The types of responses given by this subject are not as definite as those seen in other subjects and appear to be more random. Although convergent responses dominate the stimulus condition in which the disparity target is placed between the anomalous point and the fovea (1.5° N), convergent responses also appear in other stimulus conditions nasal to the fovea. There does not seem to be a clear picture of how this subject responds to various stimulus conditions.

Figure 33

Frequency of response for three different response categories for subject R.M. The percentages are for 6-12 responses for each stimulus location. Data were taken on the haploscope.

SUBJECT: R.M.

TABLE 8

VERGENCE RESPONSE LATENCIES (IN MSEC.) FOR SUBJECT R.M.
FOR VARIOUS STIMULUS LOCATIONS AND A
DURATION OF 500 MSEC.

DURATION	1.5°N	3.5°N	5.5°N	8.5°N	11.5°N	1.5°T	4.5°T
Div. responses	1210	1387	960	1547	1190	-	-
500 msec.							
Con. responses	1165	1295	1050	1550	-	1687	1580

Ave. latency of all divergent responses to nasal stimulation
1300 msec.

Ave. latency of all convergent responses to temporal stimulation
1620 msec.

Ave. latency of all divergent responses
1317 msec.

Ave. latency of all convergent responses
1424 msec.

Ave. latency of all vergence responses
1384 msec.

Figure 34

Schematic diagram indicating the stimulus location, in degrees across the horizontal meridian of the retina of the deviating eye of subject D.T. F indicates the position of the fovea. A indicates the point on the retina of the deviating eye which corresponds to the fovea of the fixating eye.

SUBJECT : D. T.

L.E.

R.E.

Figure 35

Vergence record of subject D.T. to various disparity stimuli. Convergence is an upward displacement and divergence is a downward displacement on the record. The arrows indicate the onset of the stimulus and the degree values indicate the location of the stimulus relative to the fovea of the deviating eye. Stimulus duration = 500 msec.

N = nasal

T = temporal

Chart speed = 5 mm/sec.

Figure 36

Vergence record of subject D.T. to
various disparity stimuli. Chart speed =
5 mm/sec.

Figure 37

Frequency of response for three different response categories for subject D.T. The percentages are for 6-12 responses for each stimulus location. Data were taken on the haploscope.

SUBJECT: D. T.

The latency data are found in Table 9. Again it is seen that latency periods are longer for this subject with strabismus than are found in normals. Convergent responses generally seem to have shorter latencies than divergent.

Subject R.D. has a past history of strabismus surgery and orthoptic training. For the period of time following his latest surgery he has consistently been found to have paradoxical anomalous correspondence. The objective angle of deviation for R. D. measures 22^{Δ} (12.6°) of right unilateral esotropia. The subjective setting indicates 8^{Δ} (4.6°) of exotropia. The angle of anomaly in this case is 30^{Δ} (17.2°). The stimulus conditions for subject R.D. are found in Fig. 38. No stimuli were presented temporal to the fovea since the haploscope arrangement was used and since the stimulus disc did not allow disparities greater than 8° in either direction.

The form of vergence movements observed in this subject is found in Figs. 39 and 40. Response frequency data (Fig. 44) shows that stimulation falling between the fovea and the anomalous point results in convergence most of the time. Convergence, divergence, or no response occurs with approximately equal probability as the stimulus is moved nasalward of the anomalous point.

Latency data for the various stimulus conditions and 500 msec duration are indicated in Table 10. Convergent responses here show slightly shorter latencies than divergent, but again all latencies are much longer than those seen in normal subjects.

TABLE 9

VERGENCE RESPONSE LATENCIES (IN MSEC) FOR SUBJECT D.T.
FOR VARIOUS STIMULUS LOCATIONS AND A
DURATION OF 500 MSEC.

DURATION	1.5°N	3.5°N	5.5°N	8.5°N	11.5°N	1.5°T	4.5°T
Div. responses	920	867	700	1500	1200	845	770
500 msec.							
Con. responses	1520	1334	1440	1300	1800	1720	1653

Ave. latency of all divergent responses to nasal stimulation
1455 msec.

Ave. latency of all convergent responses to temporal stimulation
808 msec.

Ave. latency of all divergent responses
1521 msec.

Ave. latency of all convergent responses
945 msec.

Ave. latency of all vergence responses
1270 msec.

Figure 38

Schematic diagram indicating the stimulus location, in degrees across the horizontal meridian of the retina of the deviating eye of subject R.D. F indicates the position of the fovea. A indicates the point on the retina of the deviating eye which corresponds to the fovea of the fixating eye.

SUBJECT: R. D.

L.E.

R.E.

Figure 39

Vergence record of subject R.D. to various disparity stimuli. Convergence is indicated by an upward displacement on the record while divergence is a downward displacement. The arrows indicate the location of the stimulus relative to the fovea of the deviating eye. Stimulus duration = 500 msec.

N = nasal

Chart speed = 25 mm/sec.

Figure 40

Vergence record of subject R.D.
to various disparity stimuli. Chart
speed = 25 mm/sec.

Figure 41

Frequency of response for three different response categories for subject R.D. The percentages are for 6-12 responses for each stimulus location. Data were taken on the haploscope.

SUBJECT: R. D.

● CONVERGENCE
○ DIVERGENCE
□ NO RESPONSE

TABLE 10

VERGENCE RESPONSE LATENCIES (IN MSEC.) FOR SUBJECT R. D.
FOR VARIOUS STIMULUS LOCATIONS AND A
DURATION OF 500 MSEC.

DURATION	9°N	12°N	15°N	16°N	17°N	18°N	19°N	22°N	25°N
Div. responses	1233	-	1080	-	747	1400	866	975	967
500 msec.									
Con. responses	740	875	767	740	760	1075	1033	1133	944

Ave. latency of all divergent responses to nasal stimulation
991 msec.

Ave. latency of all convergent responses to nasal stimulation
853 msec.

Ave. latency of all vergence responses
889 msec.

DISCUSSION

It has been noted that when lateral prisms have been used to correct for the angle of deviation in subjects with strabismus and anomalous correspondence, the prism was found to increase the angle of squint by an amount equal to the power of the prism. The logical explanation for this is that the subjective angle is zero at the outset and the disparity produced by the prism causes the eyes to converge to make the images fall again on the anomalously corresponding retinal points. Alpern, who has strabismus and anomalous correspondence, found this to be true in his own case and he and Hofstetter have made a study of many aspects of this phenomenon³. Kerr has found similar effects on other anomalous corresponders⁵.

The traditional method of determining corresponding retinal points is to stimulate each eye such that the two perceived images have identical visual directions. Another approach which has been used for normal subjects, but not those with strabismus^{8,9}, is to use disparity induced vergence responses as the criterion for correspondency. Of particular interest is the question of whether disparity-induced vergence responses can be invoked in strabismic subjects, and if so, how the state of correspondence measured by this objective method compares with subjective responses.

First of all, vergence responses in squinters are difficult to elicit as evidenced by the larger percentage of the "no response"

category in the strabismic subjects as compared with normals. This is not surprising since the fusional mechanism is generally considered to be abnormal or underdeveloped. In normal subjects the task of analyzing vergence responses is relatively easy since the vergence responses occur directly after the stimulus and since the base line shows relatively little activity. In strabismic subjects, however, the vergence responses are often times small and not so obviously associated with the stimulus. In other words the vergence responses are sometimes inappropriate and occur at longer and varying latencies with respect to the onset of the stimulus. As mentioned in the Procedure, results were analyzed by choosing as a response those vergence movements which appeared to be associated with the stimulus. This task was fairly simple for some vergence records of strabismic subjects (See Figs. 26, 28, 35) and not so simple for others (See Fig. 19). It should be pointed out that some of the apparent spontaneous vergence movements throughout the record of M. S. as seen in Fig. 19 were caused by asking the subject to reset the subjective angle after each stimulation.

In order to test this method of analysis to insure that the responses observed were truly associated with the stimulus, the data for subject R.D. were analyzed by summing the responses for a single disparity condition for which the response was always convergence as determined by inspection. The summed data for the disparity condition 12° N indicated a convergent response to the stimulus. If

the vergence movements noted were not truly associated with the stimulus the data would have averaged out to a straight line with such a procedure. Figure 42 shows the sum of eight convergent responses for R.D. for disparity condition 12° N. Data was not analyzed for all subjects in this manner because of the difficulty in using this technique on recordings that were charted at 5mm/sec and because not enough responses were obtained for each point to adequately use such a procedure. If these types of movements are to be more critically analyzed in the future, then techniques such as the use of averaging computers should be employed.

In examining data from normal subjects in regards to the direction of these responses, one finds that subjects with single binocular vision respond to disparate stimuli in the same manner. Stimuli temporal to the fovea evoke convergent responses and stimuli nasal to the fovea evoke divergent responses. This point is evident from Fig. 43 which displays the averaged response data from all of the normal subjects. These results are consistent with the results of Mitchell⁸ and Jones⁹ on normal subjects.

The results of the strabismic subject J.W. indicate that this subject with normal correspondence responds in the same manner as do the normal subjects as far as the direction of the vergence response is concerned. The type of response for J.W. is determined by the location of the stimulus on the retina with respect to the fovea. The category of "no response" is slightly higher for this

Figure 42

Sum of 8 convergent responses of
subject R.D. for disparity condition
12° N.

Figure 43

Frequency of vergence responses of all
subjects with normal binocular vision.

subject than normals for disparate stimuli.

Three of the subjects with anomalous correspondence showed a trend of response much different from that of normal subjects. These subjects, W.H., R.M., and R.D. gave responses based on the anomalous retinal point in the deviating eye (the point which corresponded to the fovea of the fixing eye) and not the fovea as found in normals. In other words stimulation of the retina temporal to this anomalous point but nasal to the fovea of the deviating eye resulted most of the time in convergence and not in divergence as would be found in normals. This result substantiates the subjective data found by Alpern and Hofstetter³ and Kerr⁵ as discussed previously. For the most part these subjects responded to disparate stimuli in such a manner as to eliminate the disparity but did so on the basis of their anomalous correspondence. It is seen from these observations that an objective technique can be used to substantiate the subjective findings in anomalous correspondence. The fourth subject gave results that showed no definite trend of response, and could not be interpreted as showing any definite trend.

Reaction time to stimuli have also been measured in this investigation. The latencies even for normals were found to be much longer than reaction times reported in the literature for normal subjects. Most investigators put latencies for vergence movements at about 200 msec.^{12, 13, 14} The average latency of response recorded in this investigation for all normal subjects was about 360 msec.

The recording tapes were run at a fairly slow speed (5 mm/sec) and hence the reaction time could not be determined with any greater precision than ± 20 msec. The more probable explanation for this observation is that the disparities used in this investigation were quite large compared to the disparities used by the investigators who found 200 msec. as the average reaction time. A trend toward longer latencies for larger disparities is quite evident in tables 2, 3, and 4. Another illustration of this trend can be shown by averaging the data for the 3 subjects with normal binocular vision (M.S. excluded because of past history of strabismus) for the 1° T condition as compared to the 8° T condition. The smaller disparity condition gives an average latency of 304 msec. as compared to 392 msec. for the 8° T disparity.

This type of phenomenon for fusional responses has also been observed by van Heuven in 1926.¹⁵ In his study, prisms were placed before the eyes as a chronoscope was started. On subjective fusion of the images the observer stopped the chronoscope. van Heuven's data are reproduced in Figure 44. Response times are found to increase as prism power (disparity) increases.

It has been noted in the results that the latency of response is much longer in strabismic subjects than in normals. This is also true, to a certain extent, of the subject with normal correspondence (J.W.) although his reaction times are considerably shorter than those found in the strabismic subjects with anomalous correspondence.

Figure 44

Response time as a function of
prism power (van Heuven).

VAN HEUVEN

The average latency of vergence response for J.W. was 721 msec., as compared to about 1100 msec. for strabismic subjects with anomalous correspondence. The fact that J.W. shows a somewhat slower response time is not surprising in view of the fact that highly stable and adaptable fusional vergence movements characteristic of the normal observer are not present in the subject with strabismus. Slower reaction times are characteristic of retarded systems. The point is however that the latency observed in subject J.W. is much shorter and much more "normal" than the latencies observed in each of the subjects with anomalous correspondence (Subject W.H. = 965 msec, Subject R.M. = 1384 msec, Subject D.T. = 1270 msec, Subject R.D. = 889 msec). Jones¹⁶ has noticed comparable reaction times (1-3 sec.) for vergence responses in so called "stereoblind" subjects.

One of the initiating factors in this investigation is a statement by Kerr in his study of the fusional vergence component in squinters:

"If changes in retinal correspondence can result only from changes in the non-accommodative vergence component, then it would seem that treatment of anomalous correspondence should be directed toward altering this non-accommodative vergence system. Although this approach has been practiced with some success (Gibson, 1955; Flom; 1968), it is not likely that it has been fully exploited, since relatively little is known about how to stimulate this vergence movement in subjects with anomalous correspondence."

This investigation has been a first attempt to drive this non-accommodative vergence system in subjects with strabismus. The differences in responses seen among the strabismic subjects can be reconciled on the status of the non-accommodative vergence system operating in these people. Surely this status must vary in these subjects as noted by various factors which influence the prognosis for treatment of strabismus such as age, age of onset, maturity, intelligence, direction of squint, etc.

Various authors have put forth various schemes to account for anomalous correspondence and strabismus. Any one scheme can be used to account for variability among strabismic subjects. Richards¹⁷, for example, proposes that strabismus results from the lack of one or more of the classes of disparity detectors in one or both hemispheres. He claims that fusional mechanisms may be disrupted when stereopsis is absent in one hemisphere. Richards says that strabismus is an inherited phenomenon and produced due to the lack of inheritance of the proper classes of disparity detectors. Orthoptics procedures would seem useless in such a scheme. Richards also has investigated anomalous stereoscopic depth perception.¹⁸ Subject A.L. would be a subject of this type responding more to divergent (uncrossed) disparity than to convergent stimuli. Richards claims this anomaly to be due to an absence of one of the disparity pools. Jones¹⁶ has recently found however that prolonged stimulation elicits a proper response in this same subject thus indicating that

the disparity detection process can not be totally absent as Richards suggests.

Jones⁹ found that both disparity and target similarity are needed for completion of a fusional movement. Subjects lacking or possessing a retarded mechanism which can not process this type of information adequately would expect to vary in responses according to which feature of the mechanism is faulty and the degree of abnormality.

One might also interpret the ability of a subject to respond to disparate stimuli on the basis of a scheme such as proposed by Worth.¹⁹ He described three levels or stages in the development of fusion in normal corresponders. These are:

1. First grade. Simultaneous macular perception.
2. Second grade. True fusion with some amplitude.
3. Third grade. Sense of perspective.

Individual subject differences could occur on the basis of the development of the stage of fusion of the individual.

Kerr²⁰ has suggested the use of a technique such as outlined in this investigation as a means of driving the non-accommodative vergence system and as a means of the simultaneous orthoptic treatment of the sensory and motor aspects of strabismus and anomalous correspondence. Anomalous correspondence has plagued clinicians for years because of the poor response of this condition to orthoptic treatment. Some authors claim success with orthoptics procedures^{21,22} but the others claim little or no success in eliminating the

anomalous correspondence and establishing single binocular vision²³,
²⁴, ²⁵ Whether or not the procedure suggested by Kerr would be worthwhile is pure conjecture at this point and is only mentioned here because of the possible clinical role of the technique used in this investigation. Considerable research needs yet to be done to determine what kind of procedure is best, if any, at the clinical level.

It is entirely possible that subjects used in this experiment do not give responses which are as consistent as other strabismic subjects might have given if a larger population of squinters had been used.

The complete study of all possible methods of stimulation, duration times, and a large population of subjects is beyond the scope of this investigation. Despite such shortcomings however it has been fairly well established that objective recording of vergence movements may be a worthwhile means of studying anomalous correspondence. It has also been established by this investigation that the vergence movements in squinters with anomalous correspondence are distinctly different from fusional vergence movements observed in normals. Hofstetter² also recognized differences and because of this postulated a different type of vergence from those described by Maddox. The measured responses to different disparities show that there is no evidence to indicate that anomalous squinters react like normal subjects or subjects with strabismus and normal

correspondence. Normal fusional mechanisms do not appear to be operative for anomalous corresponders.

SUMMARY

Vergence movements in response to disparate stimuli were recorded in normal and strabismic subjects. The important findings are summarized as follows:

1. Subjects with normal binocular vision respond in a predictable manner based upon the location of the stimulus with respect to the fovea. Temporal stimulation initiates convergence and nasal stimulation initiates divergence.
2. The subject with strabismus and normal correspondence responded in the same manner as subjects with normal binocular vision.
3. Three of the four subjects with strabismus and anomalous correspondence consistently responded on the basis of the anomalously corresponding retinal point rather than the fovea of the deviating eye. These subjects responded as if to realign the disparate image with the anomalous retinal point.
4. Response times were found to be much longer for anomalous correspondence than for normal subjects or for the subject with strabismus and normal correspondence.

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