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Panoramic Viewing, Visual Acuity of the Deviating Eye, and Anomalous Retinal Correspondence in the Intermittent Exotrope of the Divergence Excess Type

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Abstract
Monocular visual acuities in a binocular field of view, field of view under binocular conditions, and retinal correspondence were investigated in five intermittent exotropes of the divergence excess type. Results indicated that all five intermittent exotropes demonstrated (1) normal visual acuity in the deviating eye without suppressing the fixating eye, (2) a lateral extension of the temporal field of view (panoramic viewing), (3) anomalous retinal correspondence.

Key Words: intermittent exotropia, anomalous retinal correspondence, panoramic viewing, visual acuity, divergence excess, strabismus, field of view

Various atypical binocular findings during deviation have been ascribed to the intermittent exotrope of the divergence excess (DE) type. Two of the previously reported atypical sensory findings are anomalous retinal correspondence (ARC) and panoramic viewing, which increases the peripheral field of view. A third finding, which is consistent with ARC and has not previously been reported, is nonsuppression of the fovea of the deviated eye. These sensory findings, which may occur separately or together, may allow the DE patient to function more effectively than a person with normal binocular vision.[1]

ARC, or anomalous projection, has been reported to occur in some intermittent exotropes.[1-8] This condition may provide certain functional advantages, such as rudimentary binocular vision during deviation, a mechanism to avoid diplopia and visual confusion, and a mechanism to restore bifoveal fixation in the presence of disparity cues. However, the presence or absence of ARC in the DE patient has been controversial, because none of the previous studies have controlled for ocular position during ARC testing.[1-3, 5-7] This is especially important in light of the fact that some DE patients deviate most of the time, whereas others deviate rarely. Also, Hallden[9] and Morgan[10] suggest that there may be covar-

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iation of the angle of anomaly (the subjective angle remains constant as the objective angle changes). Thus, one might expect harmonious ARC when deviated and normal retinal correspondence (NRC) when aligned. One of the purposes of the present experiment was to control for ocular position by measuring retinal correspondence during conditions of deviation.

Panoramic viewing, first reported by Cass,[11] represents a peripheral extension of the field of view under conditions of binocular viewing which occurs during ocular deviation. This phenomenon has also been reported by Costenbader[12] and Cooper.[1] Cooper has suggested that the extension of the field of view might be an advantage that DE patients have that normals do not have. However, no study has yet been reported which provides scientific or empirical evidence that DE patients do in fact possess panoramic viewing.

Last, if the DE patient does have harmonious ARC, then it is conceivable that the fovea of the deviating eye is not suppressing. This would provide the DE patient with two areas of clear vision, one straight ahead and the other off to the side. There has been no study evaluating this phenomenon.

The purpose of the present paper was to test the hypothesis that intermittent exotropes of the DE type do exhibit panoramic viewing, ARC during deviation, and normal monocular visual acuities under conditions of binocular viewing without suppressing. These were determined by measuring the field of view under binocular conditions during periods of bifoveal fixation and deviation, monocular visual acuities under conditions of binocular viewing while one eye deviated, and the realtive retinal projection of the two foveal stimuli during the visual acuity portion of the experiment. By measuring these sensory functions in a testing situation that does not separate the sensory inputs into each eye, we thought that this would demonstrate how the DE patient "sees" under relatively natural viewing conditions.

METHODS

There were three male and two female subjects (age range, 18 to 26 years). All were diagnosed as having an intermittent exotropia upon distance viewing according to the following criteria: intermittent exotropia at distance (cover test), less than one line difference in visual acuity (Snellen chart), 20/20 (6/6) visual acuity at 1 m without glasses; at least 60 sec arc in stereoacuity during alignment (Titmus Stereo test); and good fixation ability (visuoscopy). Additional clinical tests administered included the random dot stereogram test,[13] troposcope evaluation for ARC using 1° targets, Hering-Bielchowsky after-image test, the Bagolini striated-lens test, and a red lens test for diplopia.

The principal components of the experimental apparatus were an eye movement monitor (EOG) and a sandblasted Plexiglas hemisphere. Eye movements of both eyes were recorded by a Beckman Dynagraph (model R 511A) with two direct nystagmus couplers (type 9859). The EOG was calibrated so that a 1-mm pen deflection was equivalent to a 1° movement by either the right or left eye. The output from the EOG was passed through an absolute voltage regulator, wired to two BRS digibit Schmitt triggers (Tech Serv Inc.). The two Schmitt triggers, each associated with the input from one eye, were used to signal the occurrence of eye movements greater than 2° from fixation points during each experimental trial. When such an ocular movement occurred, auditory feedback from a BRS click generator (CL 201) or audio oscillator (AO 201) was produced. A 65-dB 10-Hz click signal was associated with a movement from the divergent eye, and a 65-dB 1000-Hz tonal signal was associated with a movement from the fixating eye.

The subject looked into a rotated Plexiglas hemisphere, 91.44 cm in diameter. On the rear surface of the hemisphere, a 1° white fixation light (19.5 cd/m^2) was permanently mounted at a point perpendicular to, and at the level of, the fixating eye. On the same side as the divergent eye, a peripheral viewing test stimulus was placed on the hemisphere. During the binocular field of view portion of the experiment, the test stimulus was a 1° red light-emitting diode (LED) (0.12 cd/m^2). During the visual acuity portion of the experiment, that test stimulus was replaced by a visual acuity letter projected by a Bausch & Lomb acuity projector (1.0 cd/m^2).

All trial periods, fixation and peripheral viewing stimulus presentations, auditory feedback signals, and response recordings were controlled by the BRS digibit programming system.

Part 1—Panoramic Viewing—Field of View During Bifoveal Function (Ocular Alignment)

The subject was seated in front of the hemisphere with his head in a headrest. Seating and headrest modifications were made for each subject so that the foveal line of sight of the fixating eye was at the level of, and perpendicular to, the white fixation light. Electrodes from the EOG were attached to the subject's outer ocular canthi and to a forehead ground reference. After electrode placement, the EOG was calibrated to produce a zero-voltage output when either the right or left eye fixated the white light (ocular alignment). Ocular movements greater than ±2° resulted in the firing of the Schmitt triggers.

The subject was then instructed to look at the white light with both eyes. He was then told that "from time to time you may see a red light off to the side (deviating eye side). This light will be presented only when the white light is on (i.e., during a trial). Sometimes the red light will be on during a trial and sometimes it will not. If you see the red light, press the righthand telegraph key once. If you think the red light is not on, press the lefthand telegraph key once." If a telegraph key response was made with the eyes in proper alignment, then the white light and the red light went off, the response was automatically recorded, and the trial ended. The inter-trial period was 6.5 sec, and a new trial began with the onset of the white light. During a trial, the onset of a clicker sound meant that the subject's deviating eye was not looking at the white light, whereas the onset of a tone meant that the fixating eye was not looking at the white light. The auditory signals were produced when ocular movements greater than ±2° from appropriate fixation occurred. When either or both of these signals were on, the telegraph key response was not recorded, and the white light stayed on. The subject was instructed to move his/her eyes to shut off the sounds. When the sounds went off, the eyes were properly aligned and a telegraph response could be recorded.

Each trial was scheduled to last for 10 sec or until a proper (eyes-aligned) telegraph key response was made. The red light was scheduled to appear on 50% of the trials (randomly determined). On the first trial, the red test light was presented 10° from the white light on the deviating eye side. If the subject made a correct telegraph key response on each of five consecutive trials, the red light was presented 5° further away from the white fixation light on the next five trials. The 5° increases continued after every five trials as long as the subject responded correctly. In addition, the subjects were asked to report any change in the size of the movements of the red light stimulus. When the subject responded less than 80% correctly in a five-trial block, the red light was presented at the same test position in the next five-trial block. If the subject again responded less than 80% correctly, part 1 of the experiment was terminated. The maximum peripheral field of view was recorded as the red test light position which yielded at least 80% correct responding.

Part 2—Panoramic Viewing—Field of View During Ocular Deviation

The same general procedure reported above was repeated again. However, this time the deviating eye was made to deviate (using the method of occlusion) so that it was positioned in a divergence excess state. Thus, the fixating eye continued to fixate the white light while the other eye deviated. The EOG was once again calibrated so that a zero-voltage output occurred for the fixating eye (in its fixating position) and a zero-voltage output occurred for the deviating eye (in its divergence excess position). As during Part 1, any movement of either eye greater than 2° from the zero-voltage settings resulted in the following: onset of one or both auditory feedback signals, the inability to make a telegraph key response, and the turning off of the red peripheral viewing stimulus (if on). Instructions to the subject, trials, visual stimulus presentations, and response-recording procedures were the same as during Part 1 of the study.

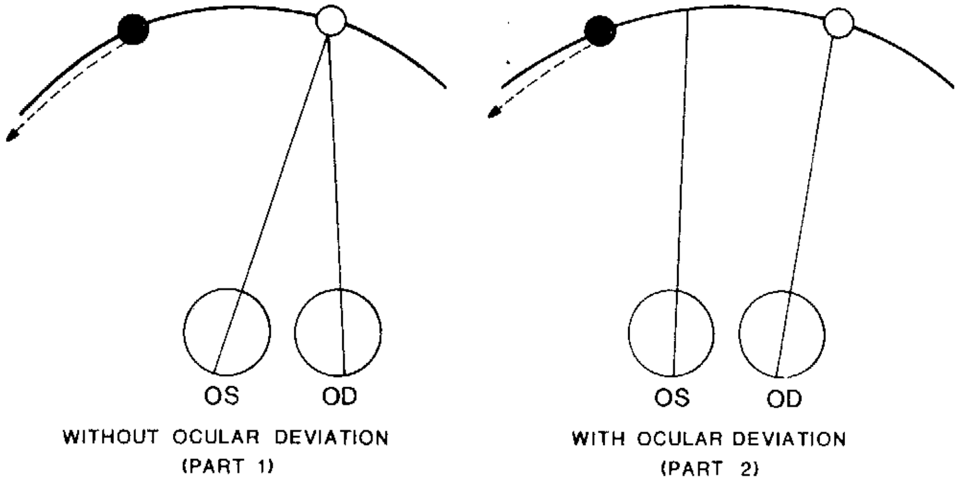

FIG. 1. Schematic representation of panoramic viewing under conditions of ocular alignment (left panel) and ocular divergence (right panel). Under both conditions, the red LED (●) test light was moved 5 deg further away from fixation light (○) when five correct responses were made by the subject.

Fig. 1 demonstrates, schematically, Part 1 and Part 2 of the panoramic viewing portion of the study.

Part 3—Foveal Visual Acuity of Deviated Eye

During this phase of the experiment, the red test light was replaced by a visual acuity letter projected by a Bausch & Lomb acuity projector. The letter always appeared on the hemisphere at a point equal to the objective angle of squint, as previously measured from the EOG readings. The EOG remained calibrated so that the fixating eye was straight ahead and the other eye was deviating to produce zero voltages. Accurate placement of the letter was checked by having the subject visually track a small light source (different from the fixation target) with his deviating eye until the EOG pen was exactly at zero. Correspondence between the small light source and the projected acuity letter was determined prior to testing to ensure proper foveal alignment of the deviating eye. The fixating eye still looked at the straight ahead 1° white light.

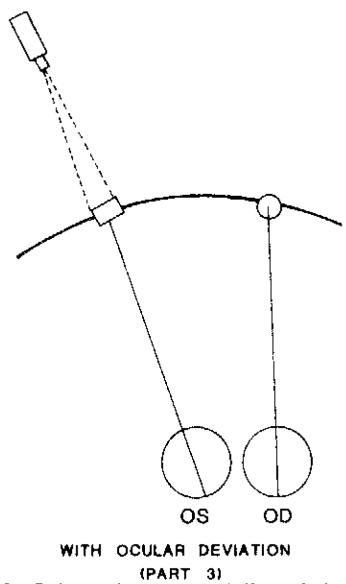

FIG. 2. Schematic representation of visual acuity testing under conditions of ocular divergence. The visual acuity letter (□) was presented off to the side at the objective angle of squint. The white fixation light (○) was placed straight ahead.

The subject was told to "try to keep your deviating eye out while looking at the white fixation light with your fixating eye. If you move your eyes, the clicker or tone will come on and the letter will disappear. When the letter is on (in the presence of the white light and no auditory signals), please read it aloud. If the white light disappears or changes position (i.e., does not appear straight ahead), tell us. Also tell us where the white light is in relation to the letter."

The projected acuity letters were then presented to the subject with an increasing visual acuity requirement. The maximal visual acuity and specific location of projected letters were recorded in degrees.

Table 1 summarizes the findings for each

TABLE 1. Summary of clinical and experimental results.

Subject	Exo Deviation (Cover Test)		Stereopsis		Diplopia Awareness		Retinal Correspondence			
	At 6 m (Δ)	At 40 cm (Δ)	Titmus (sec)	RDS 660 sec	Patient history	With red lens	Hering-Bielschowsky Aligned	Hering-Bielschowsky Deviated	Tropo-scope*	Bago-lini*
1	18x(T)	8x	40	Yes	No	Yes	NRC	ARC	ARC	NRC
2	15x(T)	5x	40	Yes	No	Yes	NRC	ARC/NRC (1)	NRC	
3	18x(T)	18x(T)	40	Yes	Some-times	Some-times	NRC	ARC/NRC (2)	NRC	NRC
4	14x(T)	6x	40	Yes	Yes	Yes	NRC	NRC	NRC	NRC
5	45x(T)	6x	40	Yes	No	No	NRC	ARC	(3)	(4)
6	16x(T)	12x(T)	50	Yes	No	Yes	NRC	ARC	ARC	(4)

x = exophoria, x(T) = intermittent exotropia, NRC = normal retinal correspondence, ARC = abnormal retinal correspondence. Field ARC = the maintenance of normal geometric projection in both the area of binocular overlapping visual fields and in the area of nonoverlapping visual fields; RDS = random dot stereogram.

* Tested in deviated position: (1) ARC or NRC (variable); (2) ARC when OS elevated, NRC when OD deviated; (3) bi-ocular, no correspondence; (4) suppression.

of the DE patients in terms of angle of deviation, stereopsis during bifoveal fixation, diplopia awareness during deviation, retinal correspondence, panoramic viewing, visual acuity at the objective angle, and field ARC.[a] It is apparent that all subjects exhibited an increased field of view under binocular viewing conditions during ocular deviation. This was approximately equal to the amount of deviation shown in the panoramic viewing section of the table. In 2 of the subjects, there was a 10° increase (compared to non-deviation); in 2, a 20° increase; and, in 1, a 45° increase. Table 1 also shows that all subjects demonstrated "normal" foveal visual acuity during ocular deviation with the visual acuity letter presented at the objective angle of squint. In 3 subjects, visual acuity was 20/20 (6/6) and in 2, it was 20/40 (6/12). Interestingly, all subjects also showed a significantly larger deviation in the hemisphere compared to cover test findings.

Both the panoramic viewing portion and the visual acuity portion of the experiment provide supporting evidence for ARC. All subjects stated that, during deviation, the red test stimulus moved in equal increments along the visual field. If NRC was present with a temporal hemisuppression, one would expect the red test stimulus to "jump" when the limit of the monocular field of the fixating eye was reached. This is predicted on the basis of a shift in projection due to ocular deviation. However, no subject reported this phenomenon. All reported proper physical localization of the red test stimulus in each test position. Thus, harmonious ARC must have been present.

In the visual acuity portion of the experiment under conditions of ocular deviation (Part 3), both foveas were aimed toward different stimuli. The fixating eye viewed the white fixation light while the deviated eye viewed the acuity letter off to the side. The presence of harmonious ARC was suggested by combining the following evidence: No subject reported suppression of either stimulus; all subjects stated that the white light was clear and straight ahead; all subjects said that the acuity letter was off to the side and matched the objective angle of turn (obtained by finger pointing); and all subjects demonstrated exceptionally good visual acuity of the deviated eye [20/20 (6/6) to 20/40 (6/12)] under conditions of ocular deviation.

Two subjects reported variations in correspondence during visual acuity testing. Subject 2 reported twice during testing that the acuity letter "jumped on top of" the white fixation light and then back to its original separation. During these episodes of NRC and visual confusion, no motor movement of the eyes was recorded by the

[a] Field ARC was defined as maintenance of normal geometric projection in both the areas of binocular overlapping visual fields and in the area of nonoverlapping visual fields.

Other Results				
Deviated position (deg)	Field of view: Straight eye (deg)	Field of view: Deviated eye (deg)	VA at objective angle of deviation	Field ARC
9	75	85	20/20	Yes
17	50	70	20/40	Yes
15	70	90	20/40	Yes
15	70	80	20/20	Yes
37	40	85	20/20	Yes
		Could not deviate		

EOG. Subject 3 reported instances of diplopia throughout testing. However, there was a large separation distance between the diplopic white fixation light and the diplopic visual acuity letter. Therefore, the subjective angle of turn did not equal the objective angle, indicating nonharmonious ARC under testing conditions.

The traditional clinical tests administered to our experimental subjects indicated normal stereopsis on lined or contoured stereograms (Titmus Stereo test) and on random dot stereograms, diplopia awareness enhancement by using a red lens (indicating different ARC/NRC responses under various testing conditions), and dual correspondence depending on the ocular position (i.e., straight or deviated). All correspondence testing was carried out during ocular deviation. In addition, the Hering-Bielchowsky test was also carried out during alignment. In this test, all subjects reported a cross during alignment; during deviation, all except subject 4 reported the cross separating. The Bagolini striated-lens test, which gives the highest percentage of ARC with esotropia, elicited either NRC (Maddox scale measurement) or suppression with our experimental subjects when the eyes were in the deviated position.

DISCUSSION

All of our intermittent exotropes of the divergence excess type demonstrated panoramic viewing, ARC (depending on the test), and nonsuppression of the foveas during experimental testing. Budd and Boyd[14] studied constant unilateral exotropes, using a variety of clinical tests, and reported findings that were similar to our experimental findings. The traditional clinical tests for ARC yielded variable results. However, these traditional tests indicated a greater frequency of ARC than usually reported.[15] This might be accounted for by the fact that testing was done during ocular deviation. When these tests for ARC are done under ocular alignment, NRC is observed. This suggests that ARC may be a transitory phenomenon somewhat dependent upon the position of the eyes. Most authors state that the Bagolini striated-lens test gives the highest percentage of ARC when compared to the Hering-Bielchowsky afterimage test.[16] This difference is explained on the basis of the Bagolini test more closely approximating normal viewing conditions. We did not find this to be the case with our intermittent exotropes. The Hering-Bielchowsky test gave the highest percentage of ARC and the Bagolini the lowest. Obviously, the hypothesis that the test which more closely approximates natural viewing conditions gives the highest percentage of ARC was not supported. In addition, our findings did not support Flom and Kerr's[17] findings that ARC responses are not dependent on the test used. We found that ARC findings varied depending on the method used for testing.

Conceptually, ARC may be thought to serve four functions. The first is to avoid diplopia. The second is to establish appropriate conditions for some type of binocular vision. Boucher[4] has shown that intermittent exotropes, during deviation, demonstrate a horopter. Thus, presumably they have the ability to process stereoscopic information. The third function of ARC might be to determine the amount of ocular movement needed to restore binocularity. Fourth, clinical observations have indicated that intermittent exotropes tend to align their eyes in the presence of stereoscopic detail.[1] They tend to deviate their eyes when such information is lacking. Thus, ARC might be important in identifying those stimulus conditions under which ocular alignment should be resumed. Future research will address these questions.

The findings from the visual acuity portion of the experiment demonstrate that both foveas are functioning simultaneously, since none of the subjects reported any suppression of either target during ocular deviation. Also, we have shown that the deviating fovea is functioning at a high sensitivity level. The slightly lowered visual acuity in two of the subjects [20/40 (6/12)] might be explained by vertical deviations, which were not controlled for in our study, or by a slight misalignment of the target off the fovea of the deviating eye not detected by the EOG. In addition, foveal correspondence appears to be altered during deviation. In the deviated position, harmonious ARC seems to be the rule, since our patients were capable of localizing the visual acuity letter at its proper geometric position.

The common report of hemiretinal and foveal suppressions of the deviating eye[7, 15, 18] may be related to the type of stimulus presentation used in clinical testing. Our study did not separate input into each eye by using lenses, prisms, or filters and did not indicate the presence of foveal suppressions. The procedure used in other studies, as well as during traditional clinical testing, presents artificially separated first degree fusion stimuli to the two eyes. It is our contention that the intermittent exotrope probably does not suppress under normal viewing conditions and functions with ARC.

Panoramic viewing, an extension of the lateral field of view under binocular conditions, was also demonstrated in all of our subjects during deviation. It is possible that the intermittent exotrope of the divergence excess type initiates alignment to obtain normal stereopsis and deviation for panoramic viewing. This extension of the binocular field of view may be functionally advantageous. Panoramic viewing may be useful in extending the motion detection system laterally and, thus, provide a functional benefit for deviation. On the other hand, the DE patient may initiate alignment and give up panoramic viewing for the benefits of stereoscopic vision.

CONCLUSION

Nonsuppression of the foveas, panoramic viewing, and harmonious ARC were demonstrated in all of our experimental subjects. We have tested a number of patients for panoramic viewing in the clinic by conducting a binocular confrontation test with the eyes in either the aligned or deviated position. Under these conditions, we observed an increase in the field of view during ocular deviation. We have also clinically observed harmonious ARC without foveal suppression by eliciting a deviation and then measuring the foveal acuity of each eye at the same time. All our clinical patients demonstrated normal visual acuity in the right and left eyes with proper geometric localization of the targets. This indicates that harmonious ARC without foveal suppression was present. Therefore, nonsuppression of the foveas, panoramic viewing, and harmonious ARC can be demonstrated under both clinical and rigid laboratory conditions in the intermittent exotrope of the divergence excess type.

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