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BY

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Increased drift in amblyopic eyes

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ABSTRACT Reports are conflicting on the presence of increased drift in amblyopic eyes. Furthermore, the individual effects of either amblyopia or strabismus alone on ocular drift have not been systematically investigated. We therefore used a photoelectric method to record horizontal eye position during monocular and binocular fixation in patients having amblyopia without strabismus, intermittent strabismus, or constant strabismus amblyopia. Our principal finding was increased drift amplitude (up to 3·5 degrees) and velocity (up to 3·0 degrees per second) in amblyopic eyes during monocular fixation. While increased drift was found 75% of the time in amblyopia without strabismus and 50% of the time in constant strabismus amblyopia, it was found only 20% of the time in intermittent strabismus. Amblyopic drift could be either error-producing or error-correcting in nature. Increased drift was not present during monocular fixation with the dominant eye or during binocular fixation in any of our 16 patients. We therefore conclude that amblyopia and not strabismus is a necessary condition for the presence of markedly increased fixational drift. Increased drift amplitude but not velocity may adversely affect visual acuity in the amblyopic eye.

The eye is not perfectly still during attempted steady fixation. Fine high-frequency tremor, microsaccades, and slow drifts keep the eye in constant motion, and these phenomena have been quantitatively analysed in detail in normal subjects (Ditchburn, 1974).

Fixational eye movements in persons with amblyopia and strabismus have also been studied, though whether they have increased ocular drift remains unclear. Matteucci (1960) presented records showing the fixation pattern in 1 patient having amblyopia without strabismus and several patients having strabismus amblyopia. Pronounced drift appeared to be present in all records, but it was not quantified. Lawwill (1968) observed, but did not record, horizontal drifts as large as 2 degrees in amplitude in the amblyopic eyes of strabismic amblyopes during monocular fixation. Accurate fixation was shorter and drift magnitudes greater in patients with deep amblyopia. In contrast Schor and Flom (1975) found similar drift magnitude, duration, velocity, and direction between the amblyopic eye and fellow dominant eye in patients with constant strabismus amblyopia. However, recently Schor and Hallmark (1978) reported increased mean drift velocities in the amblyopic eye of some patients with strabismus amblyopia, but their method of analysis was not specified, and mean drift amplitudes were not provided.

Thus reports are conflicting and incomplete on the presence of increased drift amplitude *and* velocity in amblyopic eyes. Furthermore, most patients in previous studies had both amblyopia and strabismus. The individual effects of either amblyopia or strabismus alone on ocular drift have not been systematically investigated. Therefore in our study we expanded the test categories and quantitatively assessed fixational drift in patients having amblyopia without strabismus, intermittent strabismus, or constant strabismus amblyopia. Our results indicate that amblyopia and not strabismus appears to be a necessary condition for the presence of markedly increased drift.

Patients and methods

A photoelectric method was used to record horizontal eye position (Stark *et al.*, 1962). The band width of the entire recording system was 75 Hz (–3dB). Resolution was approximately 12 min arc. A chin rest and head rest, usually in conjunction with a bite bar covered with dental impression material, were used to stabilise the head. A PDP 8/I minicomputer was used to generate a small (3·5–5·0 min arc) bright test spot on a display screen placed either 57 or 91 cm in front of the

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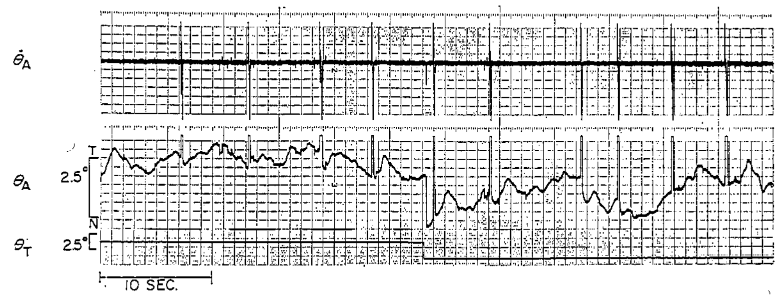

Fig. 1 *Monocular fixation with amblyopic eye. Patient 9, amblyopia without strabismus, 20/40. From top to bottom, eye velocity, eye position, and stimulus, respectively. Note increased drift amplitudes and velocities, and paucity of saccades comparable in magnitude to drifts. Deflections driving pens to edge of record due to blinks. Symbols for Figs. 1–4: N=nasalward eye movement, T=templeward eye movement,* θ_T*=target position,* θ_N*=eye position normal eye,* θ_{ND}*=eye position non-dominant eye,* θ_A*=eye position amblyopic eye, and* $\dot{\theta}_A$*=velocity amblyopic eye*

subject on the midline. Target luminance was always maintained at least 1 log unit above screen luminance. Eye movements were recorded as the patients either monocularly or binocularly fixated a target positioned on the midline or 2·5 or 5·0 degrees to the left or right of midline for 15–60 seconds.

Patients were obtained from the clinics at the School of Optometry. All had a thorough visual examination and were free of ocular or neurological disease. Their ages ranged from 15 to 42 years, mean 26·8 years. The patients had amblyopia without strabismus, intermittent strabismus, or constant strabismus amblyopia. Spectacles or contact lenses were worn during all testing. See Table 1 for clinical data on each patient.

Drift was analysed directly from strip chart records for 15–30 consecutive seconds of midline fixation. Drift amplitude was determined in two ways: (1) the maximum peak to peak drift amplitude, regardless of time required for completion of the movement, was found; and (2) maximum peak to peak drift amplitude during consecutive 1 second fixation intervals was obtained and averaged. Drift velocity was also determined in two ways: (1) maximum drift velocity, regardless of time required for completion of the movement, was obtained; and (2) maximum drift velocity during a 200 ms period for consecutive 1 second intervals was obtained and averaged.

Results

The principal finding of our investigation was increased drift amplitude (>12 min arc) and velocity (>20 min arc/s) in amblyopic eyes during monocular fixation. Increased drift occurred most frequently and with greatest magnitude in amblyopia without strabismus and in constant strabismus (exotropia) amblyopia, while it occurred least frequently and with smallest magnitude in intermittent strabismus. Increased drift was not present during binocular fixation or monocular fixation with the dominant eye in any patient. Drift characteristics of each patient were similar for all 5 horizontal directions of fixated gaze tested.

The presence of increased amblyopic drift is clearly seen in the eye movement records (Figs. 1–4). In patient 9 (Fig. 1, amblyopia without strabismus), increased drift amplitude (up to 3·3 degrees) with a paucity of comparably sized saccades, as well as increased drift velocity (up to 1·7 degrees per second), was prominent throughout the record. Drifts rather than saccades appeared to be used to attempt to maintain eye position during fixation. Thus, drifts functioned in either error-producing or error-correcting capacities. Comparison of monocular fixation in the amblyopic eye with monocular fixation in the fellow dominant eye is shown in Fig. 2 (patient 9, amblyopia without strabismus). The contrast between the extreme steadiness of the dominant eye (<12 min arc amplitude, <20 min arc/s velocity) and the increased drift in the amblyopic eye (1·8 degrees peak to peak amplitude and 1·7 degrees/second maximum velocity) is striking.

Important information on the cause of the drift can be ascertained from recordings of binocular eye movement during monocular fixation with the amblyopic eye. Fig. 3 represents such a record in patient 5 (constant strabismus amblyopia). This record clearly shows that the large, slow movement in the amblyopic eye is drift and is not due solely to accommodative vergence, since the movement is largest in the viewing eye (Kenyon *et al.*, 1978); it is not due solely to smooth pursuit, since the movements are nonconjugate; and finally it is not due to disparity (fusional) vergence, since the movements are not symmetrical, and they occur with 1 eye occluded.

Comparison of overall fixation patterns in each diagnostic group is of particular interest (Fig. 4). Patient 10 (Fig. 4, top), having amblyopia without

Table 1 *Clinical data of patients*

Patient	*Age*	*Prescription*	*Visual acuity*	*Vergence abnormality (prism dioptres)*	*Eccentric fixation (prism dioptres)*
Constant strabismus amblyopia					
1*	25	LE+2·00=–0·25×130	20/25	1–2 ET LE	1/2 nasal LE
		RE+2·25	20/15		
2*	23	LE+3·75=–0·50×165	20/30	18 ET LE	1 nasal LE
		RE+0·50	20/15		
3	15	LE–1·50	20/122	10 ET LE and	2·5 nasal and
		RE–1·75	20/20	1 HT LE	2 superior LE
4	32	LE+4·00	20/277	4 ET LE	16 nasal and
		RE plano	20/20		4 superior LE
5*	33	LE+0·75=–0·50×40	20/630	5–6 ET LE and	2·5–3·5 nasal and
		RE+0·25=–0·50×180	20/10	2 HT LE	3–4 superior LE
6	29	LE–1·50=–1·75×180	20/15	4 XT RE and	Unsteady central RE
		RE+4·00=–1·50×180	20/137	2 HT RE	
7	42	LE+1·50=–0·25×180	20/20	20 XT RE	2 temporal RE
		RE+1·00=–0·50×15	20/200		
Amblyopia without strabismus					
8	24	LE+0·75=–2·00×90	20/38	None	2 nasal and
		RE pl=–0·50×19	20/20		2 inferior LE
9	25	LE–2·50=–1·25×172	20/25	None	2 nasal and
		RE–5·00=–0·75×5	20/40		2 inferior RE
10**	19	LE+5·00	20/110	None	2 temporal LE
		RE+3·00	20/15		
11**	26	LE–0·25	20/15	None	1 superior RE
		RE–2·75=–3·75×20	20/165		
Intermittent strabismus with or without mild amblyopia					
12	25	LE+0·25	20/15	20 ALT. XT	Central, steady LE, RE
		RE+0·50	20/15		
13	22	LE–0·75=–0·25×148	20/20	18 ALT. XT and	Slight unsteady
		RE–3·00=–0·25×100	20/20	12 HT LE	Central LE, RE
14*	31	LE–5·00	20/20	15 XT LE	Central steady LE, RE
		RE–4·50=–0·75×20	20/20		
15**	32	LE+0·75=–1·75×180 RE+1·25=–3·50×5	20/20 20/23	40–50 XT RE	1 nasal and Superior RE
16	25	LE plano	20/32	10 XT LE and	1/2 nasal LE
		RE–1·00	20/16	20 HT LE	

*Patients 1, 2, 5, and 14 had corrective eye muscle surgery. **Patients 10 and 15 began amblyopia therapy 1 year and 1 month before participating in our study, respectively, while patient 11 underwent a brief period of unsuccessful occlusion therapy at age 10.

strabismus, showed increased drift (up to 3·4 degrees amplitude and 1·5 degrees/second velocity) in the amblyopic eye. Fixational saccades comparable in magnitude to the drifts were rarely observed. Other patients in this diagnostic group showed similar drift characteristics (Figs. 5–7). Patient 5 (Fig. 4, middle), having constant strabismus with deep amblyopia, frequently showed both increased drift (up to 3·5 degrees amplitude and 2·0 degrees/second velocity) and large saccades (up to 3·0 degrees amplitude) during fixation. Similar fixation characteristics were found for other patients

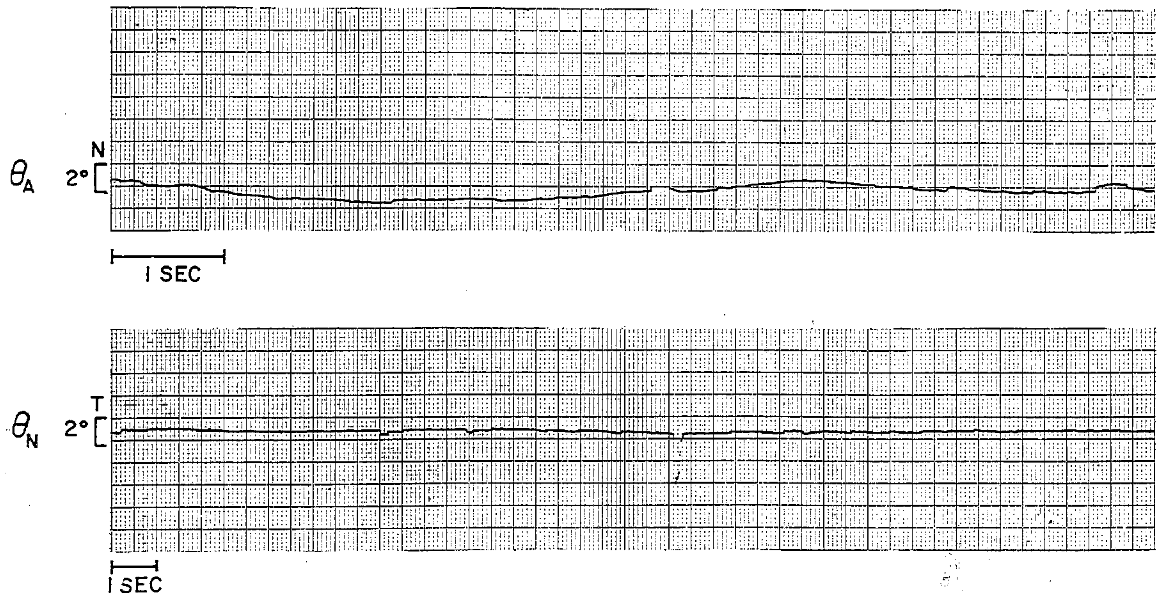

Fig. 2 *Monocular fixation with amblyopic eye (top) and dominant eye (bottom). Patient 9, amblyopia without strabismus, 20/40. Prominent drift of amblyopic eye is in marked contrast to steadiness of dominant eye*

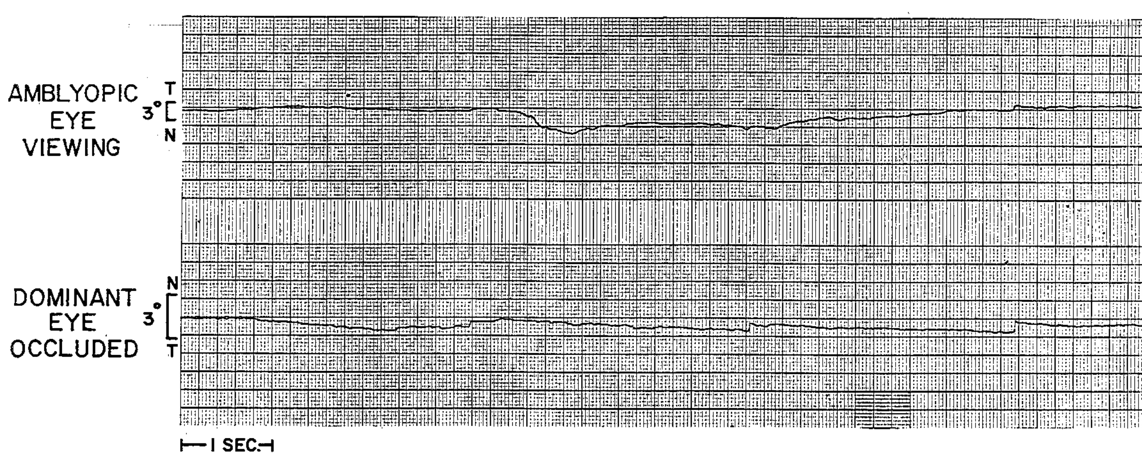

Fig. 3 *Binocular eye movement recording during monocular fixation with amblyopic eye. Patient 5, constant strabismus amblyopia, 20/630. Small drifts (≤1·0 degree) in occluded dominant eye* uncorrelated *to movements in viewing amblyopic eye. Note large (about 3·5 degrees) nasalward drift in viewing amblyopic eye with only small drift in occluded dominant eye. Record clearly shows that this large, slow movement in the amblyopic eye is drift and is not due solely to accommodative vergence, nor to smooth pursuit alone, nor to disparity vergence*

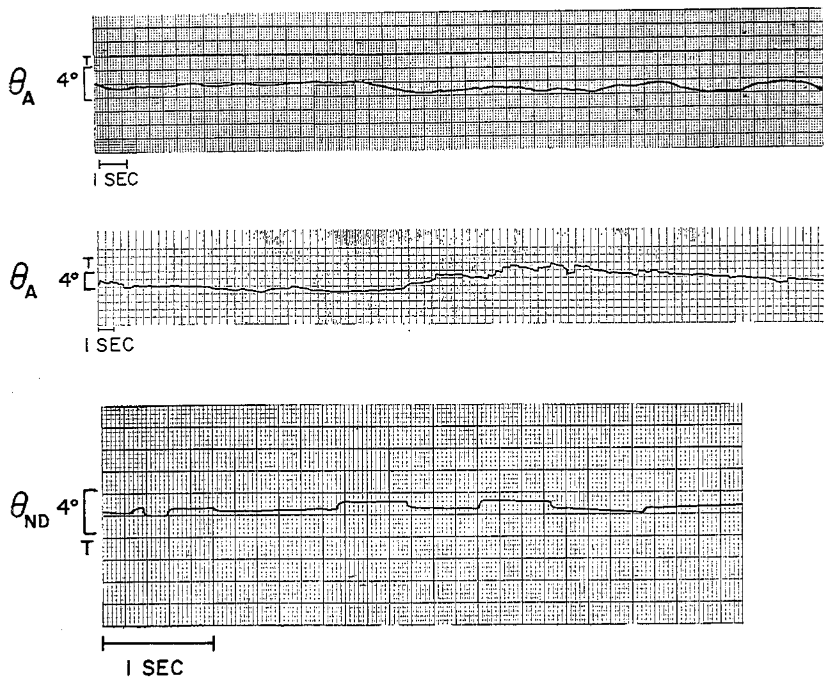

Fig. 4 *Monocular fixation with amblyopic (or nondominant) eye in amblyopia without strabismus (patient 10), constant strabismus amblyopia (patient 5), and intermittent strabismus without amblyopia (patient 13), top to bottom, respectively. Note transition in overall general fixation pattern from predominantly drift (top) to drift and saccades (middle) to predominantly saccades (bottom)*

in this diagnostic group (Figs. 5–7). For patient 13 (Fig. 4, bottom) having intermittent strabismus and normal acuity, saccadic intrusions (0·5–1·0 degree amplitudes) rather than significantly increased drifts were prominent during fixation, and this was true for most patients in this diagnostic group (Figs. 5–7). Thus, these results clearly show that the occurrence of markedly increased drift depended on the presence of amblyopia and not strabismus. The presence of strabismus alone resulted in normal or nearly normal drift characteristics, with large saccades (saccadic intrusions) now becoming the prominent feature of the fixation pattern (Ciuffreda *et al.*, 1979b).

A further analysis of drift is warranted. The presence of abnormal drift (the number of 1 second intervals in which increased drift amplitude or velocity was found divided by the total number of seconds fixation was tested times 100) was calculated for each patient (Fig. 5). Increased drift amplitude was found 50% of the time in constant strabismus amblyopia, occurring 34% of the time in the esotropes while increasing to 90% of the time in the exotropes. Increased drift velocity was found 56% of the time in constant strabismus amblyopia, occurring 43% of the time in the esotropes while increasing to 87% of the time in the exotropes. In amblyopia without strabismus increased drift amplitude and velocity occurred 67 and 85% of the time, respectively. Increased drift amplitude was found 13% of the time in intermittent strabismus, occurring only 8% of the time in patients with 20/20 or better visual acuity while increasing to 20% of the time in patients with worse than 20/20 visual acuity. Increased drift velocity was found 30% of the time in intermittent strabismus, occurring only 23% of the time in patients with 20/20 or better visual acuity while increasing to 40% of the time in patients with worse than 20/20 visual acuity. In constant strabismus (esotropia) amblyopia average maximum drift amplitude correlated well ($r_s = 0{\cdot}975$, $P<0{\cdot}05$) with visual acuity of the amblyopic eye. Maximum peak to peak drift amplitude ($r_s = 0{\cdot}90$, $P<0{\cdot}05$), and the presence of abnormal drift amplitude ($r_s = 0{\cdot}90$, $P<0{\cdot}05$) also correlated well with visual acuity of the amblyopic eye in these 5 esotropic patients. In our 4 patients having amblyopia without strabismus there was a strong trend ($r_s=0{\cdot}95$, $P>0{\cdot}05$) for average maximum drift amplitude and velocity to correlate well with visual acuity of the amblyopic eye. No other significant correlations or strong trends were found.

Discussion

Increased drift was found in the amblyopic eyes of most of our patients. The increased drift amplitude

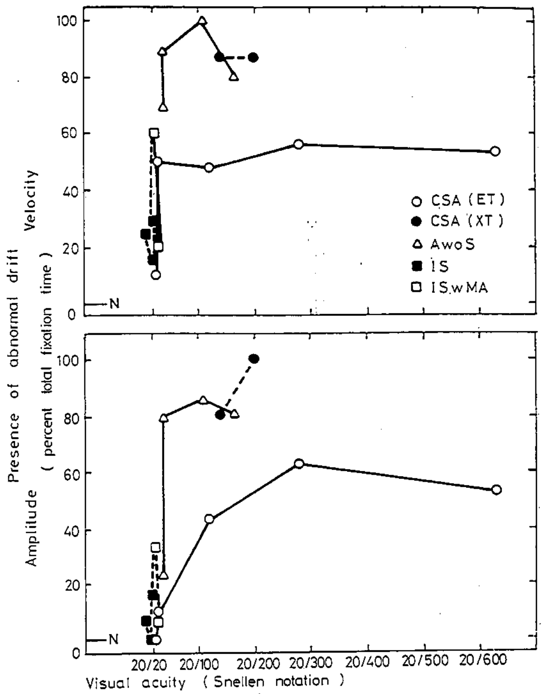

Fig. 5 *Presence of abnormal drift (per cent total fixation time of increased drift) amplitude and velocity as a function of visual acuity in the nondominant eye. Symbols for figures 5–7: CSA(ET)=constant strabismus amblyopia (esotropia), CSA(XT)=constant strabismus amblyopia (exotropia), AwoS=amblyopia without strabismus, IS=intermittent strabismus with visual acuity of 20/20 or better, ISwMA=intermittent strabismus with mild amblyopia (visual acuity worse than 20/20), and N=maximum normal drift level during binocular fixation or monocular fixation with the dominant eye*

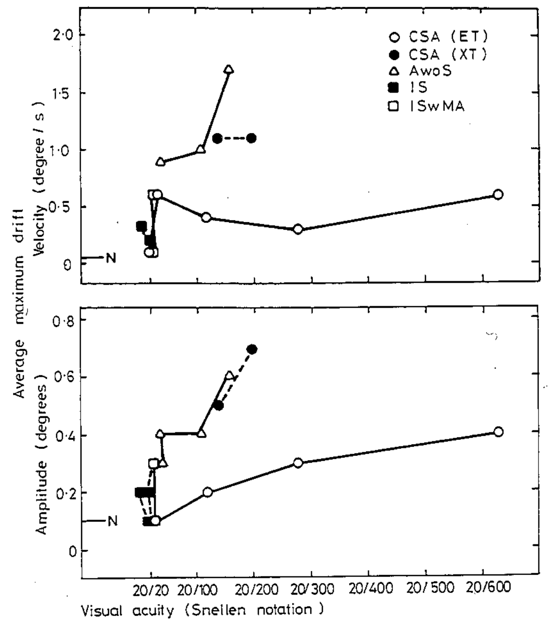

Fig. 6 *Average maximum drift amplitude and velocity as a function of visual acuity in the nondominant eye*

and velocity were most pronounced in amblyopia without strabismus and constant strabismus (exotropia) amblyopia. It was evident to a lesser degree in constant strabismus (esotropia) amblyopia. Drift was either normal or nearly normal in the nondominant eyes of most patients having intermittent strabismus. Thus, the results suggest that amblyopia and not strabismus was a necessary condition for the presence of significantly increased drift.

The slightly increased drift found in intermittent strabismus is of interest. Increased drift in this diagnostic group was most pronounced in patient 15. This was probably due to the presence of slightly reduced visual acuity and eccentric fixation in the eye. Further, the patient was undergoing active orthoptic treatment at this time, which may result in increased drift due to disruption of a

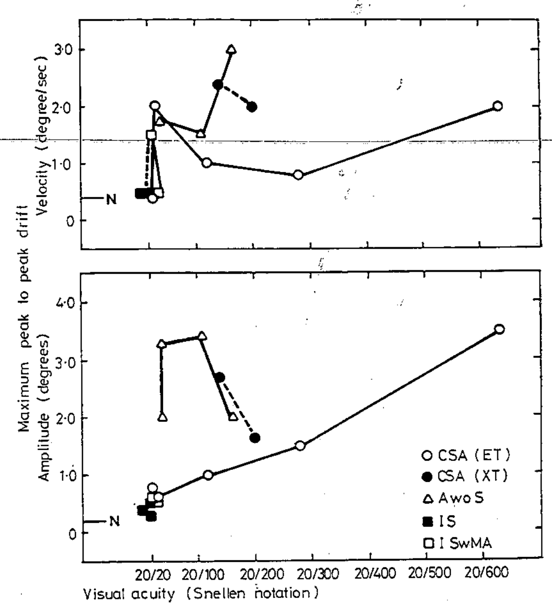

Fig. 7 *Maximum peak to peak drift amplitude and velocity as a function of visual acuity in the nondominant eye*

relatively fixed pattern of eccentric fixation in spite of concomitant improvement of visual acuity (Ciuffreda *et al.*, 1979a). The other patients in this group exhibited normal or nearly normal drift. Strabismus-induced fixation degradation, resulting in abnormally-large fixational saccades (saccadic intrusions) in most intermittent strabismics (Ciuffreda *et al.*, 1979b), could also account for part of this mild drift abnormality.

Increased drift amplitudes, without the occurrence of comparably sized corrective saccades (as was most dramatically found in patients having amblyopia without strabismus) suggest that drifts rather than saccades played a major role in the correction of fixation errors and in the maintenance of eye position in amblyopic eyes. Thus, drift could be either error-producing or error-correcting (Nachmias, 1959; St Cyr and Fender, 1968; Stark, 1971) in nature. It is interesting that Nachmias (1959), in analysing 2-dimensional monocular fixation eye movement records in normal subjects, found correction of position error by drifts in those meridians in which microsaccadic corrections appeared to be ineffective. If this line of reasoning is applied to our patients, it suggests that the microsaccadic system, one of whose functions is to correct for drift-induced fixation errors, may be less effective in amblyopic eyes. Ineffectiveness of the microsaccadic system may involve failure to integrate eye velocity (drift velocity) into a position error for subsequent correction by the saccadic system and/or processing delays in initiation of appropriately sized microsaccades, similar to the processing delays found for larger tracking saccades in amblyopic eyes (Ciuffreda *et al.*, 1978a, b). Increased drift amplitudes might also be found if processing delays in the smooth pursuit velocity-correcting system were present. These hypotheses regarding possible mechanisms underlying increased amblyopic drift amplitude warrant further careful experimental testing.

Could part of the increased drift amplitudes observed in amblyopic eyes be due to normal drift characteristics of the oculomotor system for position errors generated in the retinal periphery? Results of Sansbury *et al.* (1973) support this idea. In their experienced normal subjects, as error signals were generated by more peripheral retinal regions, small increases (a few minutes of arc) in drift magnitude were found. Thus it seems reasonable to attribute a small part of the increased drift amplitudes observed in our untrained amblyopic patients to this factor, since they did fixate on the average with nonfoveal regions, that is, eccentric fixation was present. The total extent over which the target image was displaced without execution of appropriate corrective movements may represent that region of the retina most adversely affected, in terms of eye position maintenance, by amblyopia.

Drift velocities as high as 3·0 degrees per second were found in amblyopic eyes. If drift rates were similar between the normal and amblyopic eye, and only increased drift magnitudes were found in amblyopic eyes, this might point to a simple sensory basis for the abnormality in terms of defective sensing of position error over affected (by amblyopia) retinal regions, thus allowing the eye to drift for a longer period of time, but with normal drift velocities, until the target image extended out of this relatively insensitive area. At that time a position error would be sensed and a corrective movement initiated. That this might occur at times in amblyopic eyes has been discussed elsewhere (Ciuffreda, 1977). More frequently, however, increased drift velocities were observed which may either be a consequence of delays resulting from amblyopia in the smooth pursuit velocity-correcting system, thereby allowing long duration drifts with high velocities to evolve, or may in part simply result from fixation with nonfoveal retinal regions.

What effect would increased drift have on visual acuity in amblyopic eyes? It has been clearly shown that retinal-image motion across the horizontal meridian of the fovea in normal persons must exceed 2·5 degrees per second before visual resolution is degraded (Westheimer and McKee, 1975). If this result is applied to the amblyopic eyes, visual acuity should be little if at all affected by the increased drift velocities (generally $<2{\cdot}5$ degrees/second). However, increased drift amplitudes moving the retinal image on to more eccentric positions would reduce acuity, as shown by recent measures of the visual acuity gradient in the horizontal meridian in amblyopic eyes (Kirschen and Flom, 1978), while increased drift amplitudes in any direction would contribute to increased variability in the acuity measure.

The results showed that only certain parameters of drift correlated highly with visual acuity in the amblyopic eye (there were too few patients with constant exotropia and amblyopia to perform a statistical analysis, and in intermittent strabismus the range of acuities was too narrow). But should one necessarily expect a close relationship between *all* aspects of drift and visual acuity in the amblyopic eye? Other factors, such as age of onset of strabismus, constancy of the deviation, and age of initial correction of refractive error may influence degree of fixation control in the amblyopic eye. From our data, there was also a suggestion that direction of deviation may influence amblyopic drift characteristics. Our 2 patients with constant exotropia and amblyopia consistently had high drift values when compared to our patients having constant esotropia with similar acuity losses. Further testing of patients with constant exotropia must be conducted before the idea that amblyopia secondary to exotropia is more detrimental to fixation control than amblyopia secondary to esotropia can gain support. Lastly, oculomotor control may be differently influenced by effects due primarily to suppression, as commonly found in strabismus with approximately equal refractive error, and those effects due primarily to mild form deprivation, as found in anisometropia.

The results of this study can provide insight into the clinical assessment of fixation in amblyopic eyes. During the visuscopic examination the clinician estimates, with aid of a calibrated grid pattern projected on to the fundus, the magnitude (time-average position of the eye) and range (maximum peak to peak drift amplitude with microsaccadic amplitude superimposed) of eccentric fixation, as well as 'steadiness' of fixation—a judgment based on some unknown combination of average and maximum drift amplitude and velocity with micro-saccadic amplitude superimposed. The presence of abnormal drift (in terms of per cent total fixation time) is difficult to quantify accurately, and the absolute value of average or maximum drift velocity is impossible to ascertain. Recent findings obtained with an objective eye movement recording technique show, for example, that average maximum drift amplitude and velocity tend to become normal during orthoptic treatment (Ciuffreda *et al.*, 1979a). These authors' results suggest that it is important to quantify accurately and completely these measures of drift during treatment, and a visuscopic analysis alone is inadequate for such purposes. However, objective eye movement recording techniques also have a serious disadvantage. One generally does not know the location of the fovea with respect to the retinal image of the target. Thus, as advocated by Mackensen (1957) and Ciuffreda *et al.* (1979a), use of both accurate eye movement recordings and visuscopic examination results (along with entoptically derived measures of magnitude of eccentric fixation) are essential for a complete, quantitative description of fixation in amblyopic eyes.

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