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Suppression of Fixational Saccades in Strabismic and Anisometropic Amblyopia [1]

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Abstract. Individuals with strabismus frequently exhibit large fixational saccadic pairs (saccadic intrusions) during monocular fixation with the amblyopic eye in the light. We found two conditions in which the saccadic intrusion frequency could be markedly reduced. When instructed to 'hold the eye steady' in the presence of a visible target in the light, saccadic intrusions were suppressed and eye position maintained within a few degrees of the target. These results suggest that corrective drift was used by the amblyopic eye to aid in position maintenance. When instructed to 'fixate' in complete darkness, the intrusive pattern was replaced by a jerk nystagmus-like pattern. These results clearly demonstrate that saccadic intrusions in amblyopic eyes require the presence of a visible target for their generation, and additionally, that 'extraretinal signals' were involved in maintenance of eye position under this condition. Saccades could also be suppressed during the 'hold' command in the light by patients having amblyopia without strabismus or constant strabismus amblyopia with intermittent jerk nystagmus.

Introduction

Saccadic intrusions refer to a pair of horizontal saccades, executed in opposite directions and separated by approximately 200 msec, that are sometimes found during fixation in patients with neurological disease [19]. Intrusions generally have amplitudes ranging from 0.5 to 3.0° and occur with a

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frequency of 1–4/sec [19]. Due to the opposite direction and apparent corrective nature of the second saccade of the pair, there is little net change in eye position following an intrusion.

It has been clearly demonstrated that individuals with strabismus amblyopia exhibit saccadic intrusions during monocular fixation in the light with the amblyopic eye [1, 2, 5, 6, 9, 11, 12]. Recently, *Schor and Hallmark* [12] have shown that saccadic intrusions during fixation could be suppressed in patients with constant strabismus amblyopia when instructed to 'hold the eye steady', thus confirming the preliminary findings of *Ciuffreda* [1]. However, *Schor and Hallmark*'s test conditions were somewhat complicated in that patients fixated a large (~ 2°) cross, with their foveal entoptic Haidinger's brush present at the same time. We sought to determine if generation of these intrusive saccades could be modified by employment of either the 'hold' command in the light using a simple spot stimulus or by 'fixation' in the dark. Thus, fixation commands and stimulus conditions were similar to those used by *Steinman et al.* [17], who found that microsaccades could be suppressed in normal subjects. Furthermore, we extended our observations to include patients from three diagnostically-distinct groups: constant strabismus (esotropia) amblyopia, constant strabismus (exotropia) amblyopia with intermittent jerk nystagmus, and amblyopia without strabismus, a condition in which saccadic intrusions are infrequently found [1, 2].

Methods

A photoelectric method was used to record horizontal eye position [15]. With this method, the amount of infrared light reflected from the horizontal limbal regions was monitored, and this was directly related to changes in eye position for the range of movements recorded. The bandwidth of the entire recording system was 150 Hz (–3 dB) for patient 1 and 100 Hz for patients 2 and 3. Resolution was approximately 12 min arc. A chinrest and headrest, in conjunction with a bite bar covered with dental impression material, were used to stabilize the head. During test periods, spectacle correction was worn, and the dominant eye was completely patched.

A minicomputer (PDP–8/I) was used to generate a small spot of light (5 min arc) on a display screen placed 91 cm away on the subject's midline. Target luminance was always maintained at least 1 log unit above screen luminance.

Fixation was tested under three different conditions in patient 1. In the first condition, the patient was instructed to 'fixate' the target accurately. In the second condition, with the target present, the experimenter verbally commanded the patient to 'hold the eye steady' for several test trials. In the third condition, the patient and display screen were placed within a large blackout enclosure. Following a calibration procedure and recording of midline fixation, the stimulus was extinguished. The patient was instructed to attempt to maintain 'fixation' in total darkness, where the stimulus had been previously visible. No afterimages of the previously-visible target, which might provide fixation cues, were ever observed by the patient. Fixation in the dark was not tested in patients 2 and 3. During the 'hold' command, our patients remarked that they did not pay as much attention to target detail, and perhaps position errors, as they did during the 'fixate' command. However, during both sets of instructions, attention and motivation to perform the prescribed task successfully was high. Patients 1 and 3 stated that the amblyopic eye seemed more unsteady during the 'hold' command, but that target clarity was similar for both conditions. Patient 2 noted that, at times, she relaxed accommodation and maintained relatively steady, 'saccade-free' fixation by concentrating on the defocused image; at other times, defocusing was not essential to suppress her fixational saccades. Moreover, *Steinman et al.* [18] have shown that experienced normal subjects could suppress their microsaccades with accommodation approximately 90% paralyzed [3].

3 patients were tested. Patient 1 was a 15-year-old male student. Refractive error was –1.50 and –1.75 dptr in the left and right eye, respectively. Visual acuity was 20/122 in the left amblyopic eye and 20/20 in the right dominant eye. A constant left esotropia of 10 prism dptr and a left hypertropia of 1 prism dptr were found. There was no previous history of strabismus surgery or orthoptics therapy. Unsteady eccentric fixation, measured with a calibrated ophthalmoscope, was 2.5 prism dptr nasal and 1.0 prism dptr superior in the left eye. Steady central fixation was observed in the dominant eye. Suppression and anomalous retinal correspondence were also found. Patient 2 was a 29-year-old female optometry student. Refractive error was $+1.50 = -1.75 \times 180$ and $+4.00 = -1.50 \times 180$ in the left and right eye, respectively. Visual acuity was 20/137 in the right amblyopic eye and 20/15 in the left dominant eye. A constant right exotropia of 4 prism dptr and a left hypertropia of 2 prism dptr were found. There was no previous history of strabismus surgery or orthoptics therapy. Corrective lenses were prescribed at age 7. Unsteady, central fixation was found in the amblyopic eye by using a calibrated ophthalmoscope. Fixation was steady and central in the dominant eye. Suppression in the amblyopic eye was also found. Patient 3 was a 26-year-old male optometry student. Refractive error was –0.25 and $-2.75 = -3.75 \times 20$ in the left and right eye, respectively. Visual acuity was 20/165 in the right amblyopic eye and 20/15 in the left dominant eye. No strabismus was present. Corrective lenses were prescribed at age 8, and a short but unsuccessful period of direct occlusion therapy was attempted at age 10. Unsteady eccentric fixation of 1 prism dptr superior was measured in the amblyopic eye with a calibrated ophthalmoscope. Fixation was steady and central in the dominant eye. Suppression in the amblyopic eye was also found.

Results

Representative eye position traces for fixation in the light during the 'fixate' and 'hold' commands are shown in figures 1–3 for our patients. Evident during the 'fixate' command were saccadic intrusions which occurred at a rate of approximately 1/sec with amplitudes ranging from 0.5 to 4.0° (table I). Also present were a few small single corrective saccades ($\leqq 1.0°$ in amplitude). In contrast, during the 'hold' command, there was a marked reduction in

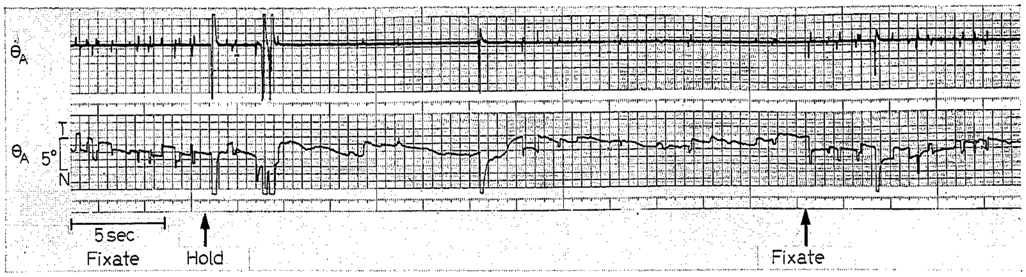

Fig. 1. Eye position (bottom trace) and eye velocity (top trace) as a function of time for patient 1 having constant strabismus (esotropia) amblyopia (20/122). Monocular fixation amblyopic eye. Patient instructed to 'fixate' carefully or to 'hold the eye steady' in the light with the target present. During 'fixate' command, saccadic intrusions occurred frequently (~ 1/sec). Note markedly reduced intrusion frequency during 'hold' command (~ 0.1/sec) and prominence of slow drift. Deflections driving pens to edge of records due to blinks. Symbols for all figures: T = Templeward eye movement; N = nasalward eye movement; $\dot{\theta}_A$ = amblyopic eye velocity; θ_A = amblyopic eye position.

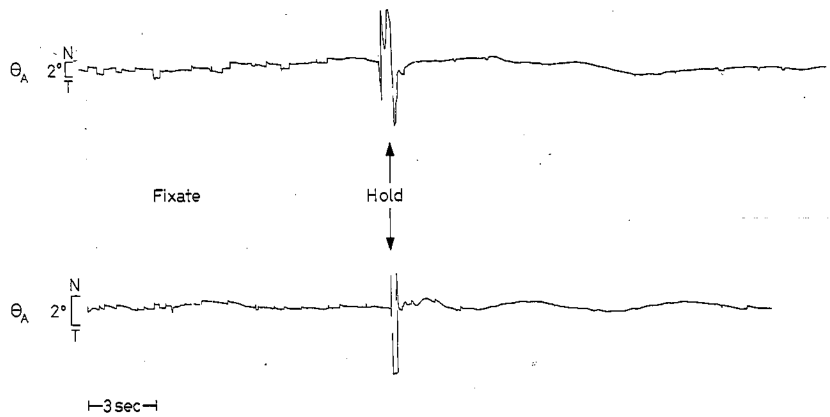

Fig. 2. Eye position as a function of time for patient 2 having constant strabismus (exotropia) amblyopia (20/137) and intermittent jerk nystagmus. Monocular fixation amblyopic eye. Upper trace: note frequent saccadic intrusions (~ 1/sec) during 'fixate' command, in striking contrast to reduced intrusion frequency (~ 0.2/sec) during 'hold' command, with drift now being the prominent feature. Lower trace: during 'fixate' command, note left jerk nystagmus comprised of templeward slow phases and nasalward corrective saccades, as well as some saccadic intrusions; during 'hold' command, note marked reduction (~ 80%) in frequency of nystagmus saccades and absence of saccadic intrusions, thus demonstrating suppression of both types of saccadic movements. Present throughout fixation were some microsaccades with very large dynamic overshoots and some saccadic intrusions with very short intersaccadic intervals; these appear as 'spikes' in the record due to slow chart speed. Large deflections at 'hold' command are blinks.

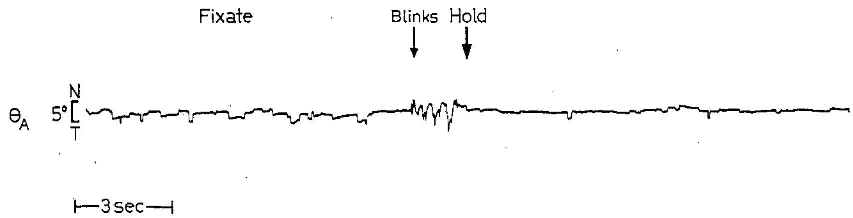

Fig. 3. Eye position as a function of time for patient 3 having amblyopia without strabismus. Monocular fixation amblyopic eye. Note saccadic intrusions (~ 1/sec) and single fixational saccades during 'fixate' command; during 'hold' command, fewer saccadic intrusions found (~ 0.5/sec). In contrast to patient 1 and 2 during 'hold' command, patient 3 maintained eye steady without presence of increased drift amplitude or velocity. Some saccadic intrusions with very short intersaccadic intervals (<100 msec) appear as 'spikes' in record.

Table I. Characteristics of drift and saccades during 'fixate' (F) and 'hold' (H) commands in the light

Patient	Test condition	Maximum drift velocity, °/sec	Saccadic intrusion frequency, Hz	Range of saccadic intrusion amplitudes, °
1	F	1.4	1.0	0.5–4.0
	H	2.5	0.1	0.7–2.5
2	F	0.5	1.0	0.5–1.5
	H	1.0	0.2	0.5
3	F	1.0	1.0	1.0–2.5
	H	1.0	0.5	0.5–2.0

saccadic intrusion frequency. It now ranged from 0.1 to 0.5/sec (table I). This reduction is clearly demonstrated in the velocity traces. Some single corrective saccades with amplitudes ranging from 0.7 to 2.5° were also found. Maximum drift velocity during the 'fixate' command was 1.4, 0.5, and 1.0°/sec, and it was 2.5, 1.0 and 1.0°/sec during the 'hold' command, for subjects 1, 2 and 3, respectively (table I).

Representative eye position traces for 'fixation' in the light and 'fixation' in the dark are presented in figure 4 for patient 1. For 'fixation' in the light, saccadic intrusions occurred at a rate of approximately 1/sec with amplitudes ranging from 1.0 to 2.5°. The nasalward primary saccade of the intrusion was

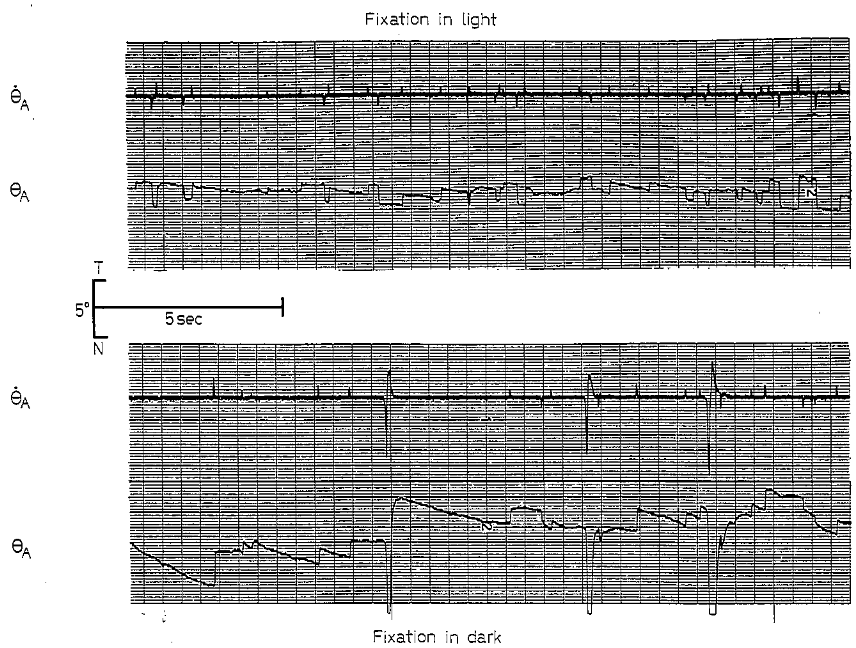

Fig. 4. Eye position and eye velocity as a function of time for patient 1 having constant strabismus (esotropia) amblyopia (20/122). Monocular fixation amblyopic eye. Patient either 'fixating' in light (top) or 'fixating' in dark (bottom). Note presence of saccadic intrusions throughout record for 'fixation' in light (~ 1/sec). In contrast, for 'fixation' in dark, few intrusions present and instead a jerk nystagmus-like pattern comprised of nasalward drift (1.0–3.0° in amplitude, 0.5–2.0°/sec slow phase velocities, and 0.5 Hz 'nystagmus' frequency) and templeward saccades (up to 3.0° in amplitude) found. Deflections driving pens to edge of records due to blinks.

followed approximately 150–500 msec later by a templeward secondary corrective saccade. Also present were single corrective saccades having amplitudes ranging from 1 to 2°. Drift amplitudes were $\leqq$0.7° with velocities $\leqq$1°/sec. In contrast, for 'fixation' in the dark, few saccadic intrusions were observed. The predominant features were now nasalward drifts (1–3° amplitudes, 0.5–2.0°/sec velocities) and templeward saccades having amplitudes as large as 3.0°.

Binocular fixation and monocular fixation with the dominant eye in the light were within normal limits (< 12 min arc amplitude, < 20 min arc/sec velocity) for these patients.

Discussion

Our results confirm the earlier findings of *Ciuffreda* [1], and *Schor and Hallmark* [12], but more importantly extend it to include patients from other diagnostic groups. Thus, suppression of saccades during fixation can now be regarded as a generalizable phenomenon in the population including normals, strabismics, and amblyopes, even when complicated by the presence of jerk nystagmus.

Steinman et al. [17] observed that microsaccades could be suppressed when experienced subjects were instructed to 'hold their eye steady' rather than 'fixate' in the presence of a visible target. That eye position was maintained under the 'hold' instruction suggested that drifts could function in a corrective capacity. Although microsaccades could be suppressed with or without the presence of a visible target during the 'hold' command, eye position could not be maintained in the dark.

During the 'hold' command, our patients suppressed saccadic intrusions. Generally, eye position was maintained within $\pm 3°$ of target position, suggesting that corrective drift (smooth pursuit) could be used to aid in eye position control [8, 10, 14, 16 (cf. fig. 15), 17], as visual feedback was still present under this condition. Recently, *Kenyon et al.* [4] have shown that retinal-image motion resulting from a stationary target and a slowly, and smoothly, moving eye (during accommodative vergence) could activate the pursuit system. During the 'hold' command, our patients exhibited more drift in the horizontal meridian than the normal subjects tested by *Steinman et al.* [17]. In fact, on a few trials the amblyopic eye rapidly drifted outside the range of our monitor. However, this is to be expected, as amblyopic eyes typically exhibit more drift than normal eyes [1].

Several interesting points can be made regarding 'fixation' in the dark. The results clearly demonstrated that the generation of saccadic intrusions was dependent on the presence of a visible target, i.e., visual feedback was required. In the absence of a target, intrusions were replaced by a jerk nystagmus-like pattern comprised of nasalward drifts and templeward corrective saccades. This is similar to the disappearance of macrosaccadic oscillations, but with continuance of gaze-holding nystagmus, reported by *Selhorst et al.* [13] for cerebellar patients in the dark. Patient 1 was able to maintain his amblyopic eye within $\pm 5°$ of the previously presented target position during most of the brief test periods (10–25 sec). This suggests that 'extraretinal signals' [7], i.e., position formation derived from sources other than retinal error, such as efference copy, were used to aid in maintenance of eye position.

And, as found by *Skavenski and Steinman* [14] in normal subjects, saccades kept the amblyopic eye near target position during these brief test periods in the dark.

These results clearly demonstrate that saccades during fixation could be suppressed in our patients. Moreover, these findings show the remarkable similarity that instruction changes had on fixation characteristics in highly-experienced normal subjects [17] and in our own inexperienced amblyopic patients, with the major differences being larger saccadic amplitudes and increased drift in our patients. However, this is to be expected for less sensitive amblyopic eyes [1, 2].

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