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Vertical Saccades in Superior Oblique Palsy

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Vertical saccadic velocities in 10 patients who had unilateral superior oblique muscle palsy and 14 normal subjects were measured with the magnetic scleral search coil. The authors sought to determine whether downward saccades in patients who had superior oblique palsy are slow. Peak velocities of 10° and 20° saccades performed in the superior and inferior fields of the orbit, and 10°, 20°, and 30° saccades performed across the center of the orbit were recorded with the eye in center gaze, 30° of adduction, and 30° of abduction. Paired t-tests did not show statistically significant differences between upward and downward saccades in patients with superior oblique palsy; no effects of orbital field or position of horizontal gaze were found ($P > 0.01$). Comparison of similar saccades between normal subjects and patients with superior oblique palsy by two-sample t-tests did not show significant differences between the two groups ($P > 0.01$). Invest Ophthalmol Vis Sci 32:1938–1943, 1991

Superior oblique palsy is a diagnosis made on the basis of clinical findings, and the generally accepted criterion is a positive finding on Parks' three-step test.[1] Although superior oblique palsy is a disorder of one of the extraocular muscles of vertical gaze, it is not known whether vertical saccades are altered in superior oblique palsy because of difficulty in accurately measuring vertical eye movements. Studies by Metz[2] and Rosenbaum[3] with electro-oculography (EOG) led to conflicting conclusions.

Eye movement-recording methods using EOG and the introduction of infrared limbus-tracking methods have affected the research and diagnosis of eye movement abnormalities. However, the use of these methods has been applied largely to the evaluation of horizontal eye movements, including saccadic velocities. Saccades are rapid, voluntary eye movements that redirect fixation from one target to another. These methods are not accurate in the evaluation of vertical saccades. EOG overestimates the peak velocity of upward saccades because of eyelid movement artifacts, and infrared limbus tracking is useful only over a limited range of vertical gaze because of interference by the eyelids.[4,5]

The magnetic scleral search coil method of Robinson,[6] adapted for use on human subjects by Collewijn and colleagues,[7] is an accurate and practical method for evaluating vertical saccadic velocities.[5] In this method, a subject wearing a soft scleral lens with several turns of an embedded, fine copper coil is seated with the eye centered in a magnetic field. Any change in the position of the eye within this field generates a current proportional to the magnitude of the eye movement. This method is not commonly used as a clinical tool for the diagnosis of eye movement disorders.

This study evaluated the velocities of vertical saccades in patients who had a diagnosis of superior oblique palsy and in normal subjects to determine whether downward saccades are slowed in patients with superior oblique palsy. Because the superior oblique muscle causes depression of the globe, particularly in adduction,[8,9] slowing of the peak saccadic velocities of downward saccades in superior oblique palsy could occur. If these saccades are slowed, the difference could be used as a diagnostic tool.

Materials and Methods

Voluntary vertical saccades were recorded in 10 subjects who had the clinical diagnosis of unilateral superior oblique palsy and in 14 normal subjects. Parks' three-step test was used to diagnose the SOP and included a hypertropia of one eye in primary gaze, an increase of the hypertropia with adduction of the affected eye, and a positive finding on Biels-

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chowsky's head-tilt test.[1] The normal subjects had no history of ophthalmologic or neurologic abnormalities. Informed consent was obtained before the study began.

A scleral magnetic search coil system similar to that described by Collewijn and colleagues[7] was used. The induction coils were pairs of horizontally and vertically oriented coils 3 ft in diameter. The detection coil was several turns of fine copper wire embedded in an annulus of soft, plastic contact-lens material (Skalar, Delft, Holland). The scleral contact lens was placed on the eye after instillation of proparacaine for topical anesthesia. A low-pass, analog filter of 1 kHz was used. The position signal was digitized at 200 samples/sec, and a two-point central difference algorithm was used to calculate peak velocities. The linear range of this system is ± 20°. Beyond this range, signal output is proportional to peak velocity by a sine wave function; assumption of a linear relationship will underestimate the actual peak velocity.[6]

Subjects were seated 1 m from a curved screen with vertically oriented dots that were a quarter of a degree in diameter and positioned at 5° intervals. The screen was positioned with the subject looking at the center dot in primary position. The subject's head was stabilized by a plastic helmet that supported the forehead, malar eminences, and occiput. Patients who had refractive errors wore appropriate corrective glasses.

Subjects were asked to do three types of fixation exercises. The first pattern involved making saccades in the superior field of gaze. Saccades were made from the center dot to the dot 10° above center, back to center, and then from center to 10° above center and back to center; this was repeated in the superior field for center to +20° and back to center. The second pattern was performed with all upward and downward saccades made in the inferior field of gaze. Saccades were made from the center dot to 10° below center and back to center; this was repeated for center to −20° and back to center. In the third pattern, all upward and downward saccades were made across the center of the field of gaze. Saccades were made between corresponding dots in the upper and lower fields. For example, 10° saccades were made from the 5° above center dot to the 5° below center dot and back to the 5° above center dot. Similar 20° and 30° saccades were made across the center between the +10° and −10° dots and again for the +15° and −15° dots, respectively.

Each of these three patterns of saccades were performed with the eye in center gaze, 30° of adduction, and 30° of abduction. In normal subjects, the right eye was tested; all patients with superior oblique palsy had their unaffected eye patched during testing. Two of the patients with superior oblique palsy who had marked overaction of their inferior oblique muscles had both their normal eye and affected eye tested. The affected eye was patched during testing. Subjects were continually encouraged to remain alert during the study.

Results

The age range was 21–60 yr for patients with superior oblique palsy and 22–41 yr of age for normal subjects. In 50% of the patients with superior oblique palsy, the right eye was affected; in the remaining 50% the left eye was affected. In patients with superior oblique palsy, the duration of superior oblique palsy ranged from less than 1 yr to 41 yr. In one of the subjects, the cause of the superior oblique palsy was iatrogenic because of removal of a palpable trochlea that was mistaken for a tumor. The cause of the superior oblique palsy in the nine remaining subjects was congenital, traumatic, or idiopathic. Two of the 10 patients with superior oblique palsy showed marked overaction of the inferior oblique muscle; their data were included in the statistical analysis. These two subjects also had their nonparetic eyes evaluated.

Table 1. Means of normal subjects

	Superior		*Inferior*		*Across center*		
	10°	*20°*	*10°*	*20°*	*10°*	*20°*	*30°*
Center gaze							
Up	255^{35}*	384^{67}	262^{34}	401^{47}	249^{34}	405^{47}	441^{69}
Down	262^{41}	367^{58}	259^{33}	367^{60}	255^{38}	364^{73}	421^{84}
Adduction							
Up	251^{43}	347^{58}	272^{52}	394^{65}	257^{47}	365^{77}	438^{85}
Down	234^{38}	305^{63}	250^{51}	350^{78}	248^{45}	338^{75}	398^{87}
Abduction							
Up	244^{29}	346^{65}	248^{33}	381^{61}	253^{44}	400^{83}	418^{70}
Down	233^{38}	346^{65}	239^{57}	352^{64}	250^{49}	371^{72}	389^{78}

* Superscripted numbers represent standard deviations.

Table 2. Means of SOP subjects

	Superior		*Inferior*		*Across center*		
	10°	*20°*	*10°*	*20°*	*10°*	*20°*	*30°*
Center gaze							
Up	250^{46}*	387^{67}	259^{57}	416^{55}	259^{60}	405^{37}	461^{75}
Down	258^{58}	370^{85}	259^{71}	384^{83}	256^{42}	380^{98}	404^{120}
Adduction							
Up	247^{38}	341^{74}	236^{68}	369^{78}	240^{37}	388^{62}	414^{65}
Down	220^{50}	307^{83}	227^{74}	345^{138}	224^{72}	317^{112}	387^{130}
Abduction							
Up	237^{34}	346^{73}	243^{41}	365^{76}	251^{57}	371^{57}	411^{86}
Down	221^{80}	321^{80}	244^{71}	326^{70}	236^{49}	344^{91}	354^{90}

* Superscripted numbers represent standard deviations.

Mean values and standard deviations for peak saccadic velocities for normal subjects and patients with superior oblique palsy are shown in Tables 1 and 2, respectively. The data are shown (Figs. 1, 2) for normal subjects and patients with superior oblique palsy, respectively. Figure 3 shows the data for vertical saccades made across the center by one of the two subjects with overaction of the inferior oblique muscle. Data obtained in different fields and on the other subject with overaction of the inferior oblique muscle were similar.

Paired t-tests were used to determine whether there was a statistically significant difference between the peak velocities of upward and downward saccades. This involved the use of multiple t-tests on multiple measurements in the same subjects. This method is known to increase the possibility of discovering erroneously significant results, or false-positive findings. However, this phenomenon is rarely considered in the choice of significance levels. Erroneously significant results occur by chance; when large numbers of t-tests are performed, there is an increased chance of spuriously positive results. This problem can be overcome in part by choosing a higher level of significance (smaller P value) as the threshold for positive results. Calculations to determine the appropriate significance level are available. Use of these formulas, however, yields P levels so small for the number of multiple t-tests in studies such as ours that the chance of detecting any significant difference is tremendously reduced. Our type II error, the chance of obtaining false-negative results, would be unacceptably large.

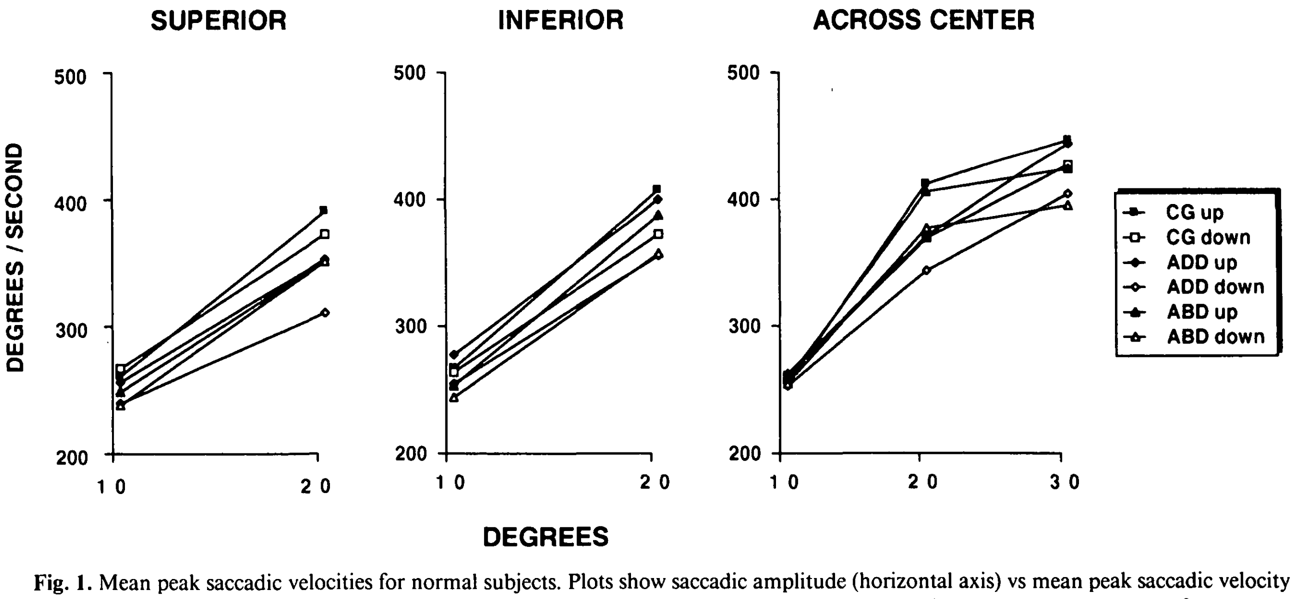

Fig. 1. Mean peak saccadic velocities for normal subjects. Plots show saccadic amplitude (horizontal axis) vs mean peak saccadic velocity (vertical axis). Upward saccades (filled shapes) and downward saccades (hollow shapes) are shown. Separate graphs are shown for saccades made in each of the three fields: superior (0° to +20°); inferior (0° to −20°); and across center (−15° to +15°). Eye position: squares, center gaze; diamonds, 30° of adduction; and triangles, 30° of abduction.

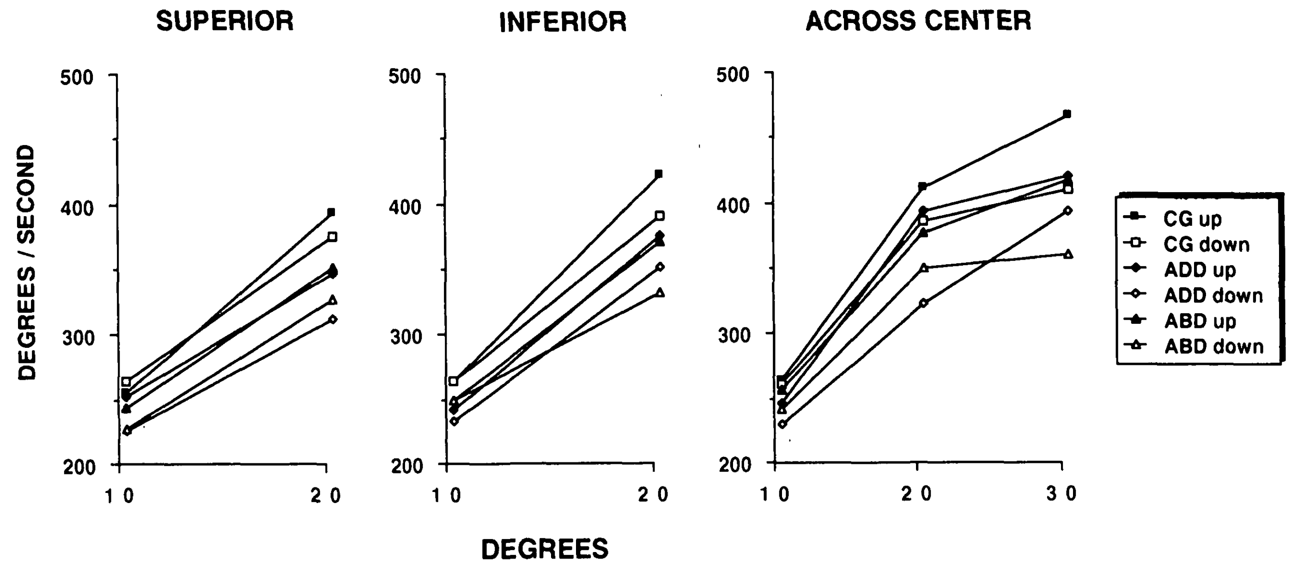

Fig. 2. Mean peak saccadic velocities for patients with superior oblique palsy. Plots show saccadic amplitude (horizontal axis) vs mean peak saccadic velocity (vertical axis). Upward saccades (filled shapes) and downward saccades (hollow shapes) are shown. Separate graphs are shown for saccades made in each of the three fields: superior (0° to +20°); inferior (0° to −20°); and across center (−15° to +15°). Eye position: squares, center gaze; diamonds, 30° of adduction, triangles, 30° of abduction.

With this in mind, we selected a $P = 0.01$ as our level of significance. This level is conservative enough to avoid large numbers of spuriously positive results yet reduces the chance of a type II error to an acceptable level. Any significant results must be interpreted accordingly.

Additionally, paired t-tests were used to determine whether there was a statistically significant difference

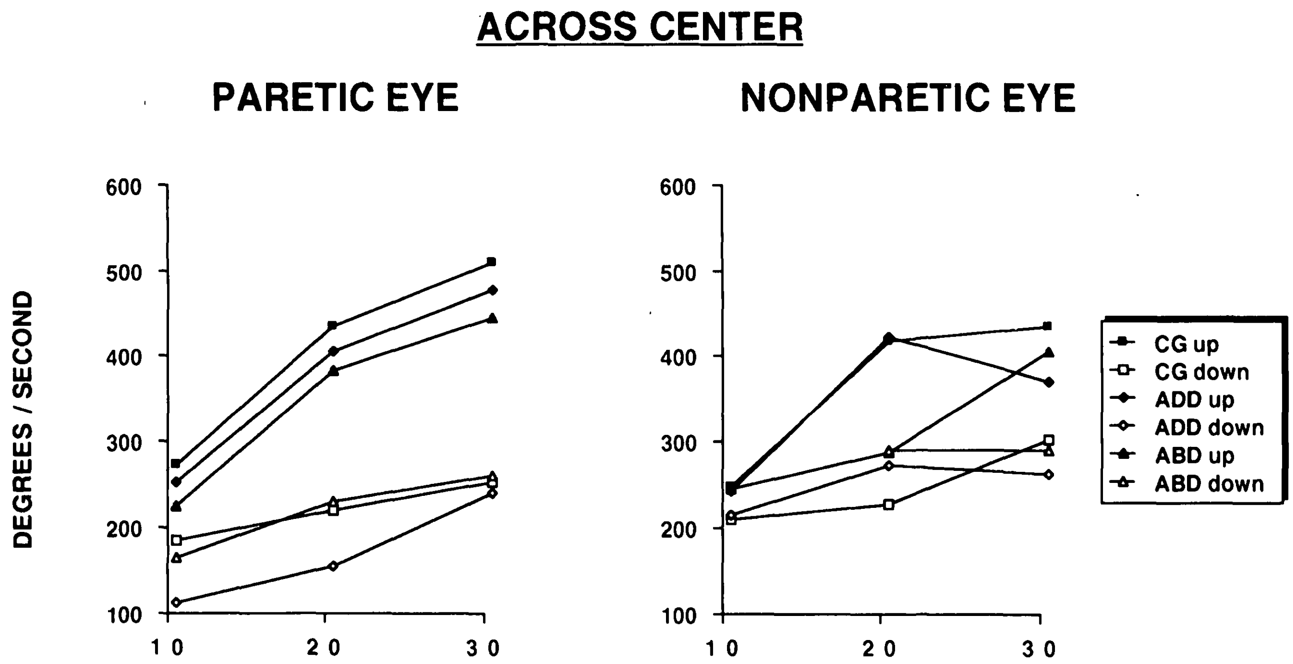

Fig. 3. Mean vertical peak saccadic velocities for one patient with superior oblique palsy and overaction of the inferior oblique. Plots show saccadic amplitude (horizontal axis) vs mean peak saccadic velocity (vertical axis). Upward saccades (filled shapes) and downward saccades (hollow shapes) are shown. All saccades shown were made across center (−15° to +15°). Separate graphs are shown for the paretic and nonparetic eyes. Eye position: squares, center gaze; diamonds, 30° of adduction; triangles, 30° of abduction.

in the peak velocity of equivalent eye movements performed in different orbital fields or positions of horizontal gaze.

In patients with superior oblique palsy, the upward and downward saccades were not statistically different, and no effect of orbital field or position of horizontal gaze was found. Additionally, two sampled t-tests were used to compare equivalent eye movements in patients with superior oblique palsy,jects and normal subjects; no statistically significant differences were found between the two groups. Power of test calculations showed that, given our sample size, we can be at least 80% confident that the statistical tests used would show, at $\alpha = 0.01$, a 99% confidence interval, a difference of at least 1.5 standard deviations in each measure tested, if such a difference were seen.

Examination of the data showed that the two patients with superior oblique palsy who exhibited marked overaction of their inferior oblique muscles showed consistent slowing of their downward saccades. In addition to the affected eye, the nonparetic eye was evaluated in these two subjects. Vertical saccades for one patient in both the paretic and nonparetic eye is shown in Figure 3. The data obtained for the other patient were similar. There was a marked difference between the peak velocity of upward and downward saccades in both the paretic and nonparetic eyes of these subjects. However, the slowing of downward saccades was not as dramatic in the nonparetic eyes.

Discussion

Studies have delineated some of the functions of the superior oblique muscle. Some studies have determined the range of action and the static positional behavior of the eye in instances of superior oblique palsy. The superior oblique muscle is believed to be an intorter in all positions of horizontal gaze, a depressor in adduction, and an abductor in abduction.[8,9] However, there have been no reliable studies establishing the contribution of the superior oblique muscle to vertical saccades.

Two previous attempts were made to study this issue using EOG with skin electrodes.[2,3] In 1977, Rosenbaum and colleagues[3] used the EOG to evaluate peak saccadic velocities in eight subjects with superior oblique palsy and six normal subjects. Measurements were made in center gaze, 20° of adduction, and 20° of abduction. Only movements from center to 20° above center and back to center were measured. The equivalent upward and downward movements were compared in each position of gaze. The authors reported a slowing of the downward saccades, particularly in adduction. In contrast, Metz[2] used EOG to study average vertical saccadic velocities in 18 subjects who had superior oblique palsy. In this study, measurements were made of saccades from 20° above center to 20° below center and back to center. These measurements were repeated in center gaze, 20° of adduction, and 20° of abduction. Nonparetic eyes were used as controls. The Metz study did not show any difference between average velocities of upward and downward saccades. Since the publication of these studies, EOG with skin electrodes has been shown to be inaccurate in measuring velocities of vertical eye movements because of eyelid artifacts that cannot be adequately eliminated by any of the methods of eyelid immobilization.[4,5] This artifact results in an overestimation of the velocity of upward but not the downward saccade. Because of several differences in the method of these two studies and the use of skin electrodes to obtain the EOG measurement, it is difficult to interpret the conflicting results.

Two subjects had marked overaction of the inferior oblique muscle and seemed to yield different results from the other eight subjects who had superior oblique palsy. When their data were examined alone, there appeared to be differences in the peak velocities of upward and downward saccades, both in the paretic and nonparetic eyes. These differences occurred even with occlusion of the paretic eye during testing of the nonparetic eye. These data suggest that overaction of the inferior oblique muscle may result in slowing of downward saccades, and this finding could be explained by either an innervational phenomenon or a mechanical mechanism in both the paretic and nonparetic eyes. Perhaps the most plausible explanation is that some type of central adaptation to avoid diplopia results in a permanent change in the vertical saccadic patterns of the patient. Only further testing of a larger group of subjects with overaction of the inferior oblique muscle will determine whether these conclusions are valid.

The results obtained in our study show that there is no difference in the peak saccadic velocity of upward and downward saccades in most patients with superior oblique palsy; this was true in all fields of horizontal positions of gaze. Even with the paretic eye adducted, a position in which the superior oblique muscle acts maximally as a depressor, there was no slowing. On the basis of these results, we believe that the superior oblique muscle does not contribute significantly to the peak velocity of downward saccades. It is possible that by studying a much larger sample of patients with superior oblique palsy, a small difference could be detected; however, this difference is unlikely to be of clinical use.

Key words: superior oblique palsy, fourth cranial nerve palsy, vertical saccades, eye movement, magnetic search coil

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