Pergamon

PII: S0042-6989(97)00067-9

Vision Res., Vol. 37, No. 19, pp. 2801–2812, 1997
© 1997 Elsevier Science Ltd. All rights reserved
Printed in Great Britain
0042-6989/97 $17.00 + 0.00

Quantitative Perimetry under Binocular Viewing Conditions in Microstrabismus

M. V. JOOSSE,*§ H. J. SIMONSZ,* H. M. VAN MINDERHOUT,* P. T. V. M. DE JONG,‡ B. NOORDZIJ,* P. G. H. MULDER†

Received 18 October 1994; in revised form 11 January 1996

In order to elucidate the type, size and depth of suppression scotomata in microstrabismus and small angle convergent strabismus, we performed binocular static perimetry in 14 subjects with strabismus and four normal observers. The strabismic cases had an objective angle of convergent squint between 1 and 8 deg, visual acuity between 0.1 and 1.25, and limited stereopsis. During testing the subjects fused pictures on two Friedmann visual field analyzers. Right and left eyes were studied separately under both monocular and binocular viewing conditions. In five strabismics a suppression scotoma was found in the squinting eye, with a diameter of 5–30 deg and a depth ranging from 4 to 14 dB. No suppression scotomata could be detected in the nine other subjects nor in the four normal observers. In conclusion, only 36% of subjects with strabismus were found to have a suppression scotoma. These scotomata were centered around the fixation point of the squinting eye, in some cases also encompassing the foveal area, and varying in depth and size. © 1997 Elsevier Science Ltd

Microstrabismus Visual fields Esotropia Perimetry Suppression scotoma

---

INTRODUCTION

It is still not exactly known how strabismic patients perceive the surrounding world. They may suffer from diplopia, confusion, or both. Diplopia is the subjective perception of two identical images next to each other, that arises when an image is projected simultaneously on the fovea of the fixating eye and on an eccentric point of the retina of the squinting eye. The eccentric point in the squinting eye onto which the foveal image of the fixating eye projects under binocular viewing conditions will be called its fixation point. This eccentric location of the fixation point occurs solely under binocular viewing conditions and should not be confused with eccentric fixation, that is seen strictly under monocular viewing conditions in an amblyopic eye. Confusion is the subjective perception that arises when different images are presented to the fovea of the fixating eye and the fovea of the deviating eye. However, it is commonly agreed that patients with early-onset convergent strabismus do not suffer from diplopia or confusion because of two compensatory mechanisms: suppression and anomalous retinal correspondence (ARC). Suppression of the image of the strabismic eye occurs in the form of a suppression scotoma under binocular viewing conditions exclusively. This scotoma is mainly located in the central part of the visual field of the strabismic eye (Harms, 1938).

ARC is the cortical adjustment in directional values supplied by the retinal elements in strabismic eyes. It permits fusion of similar images projected onto non-corresponding retinal areas by object points peripheral to the area of conscious regard (Parks, 1990). Functionally, ARC can be described as an internal compensation mechanism for external (ocular) squint. Recent work by Sireteanu & Fronius (1989) confirmed the clinical observation that in comitant strabismus ARC is present in the peripheral visual field, whereas the central visual field is more likely to show suppression.

Two types of suppression scotomata have been described: a central scotoma and a fixation-point scotoma. A central scotoma is characterized by the fact that the fovea of the squinting eye is the center of the scotoma, while a fixation-point scotoma is centered around the fixation point of the squinting eye. Both scotomata solely occur under binocular viewing conditions and disappear under monocular viewing conditions.

The first report on suppression scotomata in strabismus was performed by Bielschowsky (1900), who used dissociation by mirrors. He found that the central part of the visual field was predominantly perceived by the

---

*Department of Ophthalmology, University Clinic Dijkzigt, Rotterdam, The Netherlands.

†Department of Epidemiology and Biostatistics, Erasmus University Rotterdam, Rotterdam, The Netherlands.

‡The Netherlands Ophthalmic Research Institute, Department of Ophthalmology, Academic Medical Center, Amsterdam, The Netherlands.

§To whom all correspondence should be addressed at: Department of Ophthalmology, Westeinde Hospital, Lijnbaan 32, 2501 CK The Hague, The Netherlands.

fixating eye. Travers (1938) found an absolute, circularly shaped fixation-point scotoma in the squinting eye of esotropes.

Harms (1938) was the first to use dissociation with red and green glasses for the measurement of suppression scotomata. He found a large fixation-point scotoma and a smaller central scotoma in a group of esotropes with an angle of squint larger than 6 deg. In small angle (<6 deg) esotropes he did not find suppression. Using a synoptophore, Lang (1973) found scotomata of varying size around the fixation point in the deviating eye of microstrabismic patients. In 1981, Sireteanu and Fronius showed with red–green perimetry in esotropes, that there was suppression of the area that extended from the central to the nasal retina. In 1982, Sireteanu found that esotropes with alternating fixation had temporary suppression in the region centered around the fixation point of the squinting eye. However, depth perception was intact in the far periphery of the binocularly perceived part of the visual field. Mackensen (1959) and Pratt-Johnson & MacDonald (1976) measured suppression in esotropes using polarizing filters. Where Mackensen found both a fixation-point scotoma and a central scotoma in the squinting eye, Pratt-Johnson found a less well-defined large area of suppression in the non-fixating eye.

Herzau (1980) compared various methods of binocular perimetry for the measurement of suppression scotomata. He found a difference in size of the scotomata between the different methods of dissociation between the eyes. In addition, reproducibility varied greatly between methods. With all methods a fixation-point scotoma could be found in patients with esotropia. The only quantitative measurements of depth of suppression were made by Herzau (above-mentioned paper) and Schuy (1987) with a method of profile perimetry using phase difference haploscopy. With this device dissociation is achieved with propellors rotating in a different phase for each eye (Aulhorn, 1966).

The aim of this paper is to address the following questions. Do microstrabismic and small angle esotropic patients have a suppression scotoma under natural viewing conditions and if so, what is the size and depth and nature of this scotoma? Is it a central scotoma, a fixation-point scotoma or is it a combination of both?

SUBJECTS AND METHODS

The characteristics of 14 subjects with micro- and small-angle convergent strabismus (mean age 26 yr), as well as of four normal observers are given in Table 1. All subjects had a standard ophthalmic exam including measurement of best corrected Snellen visual acuity, slit-lamp examination and indirect fundus examination after pupillary dilatation. The standard orthoptic examination consisted of: cover test, 15 and 4 D prism test, measurement of subjective and objective angle of deviation with the synoptophore and prism-cover test at 40 cm and at 6 m, testing of stereopsis with the Titmus fly test and TNO random dot stereopsis tests, Bagolini striated glass test (Bagolini, 1958) and determination of fixation with direct fundus examination (Cueppers visuscope). Ten subjects (cases 3–5, 7 and 9–14) had microstrabismus according to Lang's definition (Lang, 1968), i.e., convergent squint with an objective angle of squint of less than 5 deg and ARC. Four subjects (cases 1, 2, 6 and 8) had a slightly larger angle of convergent squint (up to 8 deg). All subjects had either suppression of the central part of the streaks or partial suppression of the streaks in the squinting eye with Bagolini's striated glasses; suppression of the central part of the streaks on the Bagolini glasses corresponds to a fixation-point scotoma. All subjects had reduced stereopsis, and in all the random dot test was negative. In 11 cases only the Titmus fly stereopsis test was positive. In three cases no stereopsis could be found with standard stereoscopic tests. Four cases had an anisometropia of two or more diopters of spherical equivalent. Subjects 11 and 12 were homozygous twins (note: no DNA tests were performed) and cases 13 and 14 sisters. All subjects or their legal representatives gave their informed consent to participate in the study. The parents of subjects under 18 yr were in the room during the whole test procedure.

Four normal control observers, between 30 and 32 yr, were tested once for each eye under monocular as well as under binocular viewing conditions. Normal observer No. 1 was tested three times on separate days, to determine the reliability of our test results. In this person we performed an analysis of variance with random effects.

Two Friedmann visual field analyzers, designed for static perimetry of the central visual field, each operated by one investigator, were used. Normally, with the Friedmann visual field analyzer two, three or four simultaneous light stimuli can be presented in various patterns (line, triangle or square) to the subject on a black screen, while the subject looks at the central fixation point. During perimetry the subject is asked, after presentation of each stimulus pattern, which flash lights he has seen. The examiner plots these points on a standard form.

For our experiment the black surface of the two field analyzers was modified by mounting identical pictures (penguins in a polar landscape), with a blue fixation dot in the center on the black screen, leaving the original holes in the screens open. The field analyzers were placed facing each other at a distance of 90 cm, with two surface-silvered mirrors halfway in between them. These mirrors were positioned at an angle of approximately 45 deg toward the Friedmann screens and angled approximately 90 deg relative to each other with their edges joining in front of the subject. The subject sat with her/his head in a chin-rest with the frontal plane parallel to the imaginary line connecting the centers of the Friedmann field analyzers (Fig. 1). During testing the subjects wore their full spectacle correction in spherical equivalent, with reading addition according to age for subjects 7 and 10, who were over 40 yr.

The test person was asked to adjust the mirrors

TABLE 1. Characteristics of the 14 cases and 4 control subjects

Case No.	Age (yr)	Sex	Eye	VA	Refraction	Fixation	Squint type	Bagolini	Stereopsis Titmus fly	Obj./subj. Squint angle		Diagnosis/history
Case 1	32	M	R	0.8	−0.75 = −2 × 160	fovea	esotropia L	tot. supp. L	neg.	6 deg	0–10 deg	Conv. strab. surgery at 3 failed occl. ther.
			L	0.1	−2.0	2 deg nas						
Case 2	26	M	R	1.25	+2.5 = −1.0 × 180	fovea	esotropia R		pos.	8 deg	5 deg	Acc. conv. strab. occl. and glasses at 3
			L	1.25	+2.0	fovea						
Case 3	33	M	R	0.32	+4.0 = +1.5 × 70	1 deg nas	microstr. R	part. supp. R	pos.	4 deg	4 deg	Prim. microstrab., no occl., sec. div., surg at 32, microstrab.
			L	1.0	plano	fovea						
Case 4	27	F	R	1.25	plano	fovea	microstr. R	centr. supp. R	pos.	4 deg	4 deg	Prim. microstrab., no occl.
			L	1.0	plano	0.2 deg nas						
Case 5	26	M	R	1.0	plano	fovea	microstr. R	centr. supp. R	pos.	4 deg	4 deg	Conv. strab. surgery at 4 occl. at 3
			L	1.0	plano	fovea						
Case 6	43	M	R	1.25	−4.5	fovea	esotropia L	centr. supp. L	pos.	6 deg	6	Prim. conv.strab., no occl. ther., glasses at 4
			L	0.4	−5.0	0.5 deg nas						
Case 7	36	M	R	0.4	+7.5 = −1.5 × 180	0.5 deg nas	microstr. R	part. supp. R	neg.	4	<1 deg	Conv.strab., surgery at 4 failed occl. ther.
			L	1.25	+4.5	fovea						
Case 8	24	M	R	1.6	plano	fovea	esotropia L.	centr. supp. L	neg	8 deg	6 deg	Prim. conv. strab., occl. at 3
			L	1.0	plano	0.2 deg nas						
Case 9	41	F	R	1.0	+5.0	fovea	microstr. R	centr. supp. R	pos.	5 deg	<1 deg	Acc. conv. strab. occl. and glasses at 3
			L	1.25	+5.0	fovea						
Case 10	12	M	R	1.25	+2.25	fovea	microstr. L	centr. supp. L	pos.	2 deg	<1 deg	Acc. conv. strab. occl. and glasses at 3
			L	1.25	+3 = −0.5 × 180	fovea						
Case 11	12	F	R	1.0	plano	fovea	microstr. L	centr. supp. L	pos.	1 deg	1 deg	Prim. microstrab., glasses at 11
			L	0.5	+3.0	0.5 deg sup						
Case 12	12	F	R	1.25	plano	fovea	microstr. L	centr. supp. L	pos.	1 deg	<1 deg	Prim. microstrab., glasses at 11
			L	0.4	+2.0	0.5 deg sup						
Case 13	15	F	R	0.8	plano	fovea	microstr. R	centr. supp. R	pos.	1 deg	<1 deg	Prim. microstrab., no occl. ther.
			L	1.0	plano	fovea						
Case 14	17	F	R	1.0	−1.0	fovea	microstr. L	centr. supp. L	pos.	1 deg	<1	Prim. microstrab., occl. and glasses at 4
			L	1.0	−1.0	fovea						
Control 1	32	F	R	1.0	−2.0	fovea	orthotropic	pos				
			L	1.0	−2.0	fovea						
Control 2	32	M	R	1.2	−0.5	fovea	orthotropic	pos.				
			L	1.2	plano	fovea						
Control 3	31	M	R	1.0	plano	fovea	orthotropic	pos.				
			L	1.0	plano	fovea						
Control 4	32	F	R	1.0	plano	fovea	orthotropic	pos.				
			L	1.0	plano	fovea						

M, male; F, female; R, right eye; L, left eye; VA, visual acuity; Bagolini, Bagolini striated glasses test; Stereopsis, Titmus fly test. Angle obj./subj., objective and subjective angle of squint as measured with synoptophore; strab., strabismus; conv., convergent; acc., accommodative; occl., occlusion.

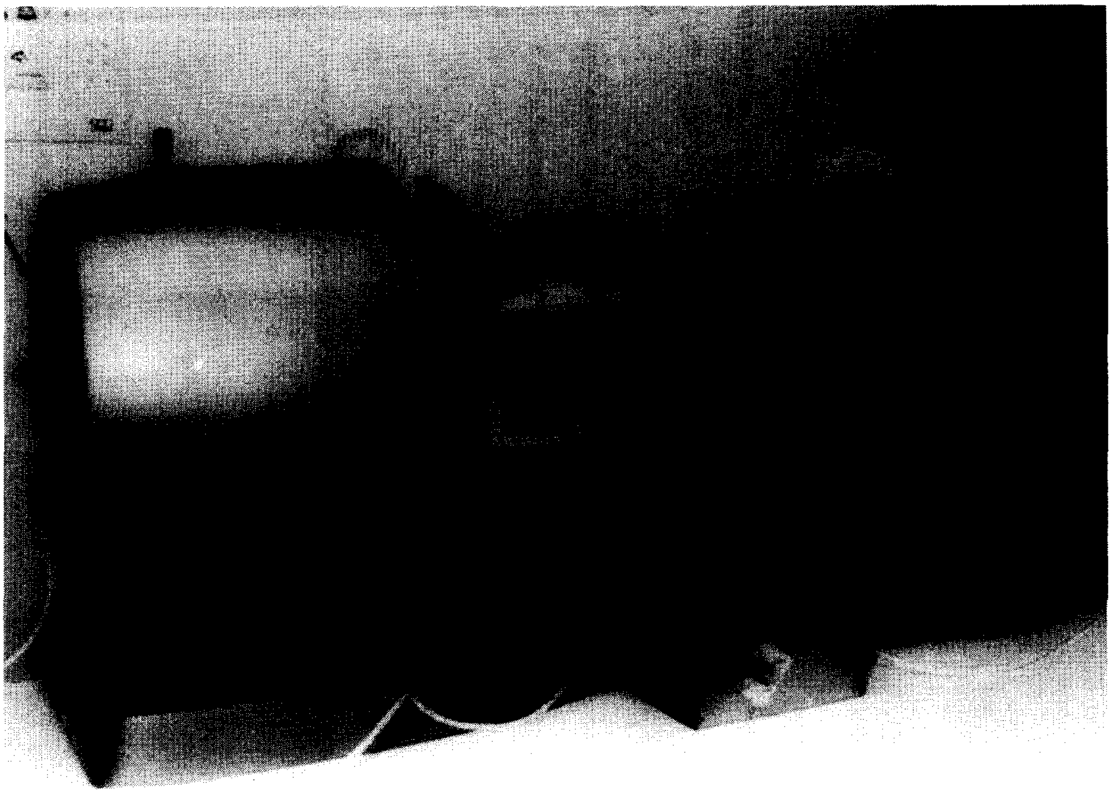


FIGURE 1. Picture of the test set-up consisting of two Friedmann visual field analyzers opposite each other, with identical pictures of penguins in the snow on their surface. The subject's head is positioned in the middle of the field analyzers. Via two mirrors angled at 45 deg the subject can fuse the two screens.

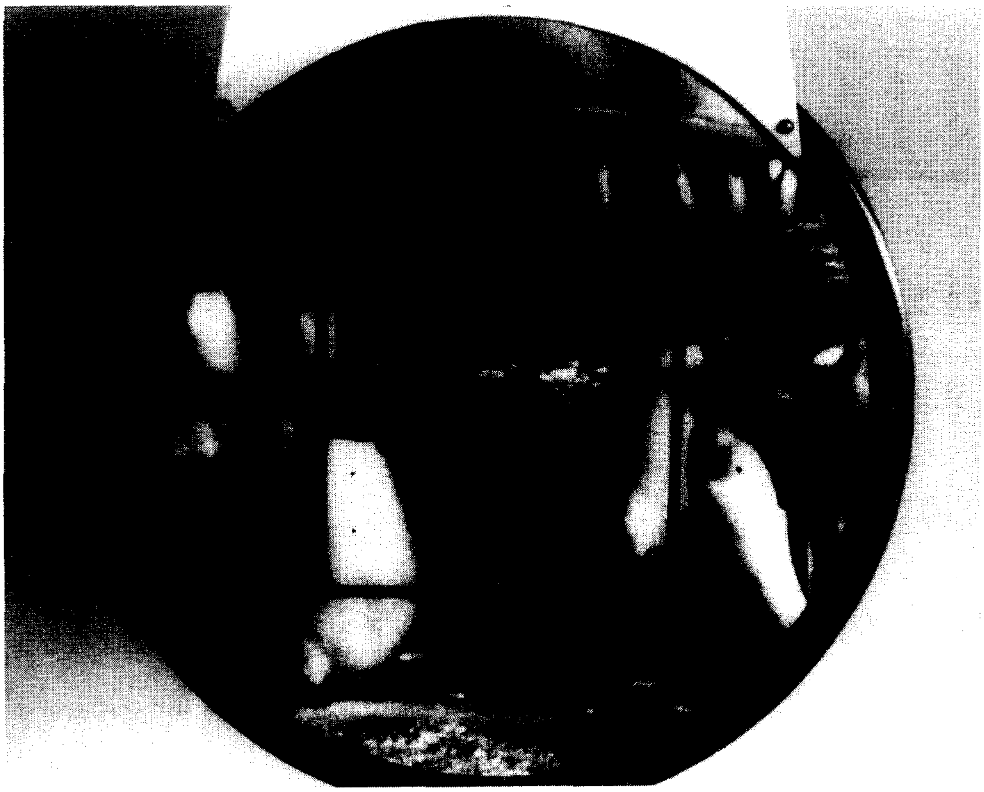


FIGURE 2. Picture of one of the test screens, with a black square drawn on the picture to indicate the square of the visual field of 25 deg vertically by 20 deg horizontally, as shown in Figs. 4–9. In the left eye the label "Left" indicates the temporal side of the visual field and in the right eye the nasal side of the visual field. In Figs. 4–9 this left side is indicated on the y-axis. "Down" indicates the bottom of the visual field and is shown in Figs. 4–9 on the x-axis.

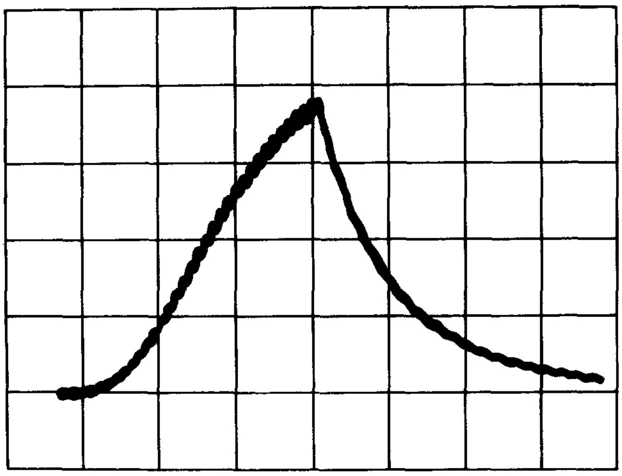


FIGURE 3. Oscilloscopic record of luminance level of a standard stimulus as produced by the halogen light in the perimeters. Horizontal axis: units of 100 msec. Vertical axis: arbitrary luminance units.

horizontally and vertically so that the images of both perimeter surfaces were fused, i.e., so that the subjective angle of squint was compensated and single vision was obtained. Note, that the images were fused mainly in the periphery. The circular screen covered by the pictures subtended 50 deg of arc. However, only a square of 25 deg by 25 deg in the center of the field analyzers could be seen, owing to the size and placement of the mirrors Fig. 2. On monocular cover-testing of the non-strabismic eye, a movement of the deviating eye occurred that approximately equaled the angle of ARC. During testing under binocular viewing conditions, the orthoptist regularly performed unilateral cover testing to check if the angle of strabismus remained constant throughout the session.

We substituted the flash light in the Friedmann field analyzers by a halogen light, because a flash light presented suddenly to an eye tends to shift attention to this eye and thus will break suppression. Voltage over the halogen light was switched on for a standardized period of 0.3 sec, leading to a gradual increase and decrease of luminance both lasting for approximately 0.3 sec (Fig. 3).

Time between light presentations was at least 3 sec. The room lights were lowered so that the mean luminance of the screens was 5 apostilbs. A standard test session would begin by testing each eye monocularly. During monocular testing the subject was asked to look with one eye via the homolateral mirror at the corresponding Friedmann screen while the other eye was occluded with a white, non-translucent eye patch. This procedure was performed for both eyes separately. Testing was always begun at the lowest luminance level with a 22 dB filter, an average 4 dB below the central threshold, presenting the central stimuli first, followed by the more peripheral stimuli. Stimulus luminance was increased by steps of 2 dB. Stimuli were presented for three times at most, or less when seen. The final test run was performed with both eyes open with stimuli presented either to the right or to the left eye, while the subject fused both polar landscapes. Again, stimuli were presented three times at most for every stimulus position at each luminance level. During this binocular test-run it was difficult for the subject to know to which eye stimuli were presented, since binocular single vision of the surface pictures was maintained. As handling the perimeters was audible, the operators would make clear and audible adjustments to both perimeters simultaneously, whereas actually stimuli were only presented to one eye at a time.

We determined the net suppression in the deviating eye by subtracting the results under binocular viewing conditions from those obtained under monocular viewing conditions. However, this procedure is slightly flawed as during monocular viewing conditions the fovea of the squinting eye fixates the center of the screen, whereas under binocular viewing conditions it is slightly off center, because there is peripheral fusion. In an attempt to make a somewhat valid subtraction we adjusted for the shift in projection of the visual axis between the two viewing conditions by shifting the field results obtained under binocular viewing conditions in a temporal direction by the amount of degrees of the objective squint angle minus the angle of eccentric fixation. Since our field resolution was about 2.5 deg, we subtracted only those points that were within 1.25 deg of each other. If by the shift a column of data points would fall outside the tested field by more than 1.25 deg we would take the sensitivity level of the nearest available data point.

RESULTS

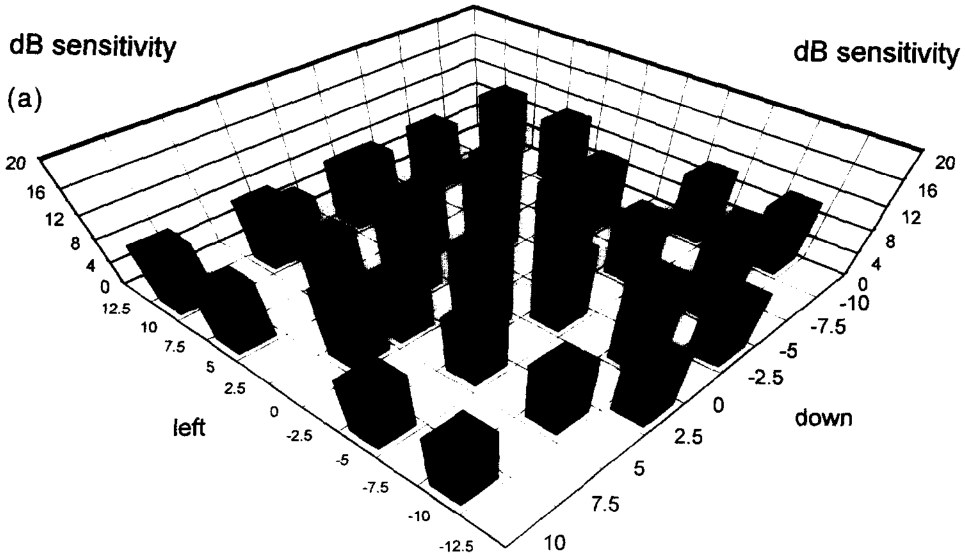
In our four control subjects we found that sensitivity levels for testing under both monocular and binocular viewing conditions ranged between 16 and 20 dB on average. The difference between the results during binocular and monocular viewing conditions was no

TABLE 2. Description of the scotomata found in cases 1, 5, 7, 10 and 11

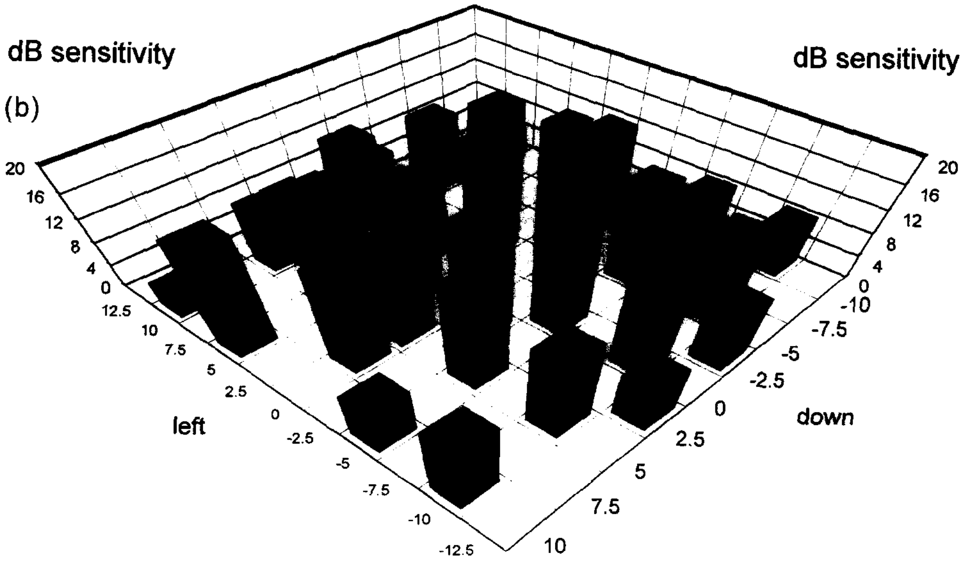
		Scotoma under binocular viewing conditions					
Case No.	Squint eye	Eye	Radius	Depth	Type	Foveal projection	Remarks
Case 1	L	L	2 deg	14 dB	fix.p.	L 6 deg N	
Case 5	R	L	5 deg	4 dB	fix.p.	L 4 deg N	strabismus R, supp. L
Case 7	R	R	7.5 deg	6 dB	comb.	R 4 deg N	
Case 10	L	L	5 deg	4 dB	fix.p.	L 2 deg N	
Case 14	L	L	> 25 deg	4 dB	comb.	L 1 deg N	

R, right eye; L, left eye; N, nasal; dB, decibel; fix.p., fixation-point scotoma; comb., combination of fixation-point and central scotoma.

Case 1, field of left eye during monocular vision



Case 1, field of right eye during monocular vision



Case 1, field of left eye during binocular vision

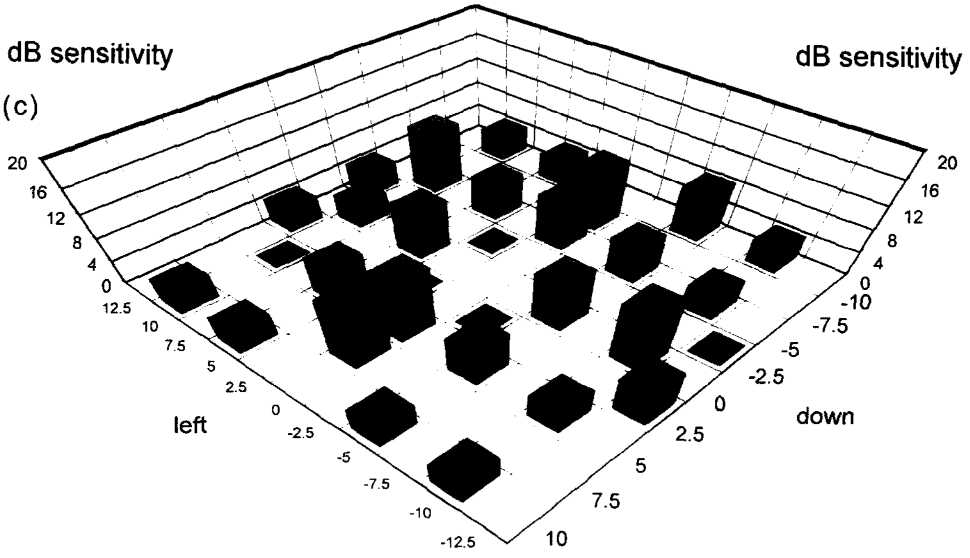
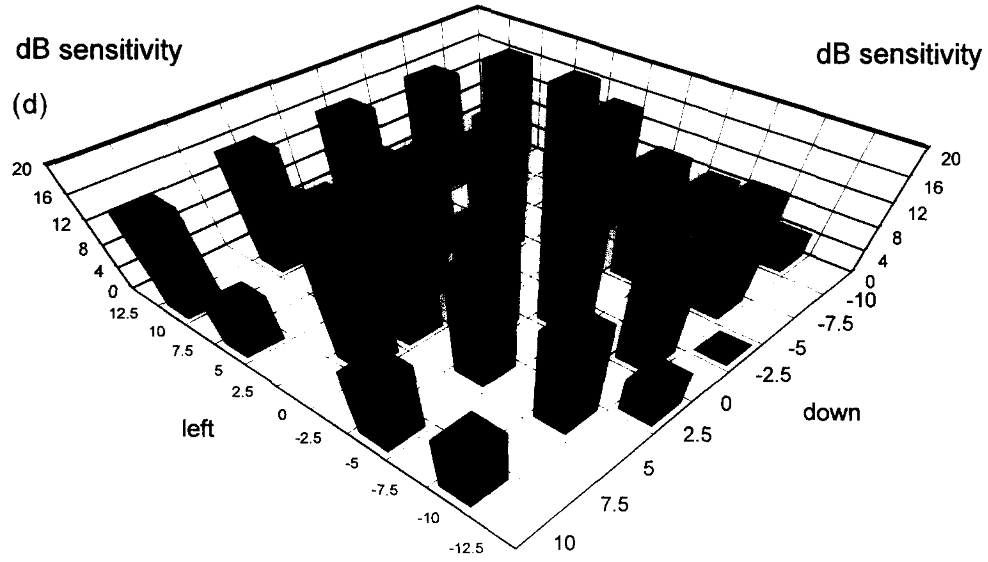
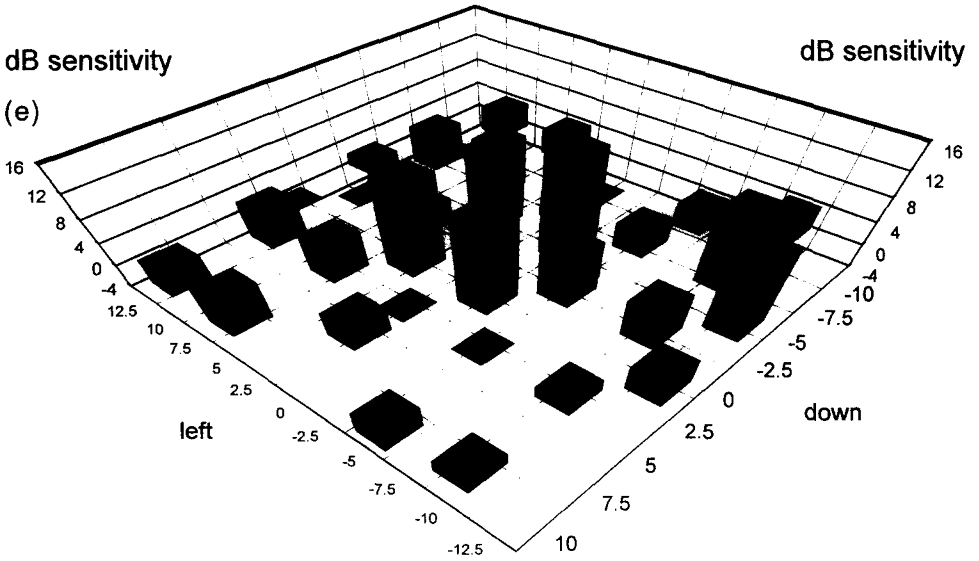


FIGURE 4—*continued opposite.*

Case 1, field of right eye during binocular vision



Case 1, suppression of left eye during binocular vision



Case 1, suppression of right eye during binocular vision

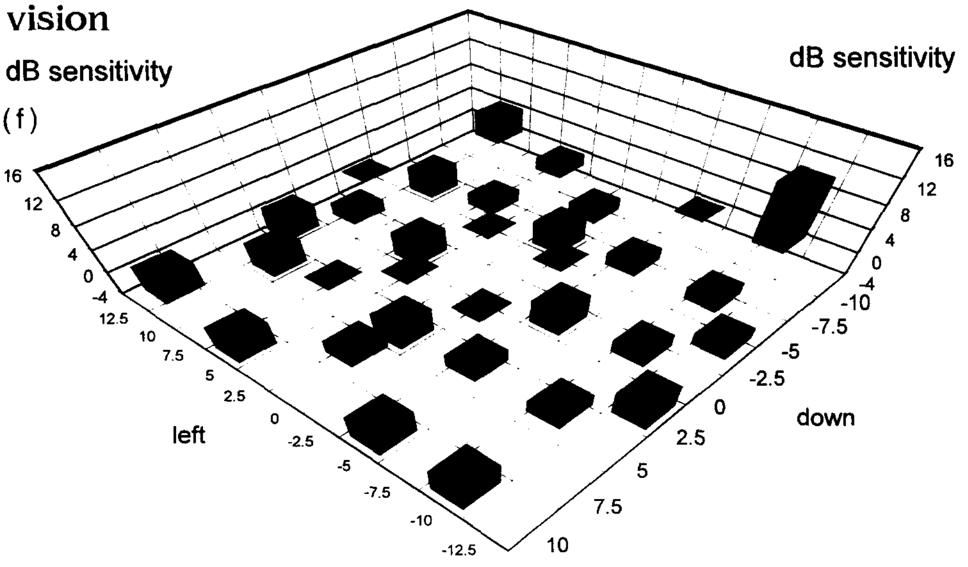


FIGURE 4—*caption overleaf.*

greater than 2 dB in this control group and thus there was no detectable pattern of suppression in these cases. In the control subject that was tested three times we performed an analysis of variance with random effects. We found an average variance of 1.39 for each field position for each viewing condition for each eye, leading to an average variance in difference between monocular and binocular viewing conditions for each eye of $2 \times 1.39 = 2.78$. Averaging across 32 field positions led to a variance in difference between monocular and binocular viewing conditions of $2 \times 1.39/32 = 0.087$ (standard deviation 0.3). Per field position, per eye the variance of the difference between monocular and binocular testing was 2.78. The standard deviation (SD) was $2.78 = 1.67$. We considered a difference to be significant if it was larger than 2 SD in absolute sense, meaning larger than $2 \times 1.67 = 3.34$, which, in our device with steps of 2 dB, is a difference of 4 dB or more per field position. Thus, we defined an area of suppression as a cluster of points in the visual field where the difference between sensitivity measured under binocular viewing conditions and monocular viewing conditions was 4 dB or more.

In five subjects (subjects 1, 5, 7, 10 and 14) we found, during testing under binocular viewing conditions, a circularly shaped suppression scotoma centered around the fixation point, the foveal projection of the fixating eye in the deviating eye. The test results of these five subjects are summarized in Table 2. The relative depths of these scotomata ranged from 4 to 14 dB, and their radii varied from 2.5 to 15 deg. In one subject (subject 5) we did not find a suppression scotoma in the deviating eye, but to our amazement we found a scotoma around the fixation point (fovea) of the fixating eye. In the nine other subjects (subjects 2, 3, 4, 6, 8, 9, 11, 12 and 13) we did not find a suppression scotoma. The monocular visual fields of all cases were normal.

We will give more detailed information on subjects 1, 5, 7, 10, 11, 12, 13 and 14 below.

In subject 1 we found a deep, small circularly shaped scotoma around the fixation point of the left eye under binocular viewing conditions (Fig. 4). Depth was 14 dB and the radius of the deep central part of the scotoma was 2 deg. Please note that the fovea of the left eye was projected 6 deg nasally to the center of the scotoma (fixation point).

Subject 5 had a 4 deg microstrabismus of the right eye. Surprisingly, we found a circularly shaped fixation-point scotoma for the left eye with a depth of 4 dB and radius of 5 deg (Fig. 5). In subject 7 we found a circularly shaped fixation point scotoma with an average depth of 6 dB and a radius of 7.5 deg in the right eye under binocular test conditions. The fovea of the right eye was positioned 5 deg nasally to the center of the scotoma (Fig. 6). Subject 10 showed a circularly shaped fixation-point scotoma with a central depth of 4 dB and a radius of 5 deg in the left eye under binocular test conditions (Fig. 7).

In subjects 2, 3, 4, 6, 8, 9 and 12 there was no significant indication for the existence of a suppression scotoma or any other pattern of suppression.

In subject 11, homozygotous twin sister of subject 12, we found a slight and not significant overall reduction of sensitivity of 2 dB on average in the left eye under binocular viewing conditions. Subject 13 showed also a not significant overall reduction of sensitivity of 2 dB on average, in the squinting eye under binocular conditions.

In the left eye of subject 14 we found an overall reduction of sensitivity, 4 dB on average, under binocular conditions (Fig. 8).

DISCUSSION

In this study we detected a suppression scotoma, centered around the fixation point of the squinting eye in five out of 14 subjects with microstrabismus and small-angle strabismus. In three of these cases we could find only a fixation-point scotoma under binocular viewing conditions. However, in two subjects (subjects 7 and 14) the scotoma was large enough to include both the fixation

FIGURE 4 (*see pp. 2806–2807*). (a) Case 1. Central 25 by 20 deg of visual field of squinting left eye under monocular viewing conditions. The *z*-axis indicates the sensitivity level in decibels.The height of each bar indicates the sensitivity level for each different stimulus position on the Friedmann visual field analyzer. Here central sensitivity is 18 dB. Sensitivity ranges from 4 to 20 dB. The bars become darker with decreasing sensitivity. "Left" indicates the temporal side of the visual field of this eye and "Down" indicates down in the visual field. The units for the horizontal (*x*) axis and vertical (*y*) axis are degrees from the fixation point. (b) Case 1. Visual field of non-strabismic right eye under monocular viewing conditions. "Left" indicates here the nasal side of the visual field. Sensitivity ranges from 4 to 18 dB. Central sensitivity is 18 dB. (c) Case 1. Visual field of squinting left eye under binocular viewing conditions. Sensitivity ranges here from 0 to 10 dB. Central sensitivity is 0 dB. Note that the fovea is located 6 deg nasally to the center of the field. The fovea of the squinting eye is shifted nasally under binocular viewing conditions because under these conditions (peripheral) fusion on the basis of ARC occurs and thus the fixation point becomes the center of the visual field of the squinting eye. (d) Case 1. Visual field of right eye under binocular viewing conditions. Sensitivity ranges here from 0 to 18 dB. Central sensitivity is 18 dB. (e) Case 1. Result of subtraction of the visual field of left eye under binocular viewing conditions from the field under monocular viewing conditions. (ie. "net" suppression). We ask the reader to place an imaginary horizontal zero dB plane in the graph when reading the subtraction figures. This zero plane was necessary because some outcomes of the subtraction of the binocularly obtained results from the monocularly obtained results had a negative value on the *z*-axis. Note: the more positive the bar, the greater the depth of suppression. The gray bars represent the values greater than 4 dB, i.e., the significant (>4 dB) net suppression (standing bars). The black bars represent the values under 4 dB (either hanging or standing bars). Suppression here reaches 14 dB in the center of the field. Also note that the fovea here again is located 6 deg nasally (right) to the center of the scotoma or the field. To make this subtraction we shifted the results under binocular viewing conditions 4 deg temporally [i.e., objective angle of squint (6 deg) minus angle of eccentric fixation (2 deg)]. (f) Case 1. Result of subtraction of the visual field of the right eye obtained under binocular viewing conditions from the field obtained under monocular viewing conditions.

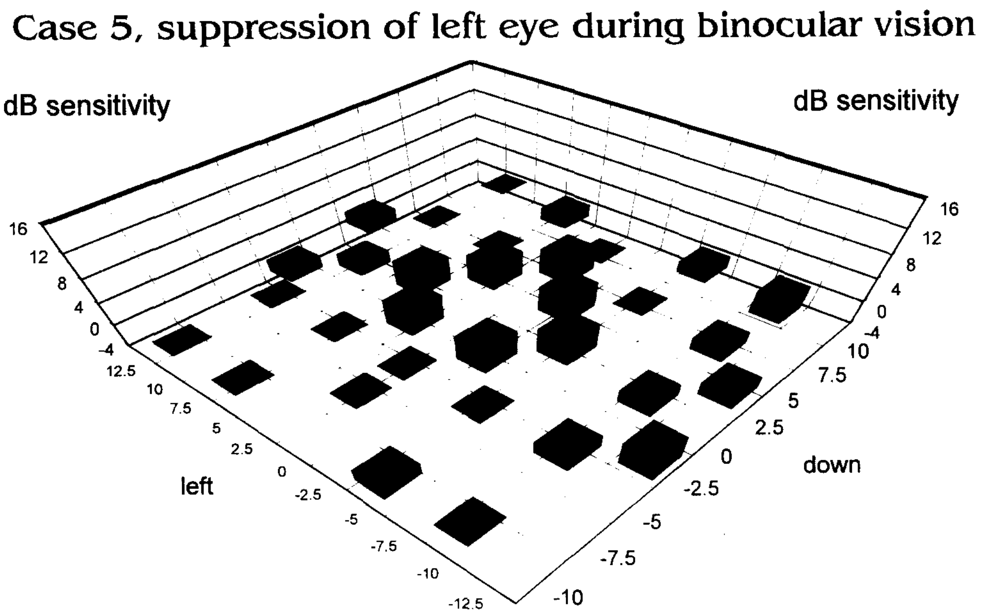


FIGURE 5. Case 5. Subtraction of fields of the left non-strabismic eye. A suppression scotoma of 4 dB is shown. The fovea is located 4 deg nasally (right) to the center of the field. For the subtraction the results under binocular viewing were shifted 4 deg temporally.

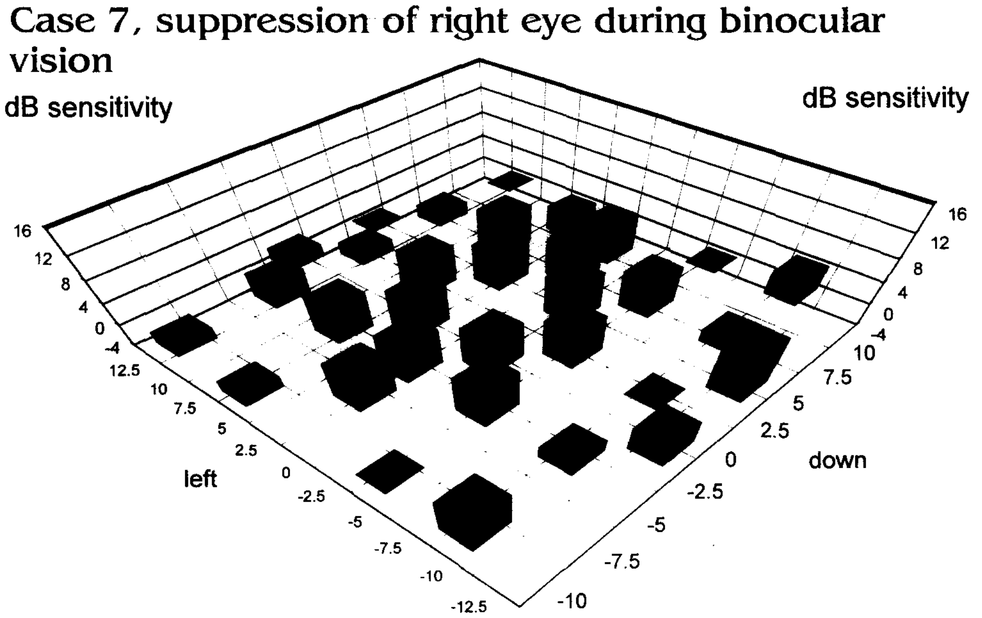


FIGURE 6. Case 7. Subtraction of fields of right microstrabismic eye. Fovea is located 4 deg nasally (left) to the center of the field. For the subtraction the results under binocular viewing were shifted 3.5 deg temporally.

point as well as the fovea of the squinting eye. Here an overlapping central scotoma and fixation-point scotoma might be present. Thus, our results indicate that microstrabismic subjects or subjects with small-angle esotropia do not necessarily have two spatially separated scotomas.

In order to measure suppression at its full extent it is important that the eyes look at identical images. This has also been stated by Jampolski (1955) and Schor (1977), most methods of binocular perimetry have in common that somewhat different images are simultaneously presented to each eye. Examples of these are: colored filters (Travers, 1938; Harms, 1938; Sireteanu & Fronius, 1981; Sireteanu, 1982), polarization filters (Mackensen, 1959; Pratt-Johnson, 1976), phase difference haploscopy (Aulhorn, 1966; Schuy, 1987) and Bagolini's striated glasses (Bagolini, 1958). Bagolini (1976), Herzau (1980), Campos (1982) and Mehdorn (1989) have compared these methods of binocular perimetry. They all agree that the more dissimilarity between the images, the less suppression will be found. Pratt-Johnson (1978) stated that when suppression is measured with more realistic complex patterned stimuli, such as drawings or pictures,

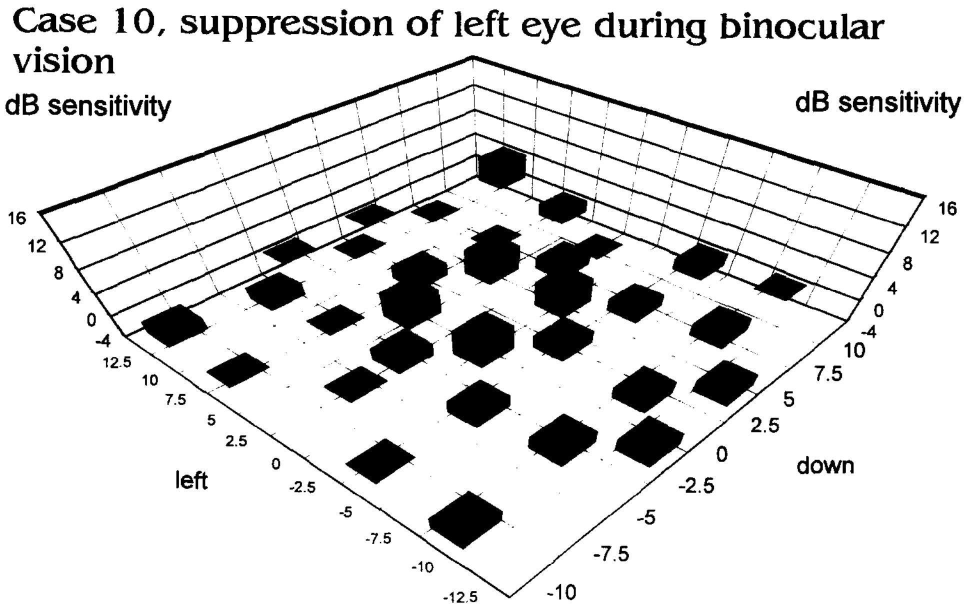


FIGURE 7. Case 10. Subtraction of fields of left microstrabismic eye. Fovea is located 2 deg nasally (right) to the center of the field. For the subtraction the results under binocular viewing were shifted 2 deg temporally.

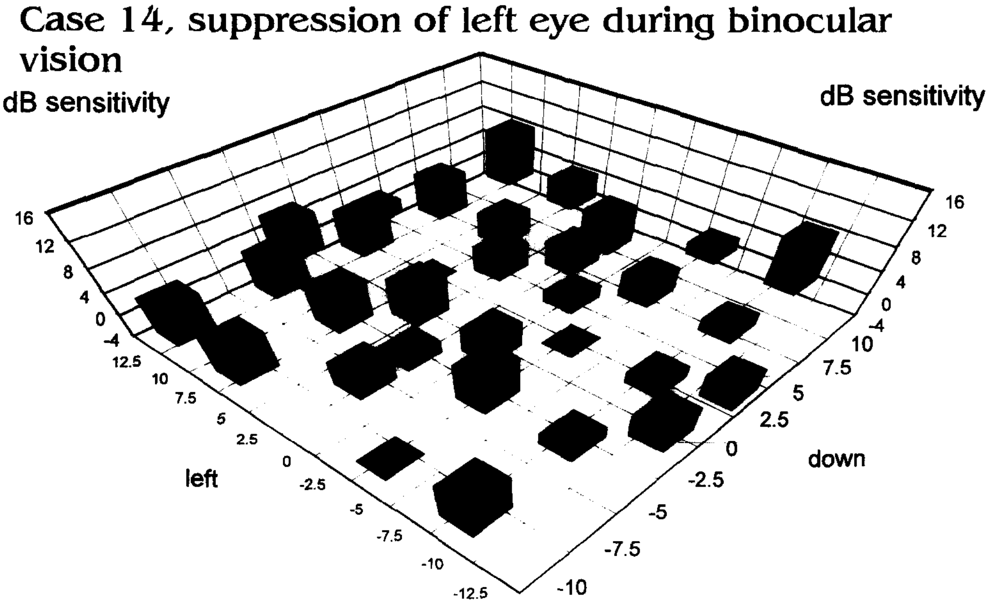


FIGURE 8. Case 14. Subtraction of fields of left microstrabismic eye. Fovea is located 1 deg nasally (right) to the center of the field. For the subtraction the results under binocular viewing were shifted 1 deg temporally.

a much greater likelihood exists of finding suppression at its full extent.

In the measurement of suppression the luminance profile of the stimulus is of great importance. Binocular perimetry employing flash stimuli has the disadvantage that attention is directed to the eye viewing the flash and hence suppression is disrupted. We used a halogen light stimulus that went on and off in a gradual fashion (Fig. 3). In the past decades some studies have been published on the time course of binocular rivalry and suppression (Kaufman, 1963; Wolfe, 1983, 1986; de Belsunce & Sireteanu, 1991). In these studies evidence is given that suppression caused by rivalrous images in normal as well as in amblyopic subjects needs some time to build up. We chose the duration of our light stimuli guided by a study by de Belsunce & Sireteanu (1991). They found that dissimilar images for both eyes, vertical lines for one eye and horizontal lines for the other, shown for periods shorter than approximately 0.1 sec, led to a superimposition of the two images, whereas presenting the images for 0.1–0.5 sec led to suppression. If the competing images were shown for periods longer than 0.5 sec rivalry occurred. This was the reason that we chose a halogen light stimulus with a triangularly shaped luminance pattern, with a base of 600 msec, leading to an effective stimulus lenghth of approximately 300 msec.

We can only speculate on the reasons for the variability in size and depth of the scotomas we have found. It could be that cases with a history of large-angle strabismus, surgically corrected at the age of 3–5 yr following amblyopia treatment, as in cases 1 and 7, have total suppression with Bagolini's glasses and large scotomata with our test set-up. In fact, it is possible that these cases had total suppression of one eye; this cannot be demonstrated with our method since our test field only subtended 25 deg of arc.

Another reason for the large size of the scotomata in subjects 1 and 7 could be anisometropia. There is evidence that subjects with anisometropia have a larger suppression scotoma than subjects with microstrabismus (Hess *et al.*, 1980; Sireteanu & Fronius, 1981). Perhaps the large scotomata in these two subjects are caused by a combined suppression on the basis of both anisometropia and microstrabismus. It is believed by some (Jampolski, 1955; Campos, 1982) that the size of the angle of strabismus correlates with the extent of the suppression scotoma. In subjects 5 and 10 this relationship was found. However, in subject 1 the radius of the scotoma was smaller than the angle of squint; in subjects 7 and 14 the radius of the scotoma was larger than the angle of squint.

Subject 5 had had successful treatment of amblyopia with a central scotoma with Bagolini's glasses for the right eye, whereas we found a small (2.5 deg radius) shallow (4 dB) scotoma in the other, left eye. Our explanation for this discrepancy between Bagolini testing and our test results is that this subject might have fixated with the left eye during Bagolini testing and fixated with the right microstrabismic eye during our test procedure. This change in fixation between both test situations was possible here because of successful amblyopia treatment and resulting alternating fixation.

We do not know exactly why we found suppression scotomata only in 5 of our 14 subjects and not in all. One reason could be that even though in our test situation identical images were seen with both eyes, pure binocular vision was slightly disturbed by the fact that stimuli were only presented to one eye during our testing under binocular viewing conditions.

A second reason might be that some microstrabismic subjects have a suppression scotoma that is too small to be detected with our set-up. Scotomata with a radius of less than 1.5 deg cannot be detected with our modified Friedmann devices, since the most central stimulus points are at 1.5 deg eccentricity. We used Bagolini's striated glasses as a predictor of suppression in the primary screening of our subjects. In microstrabismics a central "hole" in one of the crossed Bagolini streaks correlates with an extremely small part of the visual field, in most cases smaller than the scotomas that can be detected with our method of binocular perimetry. This could be in accordance with the theory that in convergent strabismus ARC occurs in the peripheral visual field and suppression only occurs in the central part of the visual field (Sireteanu & Fronius, 1989). It is surmised, that because the receptive fields are larger in the periphery than in the center of the visual field, and because during early development the receptive fields shrink in size, suppression is needed in the center of the visual field but binocular vision can be maintained in the peripheral visual field leading to ARC (working hypothesis forwarded by Sireteanu, Bielschowsky Gesellschaft Meeting, Heidelberg, October 1992).

A third reason, why we did not find suppression, might be that in some subjects with microstrabismus diplopia is avoided by ARC only, rather than by a combination of suppression in the central visual field and ARC in the more peripheral parts of the binocular visual field (Bagolini, 1976; Campos, 1982; Mehdorn, 1989). This could also explain why some subjects with very shallow suppression of only 4 dB (subjects 10 and 14) did not suffer from diplopia while being devoid of amblyopia.

In this study we present a new method of quantitative binocular perimetry, with which we can measure the extent as well as the depth of suppression. Thus, the three-dimensional "shape" of the suppression scotoma in strabismus can be shown. With this method we found that subjects with micro- and small-angle convergent strabismus have only one scotoma, in all likelihood a fixation-point scotoma.

REFERENCES

Aulhorn, E. (1966). Phasendifferenz-Haploskopie. Eine neue Methode zur Trennung der optischen Eindrücke beider Augen. *Klinische Monatsblätter für Ophthalmologie, 148*, 540.

Bagolini, B. (1958). Tecnica per l'esame della visione binoculare senza introduzione di elementi dissocianti (test del vetro striato). *Bolletino d'Oculisto, 37*, 195.

Bagolini, B. (1976). Sensorial anomalies in strabismus, Part 1. *Documenta Ophthalmologica, 41*, 1–22.

de Belsunce, S. & Sireteanu, R. (1991). The time course of interocular suppression in normal and amblyopic subjects. *Investigative Ophthalmology and Visual Science, 32*, 2645–2652.

Bielschowsky, A. (1900). Untersuchungen über das Sehen der Schielenden. *Albrecht v. Graefes Archives of Ophthalmology, 50*, 406–509.

Campos, E. C. (1982). Binocularity in comitant strabismus: binocular visual field studies. *Documenta Ophthalmologica, 53*, 249–281.

Harms, H. (1938). Ort und Wesen der Bildhemmung bei Schielenden. *Graefes Archives of Ophthalmology, 138*, 149–209.

Herzau, V. (1980). Untersuchungen über das binokulare Gesichtsfeld Schielender. *Documenta Ophthalmologica, 49*, 221–284.

Hess, R. F., Campbell, F. W. & Zimmern, R. C. (1980). Differences in the neural basis of human amblyopias: the effect of mean luminance. *Vision Research, 20*, 295–306.

Jampolski, A. (1955). Characteristics of suppression in strabismus. *Archives of Ophthalmology, 154*, 683–696.

Kaufman, L. (1963). On the spread of suppression and binocular rivalry. *Vision Research, 3*, 401–415.

Lang, J. (1968). Evaluation in small angle strabismus or microtropia. Strabismus Symposium, Giessen, Karger, Basle, pp. 219–222.

Lang, J. (1973.) Mikrostrabismus. Bücherei des Augenartztes Nr. 62. Enke, Stuttgart.

Mackensen, G. (1959). Monoculare und binoculare statische Perimetrie zur Untersuchung der Hemmungsvorgänge beim Schielen. *Graefes Archives of Ophthalmology, 160*, 573–587.

Mehdorn, E. (1989). Suppression scotomas in primary microstrabismus—a perimetric artefact. *Documenta Ophthalmology, 71*, 1–18.

Parks, M. M. (1990). Binocular vision adaptations in strabismus. In Tasman, W. & Jaeger, E. A. (Eds), *Duanes clinical ophthalmology* (Vol. 1, Ch. 8, pp. 1–7). Philadelphia: J. B. Lippincott.

Pratt-Johnson, J. A. & MacDonald, A. L. (1976). Binocular visual field in strabismus. *Canadian Journal of Ophthalmology, 11*, 37–41.

Schor, C. M. (1977). Visual stimuli for strabismic suppression. *Perception, 6*, 583–593.

Schuy, K. (1987). Binokulare statische Perimetrie und räumliches Sehen bei Patienten mit Microstrabismus und Normalpersonen mit künstlicher einseitiger Visusherabsetzung. Inaugural-Dissertation, Giessen.

Sireteanu, R. (1982). Binocular vision in strabismic humans with alternating fixation. *Vision Research, 22*, 889–896.

Sireteanu, R. & Fronius, M. (1981). Naso-temporal asymmetries in human amblyopia: consequence of long-term interocular suppression. *Vision Research, 21*, 1055–1063.

Sireteanu, R. & Fronius, M. (1989). Different patterns of retinal correspondence in the central and peripheral visual field of strabismics. *Investigative Ophthalmology and Visual Science, 30*, 2023–2033.

Travers, T. (1938). Suppression of vision in squint and its association with retinal correspondence and amblyopia. *British Journal of Ophthalmology, 22*, 577–604.

Wolfe, J. M. (1983). Influence of spatial frequency, luminance, and duration on binocular rivalry and abnormal fusion on briefly presented dichoptic stimuli. *Perception, 12*, 447–456.

Wolfe, J. M. (1986). Briefly presented stimuli can disrupt constant suppression and binocular rivalry suppression. *Perception, 15*, 413–417.

Acknowledgements—We wish to thank Prof. Dr G. Kommerell of the University Eye Clinic, Freiburg, Germany and Dr G. H. Kolling of the University Clinic, Heidelberg, Germany for their helpful comments in the early stages of this study. We are very grateful to Prof. Dr R. G. Boothe, Yerkes Primate Research Center of Emory University, Atlanta, Georgia, U.S.A. for his critical analysis of both text as well as content of the final version of the manuscript.