Studies on the Function of the Checkerboard Pattern Stimulator: Analysis of Ocular Positions During Stimulation

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Purpose: To analyze the effectiveness of the checkerboard pattern stimulator (CPS) in facilitating stereopsis in patients with acquired esotropia.

Methods: Fourteen patients were treated with checkerboard pattern stimulation following surgical correction of the ocular alignment. In order to determine the cause of the difference in the effectiveness of CPS on exotropes and esotropes, a separate study was carried out on 15 subjects: 5 orthophores, 5 exophores, and 5 esophores.

Results: Eight of the 14 patients achieved stereopsis; the remaining 6 cases did not show marked improvement in stereoacuity. The CPS was more effective on exotropes, as reported previously, than on esotropes ($P = 0.047$, χ^2 test). By recording the ocular positions of the 15 subjects in the separate study, we found a tendency toward exodeviation in the orthophoric and exophoric subjects but not in esophoric subjects.

Conclusions: Our results suggest that CPS develops sensory fusion by providing an identical pattern simultaneously to the foveas of both eyes and has no effect on convergence training and motor fusion. **Jpn J Ophthalmol 1999;43:9–15** © 1999 Japanese Ophthalmological Society

Key Words: Checkerboard pattern stimulator, convergence training, motor fusion, sensory fusion, stereopsis.

Introduction

Stereopsis is one of the most important goals in strabismus treatment. Cases with poor stereopsis, in spite of good ocular positions after surgical treatment, are quite common in patients with early onset strabismus. Binocular fusion is normally achieved by the development of binocular neurons in the visual cortex during the sensitive period.[1–5] The presence of strabismus during the sensitive period is followed by abnormal sensory adaptation, such as abnormal retinal correspondence or suppression. Once suppression is established, it is important to eliminate it in order to obtain good stereopsis.

In 1974, Blakemore and van Sluyters[6] reported that kittens with constant strabismus reared in a visual environment of striped patterns retained binocular cortical neurons. Based on this finding, Awaya and colleagues[7] developed the "checkerboard pattern stimulator" (CPS: Handaya Optical Instruments, Tokyo), which combines vertical and horizontal stripes. The CPS presents identical patterns simultaneously to the foveas of both eyes, which should reduce suppression in cases of manifest deviation.

We have reported[8,9] that the CPS is effective in promoting binocular fusion in constant exotropes who are likely to have been intermittent exotropes earlier and who had had good binocular fusion. The CPS was not effective in infantile esotropes, who are believed not to have adequately developed binocular cortical neurons.

This report covers the results of two studies. The first focuses on the effects of the CPS in 14 cases of acquired esotropia, while the second study extends these results by investigating the effects of the CPS on 15 subjects; 5 orthophores, 5 exophores, and 5 esophores.

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Subjects and Methods

Effects of CPS in Cases of Acquired Esotropia

The subjects consisted of 14 cases of acquired esotropia lacking stereopsis, as determined by the Titmus Stereo Tests or the Lang Stereotest, even after obtaining good ocular alignment by strabismus surgery or hyperopic correction. All subjects underwent CPS training for 15 minutes per session, 3 times per day. The time between surgery or hyperopic correction and the onset of CPS training was 1 week to 18 months (mean = 4.99 months). The age at onset of esotropia ranged from 27 months to 9 years. Thirteen patients had undergone strabismus surgery; 12 were orthophoric but 1 case showed residual esotropia at the time of this experiment. One case with accommodative esotropia was orthophoric with hyperopic correction. The postoperative periods at final examination ranged from 2 years to 6 years, 11 months. After CPS, those subjects who achieved stereopsis of 3/3 in the Lang Stereotest, 100 seconds of arc or better in the Titmus Stereo Tests, or 480 seconds of arc or better in the TNO Stereo Test at least three times during the follow-up period were designated as "positive," with stereopsis. Patients who failed to meet the above criteria were classified as "negative." The visual acuity, the ocular positions as measured by alternate prism and cover test, and the binocularity tested by the Bagolini striated glasses were recorded at the time of the final examination.

Ocular Positions During Checkerboard Pattern Stimulation

Subjects. The subjects for this part of the study consisted of 15 cases with no ocular diseases except refractive errors and ocular deviations. Ages ranged from 9 to 35 years; 5 were orthophores, 5 were exophores, and 5 were esophores. One of the orthophores (case 4) and 2 of the esophores (cases 2 and 4) had been operated on to correct esodeviations. All subjects had visual acuity of 20/20 or better, and 14 had achieved stereopsis of 100 seconds of arc or better on the Titmus Stereo Tests. One subject, who had been treated with surgical correction, had poor stereopsis of 0/3 in the Lang Stereotest (esophoria, Case 2).

Development of CPS. We developed the CPS, which consists of 21 × 27 cm rectangular checks. A 30-watt lamp bulb illuminates the CPS and provides black-pattern-black stimulation. The cycle of the stimulation is controlled by a thermostat attached to the lamp; the period of "pattern on" is irregular but averages about 0.5 Hz, only for enhanced stimulation with black-pattern-black exposure. In this study, the average luminance of the CPS was 200 cd/m^2, and the contrast of the checks was 37.5%. The screen was placed 20 cm in front of the subject, who was wearing lenses of +5.00 diopters over his/her correction for refractive errors. The check size was set to 1° (Figure 1).

Recording of Ocular Positions During Checkerboard Pattern Stimulation. We recorded the ocular positions continuously for 5 minutes during checkerboard pattern stimulation using an eye movement monitor made by Takei-kiki Kogyo (Tokyo). This detector is sensitive to the reflection difference between the cornea and the sclera. Before recording the ocular positions, the system was calibrated from the central point to 10° in horizontal visual angle at a distance of 50 cm from the subject.

Analysis of Ocular Positions. Ocular positions during the black-pattern-black stimulation were recorded and analyzed as angles of deviation from the baseline, which represents the initial eye position of the subject. The degree of deviation from the baseline of the left eye was subtracted from that of the right eye every second. Positive values indicate convergent motility and negative values indicate divergent motility.

Results

Results Obtained Using CPS in Cases of Acquired Esotropia

Of the 14 acquired esotropes, 8 (57%) showed "positive" effects and 6 (43%) showed "negative"

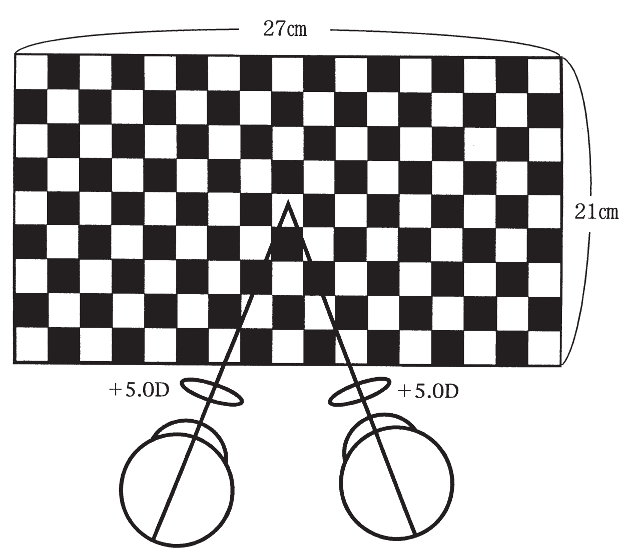

Figure 1. Diagram of checkerboard pattern stimulator.

Table 1. Cases Positive to Checkerboard Pattern Stimulation (CPS)

Case No.	Sex	Age at onset	Before Operation and CPS: Deviation N(Δ) D(Δ)	Before Operation and CPS: Lang	Before Operation and CPS: TST F	TST C	TST A	Ope	Timing of Starting CPS After Surgery	Timing of Obtaining Stereopsis After CPS	Final Findings: Visual Acuity	Final Findings: Deviation N(Δ) D(Δ)	Lang Lang II	TST F	TST C	TST A	TNO (Seconds of Arc)	Bagolini
1	F	2 Y, 6 M	s̄gl ET 30 s̄gl ET 18	0				R-R	3 M	27 M	R1.0(1.2×+1.5D= cyl+1.0D↑) L1.5(1.0×+1.5D= cyl+0.5D↑)	c̄gl E c̄gl E	3	(+)	5	3	480	R supp(±)
2	M	3Y	c̄gl ET 45 c̄gl ET 45	0	(−)	0	0	R-R	12 M	9 M	R1.2(1.5×+1.5D) L1.0(1.5×+2.0D)	c̄gl ortho c̄gl ortho	3				240	supp(−)
3	F	2Y, 11 M	s̄gl ET 70 s̄gl ET 50–70	0				R-R	5 M	5 M	R1.5(1.5×+2.0D) L1.5(1.5×+2.0D)	c̄gl ortho c̄gl ortho	3	(+)	4	3		
4	M	9 Y	c̄gl ET 35 c̄gl ET 35	0	(−)	4	0	R-R	1 M	4 M	R2.0(1.0×+1.0D) L0.9(1.0×cyl+0.5D↑)	s̄gl ortho s̄gl ortho	3	(+)	4	3	240	supp(−)
5	F	6 Y	c̄gl ET 40–45 c̄gl ET 35–40	0	(−)	1	0	R-R	18 M	3 M	R0.2(0.7×+6.0D= cyl−0.5D 160 °) L1.2(2.0×+1.5D)	c̄gl ortho c̄gl ortho	3	(+)	6	3	240	supp(−)
6	F	3 Y, 11 M	c̄gl ET 38 c̄gl ET 35	0	(−)	0	0	R-R	10 days	9 M	R1.5(1.2×+2.0D) L0.8(1.0×+2.0D)	c̄gl E (T) c̄gl ortho	3	(+)	6	3		
7	F	3 Y, 3 M	s̄gl ET 40 s̄gl ET 40	0				R-R	1.5 M	21 M	R2.0(2.0×+1.0D) L0.6(0.6×+2.75D)	c̄gl ortho c̄gl ortho	2	(+)	2	3	240	supp(−)
8	M	3 Y, 6 M	c̄gl ortho c̄gl E(T)	0	(−)	0	0		15 M (after hyperopic correction)	21 M	R1.0(1.0×+4.0D= cyl+0.5D↑) L1.0(1.0×+4.25D)	c̄gl ortho c̄gl ortho	3				240	supp(−)

A: animal, C: circles, c̄gl: cum glasses, D(Δ): deviation at distant vision (prism diopter), E: esophoria, ET: esotropia, E(T): intermittent esotropia, F: fly, Lang: Lang Stereotest, M: months, N(Δ): deviation at near vision (prism diopter), ortho: orthophoria, R-R: recession and resection, s̄gl: sine glasses, supp: suppression, TNO: TNO Stereo Test, TST: Titmus Stereo Test, Y: years.

Table 2. Cases Negative to Checkerboard Pattern Stimulation (CPS)

Case No.	Sex	Age at onset	Before Operation and CPS: Deviation N(Δ) D(Δ)	Lang	TST F	TST C	TST A	Ope	Timing of Starting CPS After Surgery	Duration of CPS Training	Final Findings: Visual Acuity	Deviation N(Δ) D(Δ)	Lang Lang II	TST F	TST C	TST A	TNO (Seconds of Arc)	Bagolini
1	F	3 Y, 8 M	s̄gl ET 50 s̄gl ET 35–45	0	(−)	4	0	R-R	2 W	27 M	R1.5(n.c.) L1.5(n.c.)	s̄gl ortho s̄gl ortho	0	(−)	1	3	(−)	supp(−)
2	M	6 Y	c̄gl ET 30 c̄gl ET 30–35	0	(−)	0	0	R-R	2 M	36 M	R2.0 L0.7(0.7×+2.5D =cyl+0.75D↑)	c̄gl ortho c̄gl ortho	0	(−)	0	0		
3	M	2 Y, 8 M	c̄gl ET 25–30 c̄gl ET 25–30		(−)	0	0	R-R	1 W	48 M	R1.5(1.2×+1.25D) L1.5(1.2×+1.25D)	c̄gl ortho c̄gl ortho		(−)	0	0		
4	F	2 Y, 3 M	c̄gl ET 45 c̄gl ET 45		(−)	0	0	R-R	1 W	24 M	R1.5(1.5×+3.0D =cyl+0.5D→) L1.5(1.5×+2.5D)	c̄gl E(T) c̄gl LHT	0	(−)	2	0	(−)	supp(−)
5	M	5 Y	c̄gl ET 10–12 c̄gl ET 10–12	0				MR recession	10 M	24 M	R2.0(2.0× +2.0D) L1.5(1.5×+0.5D)	s̄glET14 s̄glET14	0	(−)	2	1	(−)	L supp(+)
6	F	4 Y, 2 M	s̄gl ET 30 s̄gl ET 30 XT after first operation	0				① R-R ② R-R	1 M	36 M	R1.2(n.c.) L1.5(n.c.)	s̄gl ortho s̄gl ortho		(−)	3	0		

A: animal, C: circles, c̄gl: cum glasses, D(Δ): deviation at distant vision (prism diopter), E: esophoria, ET: esotropia, E(T): intermittent esotropia, F: fly, Lang: Lang Stereotest, LHT: left hypertropia, M: months, MR: medial rectus, N(Δ): deviation at near vision (prism diopter), ortho: orthophoria, R-R: recession and resection, s̄gl: sine glasses, supp: suppression, TNO: TNO Stereo Test, TST: Titmus Stereo Test, W: week, XT: exotropia, Y: years.

responses. In the positive group, 7 patients were orthophoric after surgery and 1 was orthophoric without surgery. In the negative group, 5 patients were orthophoric and 1 showed residual esotropia after surgery. Differences between positive and negative cases for time of strabismus onset, angles of deviation before and after surgery, and visual acuity at the final examination were not statistically significant (*t*-test) (Tables 1 and 2). The mean spherical equivalent of the refractive errors in the positive group was +2.23 diopters and that in the negative group was +1.14 diopters. This difference was statistically significant ($P = 0.0417$, *t*-test).

Ocular Positions During Checkerboard Pattern Stimulation

The ocular positions during checkerboard pattern stimulation in orthophores, exophores, and esophores are shown in Figures 2 to 4. The horizontal axis represents the time course in seconds, while the vertical axis represents the angle of deviation from the baseline in degrees, where positive values indicate convergent motility and negative values indicate divergent motility. We found a tendency toward exodeviation in orthophores and exophores during the stimulation by the checkerboard pattern, but no specific tendency in esophores. None of the subjects showed convergent positions repeatedly or continuously during stimulation by the checkerboard pattern.

Discussion

It is generally difficult for patients with infantile esotropia to develop good stereoacuity, despite hav-

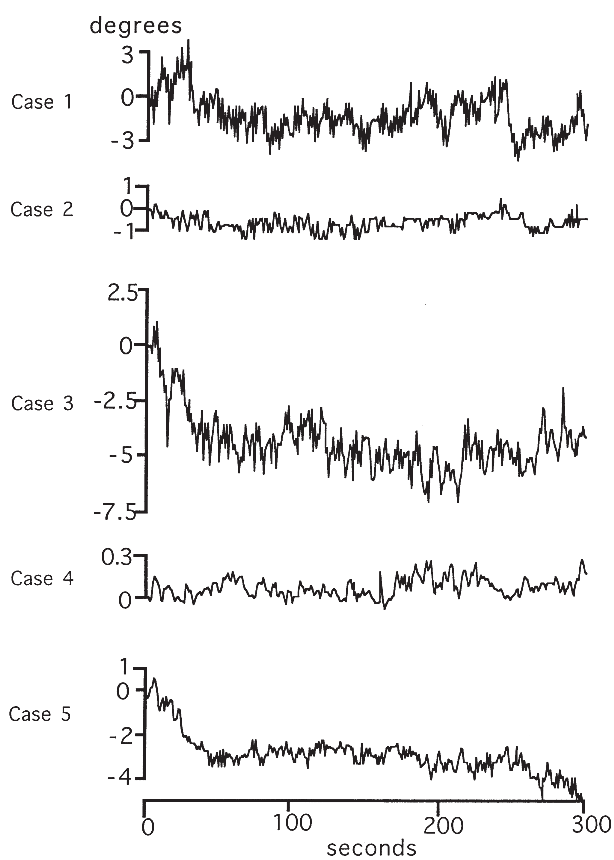

Figure 2. Ocular positions during checkerboard pattern stimulation: orthophoria. Abnormal high and spike wave may be blink artifact.

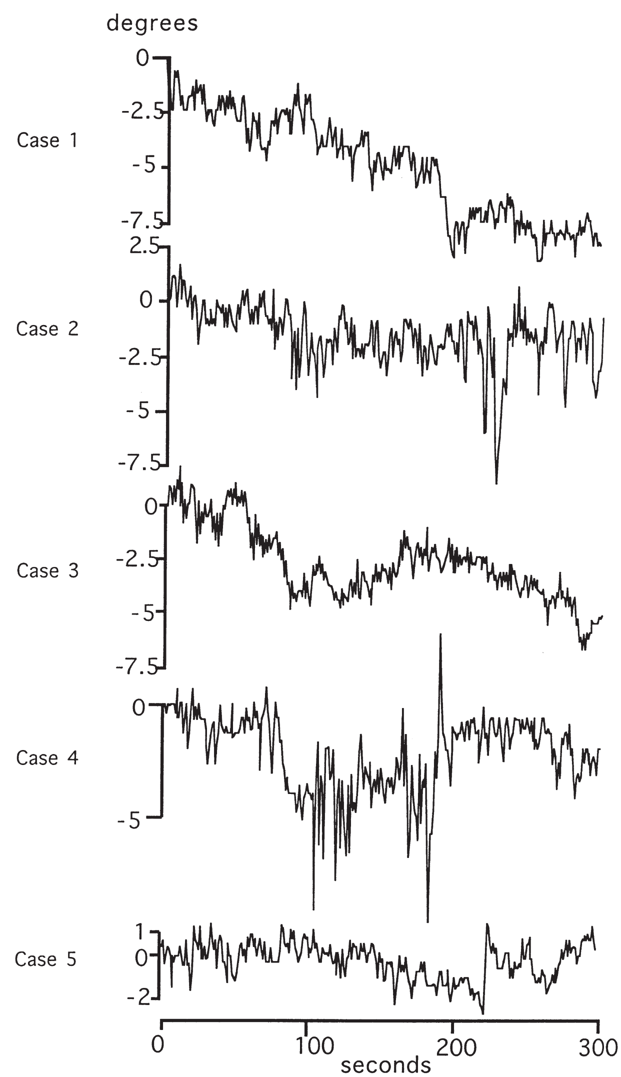

Figure 3. Ocular positions during checkerboard pattern stimulation: exophoria. Abnormal high and spike wave may be blink artifact.

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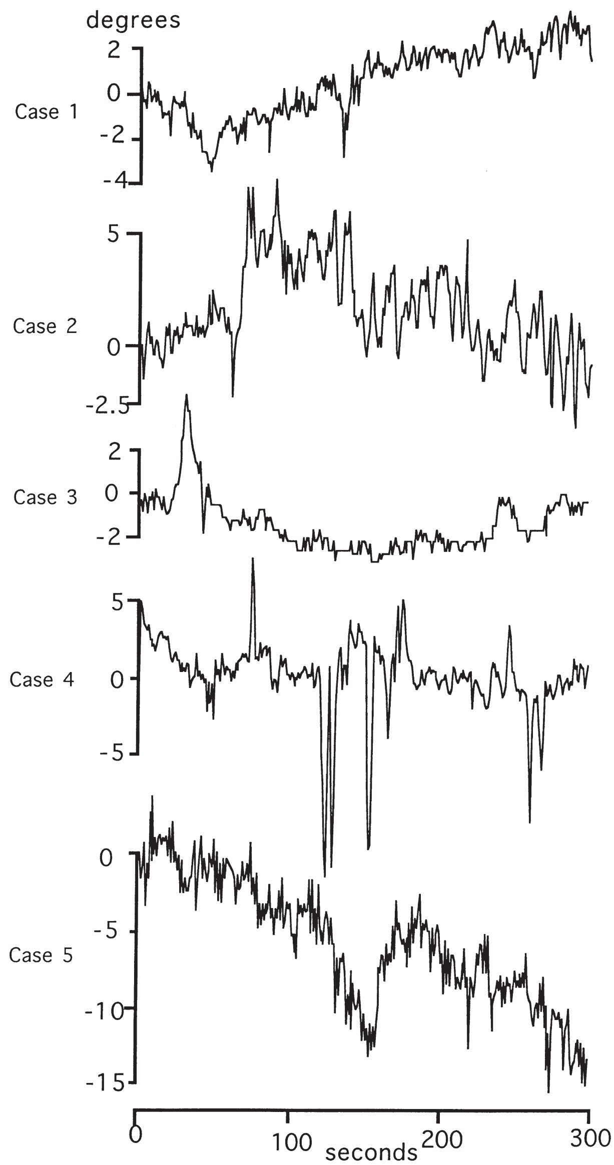

Figure 4. Ocular positions during checkerboard pattern stimulation: esophoria. Abnormal high and spike wave may be blink artifact.

ing good ocular alignment after surgical correction. This can be attributed to the fact that binocular neurons in the visual cortex do not develop well in infantile esotropes, because of the presence of manifest deviations during the sensitive period. In cases of acquired esotropia, the onset occurs after the development of binocular cortical neurons and once the deviation becomes constant, patients usually have suppression or abnormal retinal correspondence. If suppression is eliminated without delay, normalization of binocular function should be expected.[10,11]

The CPS was developed by Awaya and colleagues[7] to provide a black-pattern-black stimulation of a checkerboard pattern as a congruous stimulus to the foveas of both eyes, despite the presence of any deviation, for the purpose of removing suppression. In our first study, we reported that 8 of the 14 acquired esotropic patients obtained stereopsis by CPS training after surgical correction or hyperopic correction, and the remaining 6 patients did not show improvement in stereoacuity. The spherical equivalent of the refractive errors in the positive group was more hypermetropic than that in the negative group. There is a possibility that an accommodative element influences the effect of the CPS. An argument might be made that achieving stereopsis was not due to CPS training, but was merely the natural course following surgery. However, the time to start the training was not different in the two groups ($P = 0.106$, Mann-Whitney *U*-test). The average time after surgery or hyperopic correction to the start of CPS training in the positive group was 7.00 months, and 2.36 months in the negative group. In addition, it is clear that not all but many patients in the positive group had not achieved stereopsis, spontaneously, even after a long period following surgery. There must be other factors that contribute to the effectiveness of CPS.

The CPS was found to be more effective in constant and intermittent exotropes[9] than in acquired esotropes ($P = 0.047$, chi-square test). If CPS reduces suppression, the effect should be the same on esotropia and exotropia. Therefore, in our second study, we focused on the question of why CPS is more effective in exotropes than in esotropes. We recorded ocular positions during checkerboard pattern stimulation. By analyzing the records, we determined whether the CPS had functioned as an instrument of convergence training and accelerated motor fusion in exotropes. The tendency to deviate from the divergent positions was found in orthophores and exophores, while no specific tendency was found in esotropes. None of the patients showed convergent positions repeatedly or continuously during the recording period. Therefore, we conclude that CPS promotes sensory fusion by presenting congruous stimulation to the foveas of both eyes regardless of the ocular positions.

What factors affect the difference in the effectiveness of CPS on exotropes and esotropes? Inagaki and colleagues[9] reported that the onset of exotropia occurred at an older age in positive cases than in negative cases. The former ranged from 9 months to 30 years of age (mean = 8 years) and the latter, 3 months to 23 years (mean = 5.7 years). Constant exotropia rarely occurs in infancy and most cases have periods of intermittency in their earlier days. In this study, the onset of esotropia in the positive group ranged from 30 months to 9 years (mean = 4 years), a younger age distribution when compared with that of exotropia in the positive group in Inagaki's report. Even though there are opportunities to develop binocular function, maintaining binocular neurons in the visual cortex and reviving binocular function may become more difficult if manifest deviation occurs early in the sensitive period. In addition, the sensory behavior associated with exodeviations differs in several respects from that of patients with esodeviations. Anatomic and possibly physiological variances between the nasal and the temporal retina may be related to the differences in the characteristics of sensory adaptations in these two conditions. Sensory adaptations, such as suppression or abnormal retinal correspondence, are only superficially established in exotropes.[12] This could explain why anti-suppression therapy seems to be more effective in exotropes than in esotropes.

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