Characteristics of Hyperacuity Sensitivity in Normal and Cyclovertical Deviation Subjects

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Purpose: To compare the sensitivity of hyperacuity of patients with cyclovertical deviation with that of subjects with normal vision.

Methods: The sensitivity of hyperacuity was measured in 42 volunteers with normal vision and in 12 patients with cyclovertical deviation, using a newly developed computerized device that randomly presents two opposing targets at vertical or at horizontal directions on the cathode ray tube display.

Results: In subjects with normal vision, higher sensitivity was obtained when the targets were aligned in either a vertical or a horizontal direction. These highly sensitive ranges were defined as "the neutral zone of hyperacuity." An anisotropy of the sensitivity of hyperacuity was observed in these subjects, ie, better sensitivity was obtained when the displacement was away from the neutral zone, whereas worse sensitivity was obtained when the displacement was close to the neutral zones. In the patients with cyclovertical deviation, the sensitivity of hyperacuity was low around the neutral zones, which may confirm the dysfunction of the central nervous system.

Conclusion: This analytical method may be useful to investigate the pathophysiology of patients with cyclovertical deviations. **Jpn J Ophthalmol 2002;46:285–292** © 2002 Japanese Ophthalmological Society

Key Words: Adaptation, anisotropy, cyclovertical deviation, hyperacuity, neutral zone of hyperacuity.

Introduction

Viewing the outer world with head tilted results in a strange sensation. To investigate what brings about this sense of visual incongruity, we assessed the anisotropy[1,2] and sensitivity of hyperacuity.[3–5] The sensitivity of hyperacuity is reported to be anisotropic, in such a way that a better sensitivity is obtained when the displacement is away from the vertical and horizontal axes; whereas worse sensitivity is obtained when the displacement is close to the vertical and horizontal axes.[3] We found that there was a range where the sensitivity of the hyperacuity was high in both directions of displacement, which we call the "neutral zone of hyperacuity."[3] We also reported the position of the neutral zone and that the change of its position on head tilt is an individual characteristic.[3,6]

In the present study, the same examination was performed on clinical patients with cyclovertical deviation. We also reexamined the results that were previously reported for persons with normal vision. We compared the results in these two groups. Using hyperacuity as an index, we could detect vertical and horizontal recognition in these subjects, which has been unexamined by previous methods.

Materials and Methods

Before the tests, we obtained the informed consent of all the subjects who agreed to participate in the following tests. The Vernier performance was tested in a lighted room of 300 lux. The observer's head was fixed with chin and forehead rests at a distance of 50 cm from a cathode ray tube (CRT) display placed in front of the subject, with corrected near vision when necessary. At first, a circle target (0.9° visual angle in diameter, luminance of 7 cd/m^2) was shown on the CRT display as a fixation object in

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the center of the background circle (15 cm, 17° visual angle in diameter, luminance of 100 cd/m^2). The fixation mark disappeared 1.5 seconds after the observer pushed a starting button, and the test targets were simultaneously flashed for 250 milliseconds on the CRT display. The test targets were constructed from two rectangles (each 2.2° long and 0.4° wide, luminance of 7 cd/m^2). One was a reference and the other was attached to a half circle at the distal end (see Figure 1).

The subjects were asked to determine whether or not the proximal end was displaced. In this report, we shall call the direction of the long side of the rectangle "the axis." The two rectangles were opposite each other, 9.4° apart (the distance from the center of the background circle to the proximal end of the rectangle was 4.7°) in the direction of the axis. The test target was aligned with a certain displacement to both sides of the axis. The displacements were 0.00′, 5.16′, 10.31′, 20.61′, 41.2′, and 82.49′. The test targets were presented with the angle of the axis and the size of the displacements, in random order, controlled by computer.

Experiment 1

The subjects were 15 volunteers with normal vision from 18 to 40 years of age. The angles of the axis were 60°, 75°, 90°, 105°, 120°, and 150°, 165°, 180°, 15°, 30° in the vertical and in the horizontal directions, respectively. The subject's head was kept facing straight ahead with the CRT display in front of it (we call this head position the "vertical head position"), and the subject viewed the targets binocularly.

Experiment 2

The subjects were 36 volunteers with normal vision from 18 to 63 years of age. In order to examine the sensitivity to the vertical and horizontal areas closely, the angles of the axis were set with smaller steps than in experiment 1, at 75°, 85°, 90°, 95°, 105° and 165°, 175°, 180°, 5°, 15° in the vertical and horizontal directions, respectively. The head position was vertical and the targets were viewed binocularly.

Experiment 3

The subjects were 12 patients (6 men and 6 women) who had complained of cyclovertical deviation at ages from 39 to 76 years. Seven patients with vertical diplopia including 1 with decompensated superior oblique palsy, 1 with diabetic myopathy, 1 following cataract surgery, 1 following reoperation for pterygium, and 3 unknown. Five patients with cyclodeviation included 1 following vitrectomy, 1 following cataract surgery, 1 with diabetic myopathy, and 2 unknown. The primary position at near sight of each patient is shown in Table 1. The conditions

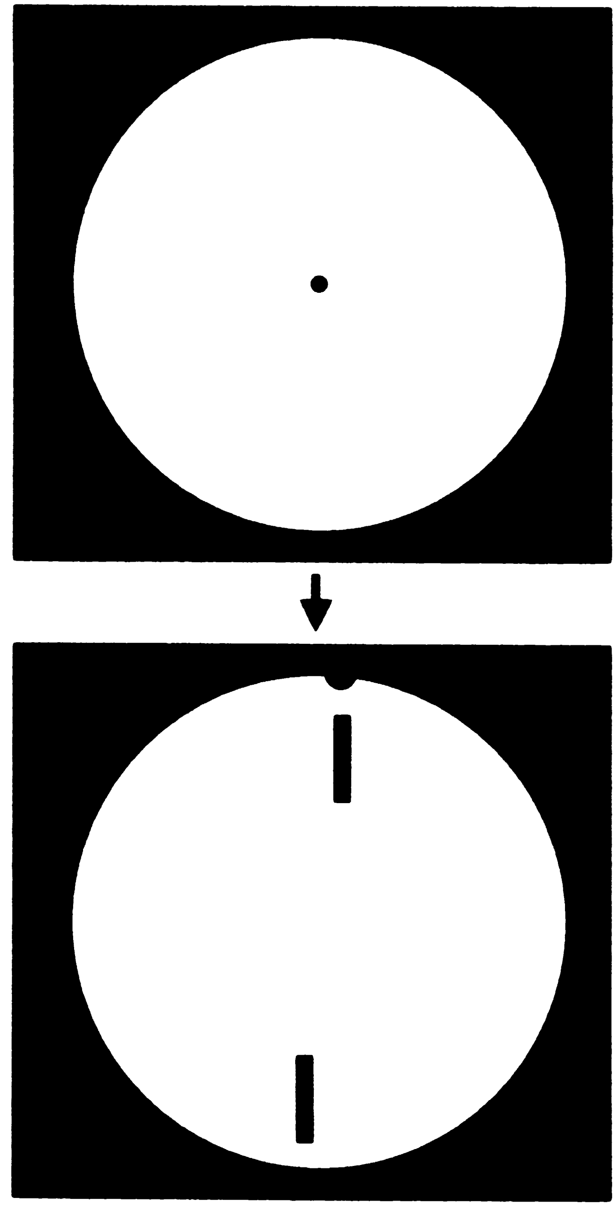

Figure 1. Test targets on cathode ray tube (CRT). At first, a circle target is shown on the CRT display (top). The fixation mark disappears 1.5 seconds after the observer pushes the starting button, and the test targets are simultaneously flashed on the CRT display (bottom). The subjects are asked to determine if the target attached to a half circle is displaced or not by comparing with other reference target. The background circle is 15 cm, 17° visual angle in diameter, the fixation mark is 0.9° visual angle, the distance between the test targets is 9.4°, and test targets are each 2.2° long and 0.4°wide and flashed on for 250 milliseconds

Table 1. The Eye Positions and the Results of Awaya's Cyclo Tests of 12 Patients

Diplopia group		
Case 1	Orthotropia	Excyclotropia 10°
2	L)Hypertropia, exotropia	
3	Exophoria 12Δ	
4	R)Hypertropia 7Δ	Incyclotropia 1°
5	Orthotropia	
6	L)Hypertropia 5Δ Exophoria 6Δ	
7	Exophoria 2Δ	
Cyclodeviation group		
8	Orthotropia	Excyclotropia 3°
9	Orthotropia	
10	Orthotropia	
11	Orthotropia	Excyclotropia 1°
12	R)Hypertropia 4Δ Exophoria 16Δ	Excyclotropia 5°

of the examination were the same as those for experiment 2. The patients complaining of vertical diplopia underwent the examination with the following head positions: (1) vertical head position, (2) 30° head tilt to the right, and (3) 30° head tilt to the left. The patients complaining of cyclodeviation underwent the examination in the following three conditions in the vertical head position: (1) binocularly, (2) monocularly with left eye closed, and (3) monocularly with right eye closed.

The task of the observer was to identify the direction of displacement by selecting either (1) no displacement, (2) right, (3) left, or (4) unable to answer, when the axis was vertically oriented; and (1) no displacement, (2) above, (3) below, or (4) unable to answer, when the axis was horizontally oriented.

Experimental runs encompassed 60–100 stimulus presentations per session depending on the observer's percentages of correct responses.

Hyperacuity was judged as follows: "good" when the sensitivity was better than 10.31′ in the direction of displacement around the axis, and "bad" when the sensitivity was worse than 10.31′.

In experiment 3, we divided the patients into two groups, a diplopia group and a cyclodeviation group, and compared the decline of the Vernier sensitivity. When the judgment was "bad" on both sides of the axis, the decline in sensitivity was (+). When the judgment was "good" on both sides of the axis, ie, the neutral zone was detected, the decline in sensitivity was (−). When the judgment was good on one side and bad on the other side, the decline was (±).

The statistical analysis was performed by using the χ^2 test. A P-value $< .05$ was considered statistically significant.

Results

Two typical examples from experiment 1 are shown in Figures 2A and 2B. The "spoke" lines show the angle of the axis. Rectangles at the end of the lines represent the side of the displacement, and the assessment of the hyperacuity (open rectangle and solid rectangle represent good and bad, respectively). In Figure 2A, the zones of 90° and 180° are "the neutral zones." In Figure 2B, the neutral zones are located between 85° and 90° and between 180° and 5° where the anisotropy is reversed. In experiment 1, we could estimate the neutral zone of the vertical orientation from the higher sensitivity or the reversal of the anisotropy in 14 of the 15 cases. In the horizontal orientation, we could similarly estimate the neutral zone in 14 of the 15 cases. In the remaining case, the neutral zones could not be estimated because the anisotropy patterns were not clear in the vertical and horizontal directions. The pattern of the anisotropy of hyperacuity in all 15 cases is shown in cross-frequency distribution (Table 2). An anisotropy pattern the same as typical examples was termed a "regular" pattern. An anisotropy pattern opposite to the regular pattern was called a "reverse" pattern. When the anisotropy pattern was indeterminate, the pattern was classified as "unknown." Of 11 subjects, 9 exhibited a "regular" pattern in the vertical direction and 10 in the horizontal direction. An "unknown" group included 4 subjects (2 vertical and 2 horizontal) whose sensitivity was so high (better than 10.31′ on many axes on both sides) that we could not detect the anisotropy. Moreover, different anisotropy patterns were observed in the vertical and horizontal directions in 1 case.

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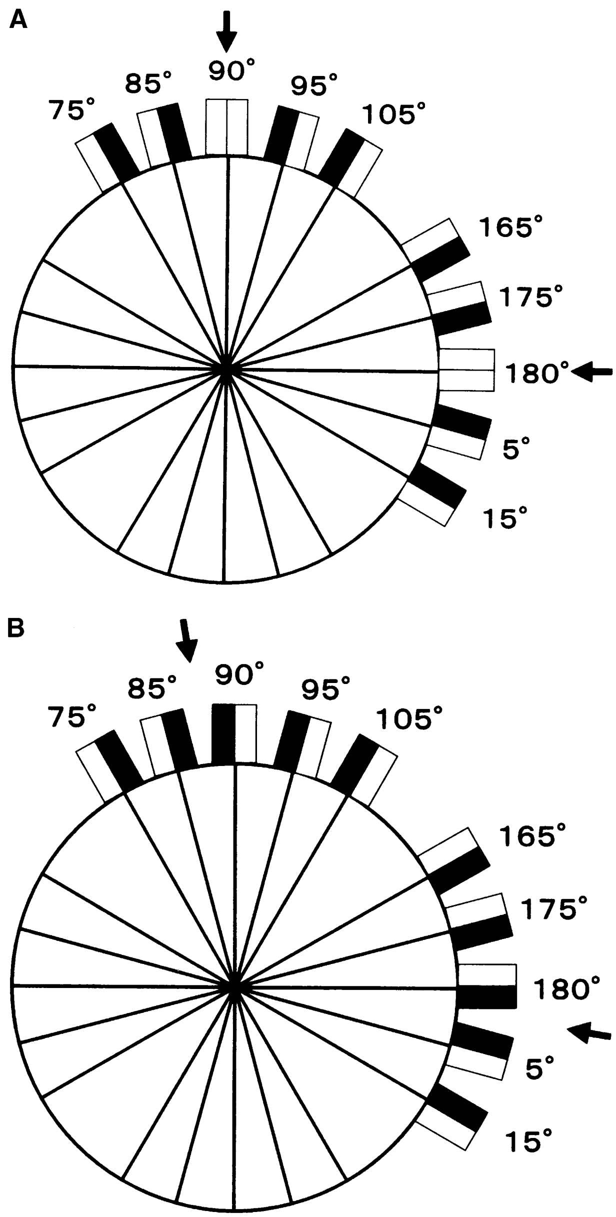

Figure 2. The typical patterns of hyperacuity from experiment 1. Rectangles at the end of the lines represent the side of the displacement and the assessment of the hyperacuity (open rectangle and solid rectangle represent good and bad, respectively). (**A**) Top: the neutral zones are located at the zones of 90° and 180°. (**B**) Bottom: the neutral zones are located between 85° and 90° and between 180° and 5°.

In experiment 2, we could detect the position of the neutral zone more precisely than in experiment 1.The deviation of the neutral zones from the absolute vertical and the absolute horizontal are shown in Table 3. In experiment 2, because of the smaller steps in the angles of axes, the neutral zone seemed to exist over a wide range. In such cases, we defined the position of the neutral zone as the center angle of that range. The vertical and horizontal neutral zones were consistent with the absolute vertical and horizontal areas in only 6 of the 36 cases. In the vertical direction, the neutral zones in the remaining cases were deviated clockwise (over 90°) in 9 cases and counterclockwise (<90°) in 10 cases. In the horizontal orientation, the neutral zones were deviated clockwise in 8 cases and counterclockwise in 10 cases. The "regular" anisotropy pattern of the subjects in experiment 2 was found in 22 subjects in the vertical direction and in 21 subjects in the horizontal direction (Table 4). The correlations of the deviation of the neutral zone with the dominant eye, the tendency of head tilt and dominant hand were proven not significant in our previous report.[6]

In experiment 3, a "positive" decline in sensitivity was found in 7 of the 12 subjects in the vertical direction and in 3 of the 12 subjects in the horizontal direction. In the 36 subjects with normal vision in experiment 2, we restudied the decline of sensitivity around the vertical and horizontal axes. A decline was found in 1 subject in the vertical direction and 2 subjects in the horizontal direction. The frequency of the decline in sensitivity in the vertical direction was significantly higher in the patients with cyclovertical deviation than in the group with normal vision ($P <$ .001). However, it was not significant in the horizontal direction.

Table 2. The Pattern of the Anisotropy of Hyperacuity (Experiment 1)

	Vertical			
Horizontal	Regular	Reverse	Unknown	Total
Regular	8	1	1	10
Reverse	0	0	1	1
Unknown	1	1	2	4
Total	9	2	4	15

Table 3. The Position of the Neutral Zone

	Vertical				
Horizontal	<90°	90°	>90°	Unknown	Total
<180°	2	4	3	1	10
180°	3	6	1	1	11
>180°	3	2	3	0	8
Unknown	2	1	2	2	7
Total	10	13	9	4	36

Table 4. The Pattern of the Anisotropy of Hyperacuity (Experiment 2)

	Vertical			
Horizontal	Regular	Reverse	Unknown	Total
Regular	17	0	4	21
Reverse	0	4	1	5
Unknown	5	1	4	10
Total	22	5	9	36

Table 6. The Decline of Hyperacuity with Head Tilt (in the Diplopia Group)

	Head Tilt to R30°		Head Tilt to L30°	
Hyperacuity	Vertical	Horizontal	Vertical	Horizontal
Decline				
(+)	7	3	6	4
(±)	0	3	0	2
(−)	0	1	1	1
Total	7	7	7	7

The anisotropy of hyperacuity in the patients showed either a "regular" or "reverse" pattern in a way similar to the normal vision subjects. Of the 12 subjects in experiment 3, the "reverse" pattern was observed in the vertical and horizontal directions in 2 and 3 subjects, respectively. In 2 of these cases, the "reverse" pattern was observed in either direction, whereas there was a different anisotropy pattern in two directions in the remaining case. In the 36 healthy subjects in experiment 2, the "reverse" pattern in the vertical or horizontal directions was observed in 5 subjects in each direction, of whom 3 showed the "reverse" pattern in both directions. The frequency of the "reverse" pattern of anisotropy did not differ between the normal vision subjects and the patients with cyclovertical deviation.

The decline in the sensitivity of hyperacuity is shown in Table 5. The cyclodeviation group tended to show less decline than the diplopia group. The results of the test with the head tilt in the diplopia group are shown in Table 6. The number of subjects showing a decline in sensitivity due to the head tilt increased especially in the vertical direction.

In the cyclodeviation group, we examined whether the position of the neutral zone reflected the complaints of cyclovertical deviation. However, it was impossible to show the relationship between the position and the complaint. The reasons are (1) that many subjects showed a decline in sensitivity (5 subjects × 3 sessions for a total of 15 measurements, 8 in the vertical direction and 7 in the horizontal direction), (2) the wide range of the decline, and (3) that the angles of the axes were kept constant in spite of the angles of deviation.

Table 5. The Decline of Hyperacuity

	Diplopia Group		Cyclodeviation Group	
Hyperacuity	Vertical	Horizontal	Vertical	Horizontal
Decline				
(+)	5	1	2	2
(±)	2	4	1	1
(−)	0	2	2	2
Total	7	7	5	5

Two interesting cases are described in the following.

Case 1. A 54-year-old policeman with decompensated congenital right superior oblique muscle paresis complained of intermittent vertical diplopia. At such times, he preferred to see with his left eye closed. He was anxious as to which eye should be closed. His visual acuity was 20/15 in each eye, he had full stereopsis, and 10° excyclotropia as determined by Awaya's Cyclo tests. With this subject, in addition to the head positions in experiment 3, the examination was done monocularly with the right and the left eye in the vertical head position. The results are shown in Figure 3. This shows that the result with the binocular performance (B) was very similar to the result with the left eye (L), but the result with the right eye showed many differences. In the right eye, the anisotropy was clear and the neutral zone was detected. The results with the subject in the head tilt position showed very bad hyperacuity on almost all axes and directions. The anisotropy pattern in this case was "reverse" in all tests.

Case 2. A 39-year-old man with diabetic myopathy. He complained of vertical diplopia for 2 days, and could not walk straight even with 1 eye closed because of the cyclodeviation. Visual acuity was 20/15 OD and 20/60 OS. He had amblyopia in the left eye, and dot hemorrhages due to diabetes were found in his retina. At the first examination, right superior rectus paresis was suspected from three-step tests, but some other extraocular muscle paresis could be considered. The Vernier performance at this time is shown in the inner circles of Figure 4. His complaints of diplopia and cyclovertical deviation disappeared in 2 months, and the Vernier performance was tested again 2 months later. The result is shown in the outer circles of Figure 4. Comparing the inner and outer circles, the disappearance of diplopia

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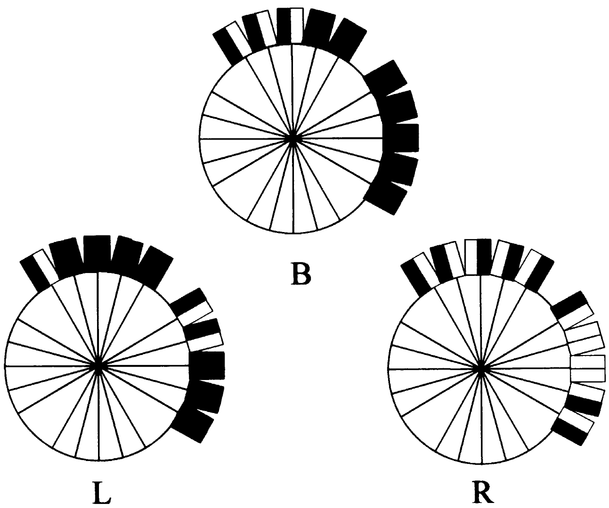

Figure 3. The test results of case 1. The results with the right eye show many differences from the others. B: both eyes. L: left eye, R: right eye.

would seem to be related to the recovery of hyperacuity. The recovery was more prominent in the horizontal direction than in the vertical direction. The neutral zone was found in the horizontal direction with vertical head position, and the decline in hyperacuity was reduced even when he was in the head tilt position.

Discussion

In the subjects with normal vision, the neutral zone of hyperacuity was observed around both the vertical and horizontal axes, and the anisotropy of hyperacuity was reversed on both sides of the neutral zone. One characteristic is that the sensitivity to the displacement away from the neutral zone is higher than that to the displacement close to the neutral zone. The reproducibility of these findings was reconfirmed in the 9 subjects who underwent both experiments 1 and 2. The pattern of anisotropy corresponded in 8 of the 9 subjects in the vertical direction and in 7 of the 9 subjects in the horizontal direction. In one subject, anisotropy could not be detected in experiment 1 in either direction, but was detected in experiment 2. This case will be discussed below. Two of these 9 subjects showed the reverse pattern in the vertical direction and one subject in the horizontal direction in both experiments 1 and 2. The frequency of the reverse pattern in the patients of experiment 3 was not different from that in the volunteer subjects; therefore, this pattern was thought to be an individual characteristic. The position of the neutral zone could not be easily compared between experiments 1 and 2 because the test angles of the axis were different. This is because some subjects showed "good" sensitivity over a wide range; that is, the threshold of these individuals was lower than the standard, 10.31′. In these cases, the position of the neutral zone was defined as the center of the "good" range. The investigations of anisotropy and the neutral zone were, therefore, reasonably reproducible.

It was surprising that the observed position of the vertical and horizontal neutral zones coincided with the absolute vertical and horizontal axes, respectively, in only 6 of the 36 subjects in experiment 2. In the ordinary Vernier test, the test targets are aligned vertically or horizontally and sometimes the thresholds are measured. However, the maximum hyperacuity is not always obtained in the absolute vertical or horizontal plane. For example, Kumar and Glaser[7] and Yap et al[8] have reported patients whose thresholds were very different in the vertical and horizontal directions. Our results should be considered in interpreting such hyperacuity data.[7,9–11]

Some hyperacuity tasks are affected by learning. We observed a learning effect also in a preliminary study. Repeated individual performance, and explanations of the test and purpose or advance predictions, may lead subjects to make greater efforts to improve discrimination, and thereby obscure the patterns of anisotropy. To avoid this effect, we did not explain anything but the task at hand to the volunteer group. We informed the cyclovertical patients that the test was to determine how they judge vertical and horizontal lines. Therefore, the results of the first experiment were adopted and analyzed. The interval between experiments 1 and 2 was at least 2 months for the volunteer subjects. We did not provide any explanation of the results to the volunteer group. However, a learning effect cannot be denied in the subject mentioned above who performed better in experiment 2 than in experiment 1. Case 2 performed the same experiment twice and an improvement was observed. The interval was more than 4 months and an explanation was given after the second time to compare the two results. This improvement in performance is thus thought to be due not to the learning effect but to the recovery of sensitivity.

In the present study, a decline in hyperacuity occurred in the patients of the diplopia group. The range of the decline covered, at most, 15° to either side of the vertical and horizontal axes. Such declines were found more often with the head tilt, especially in the vertical direction (Table 6).We have

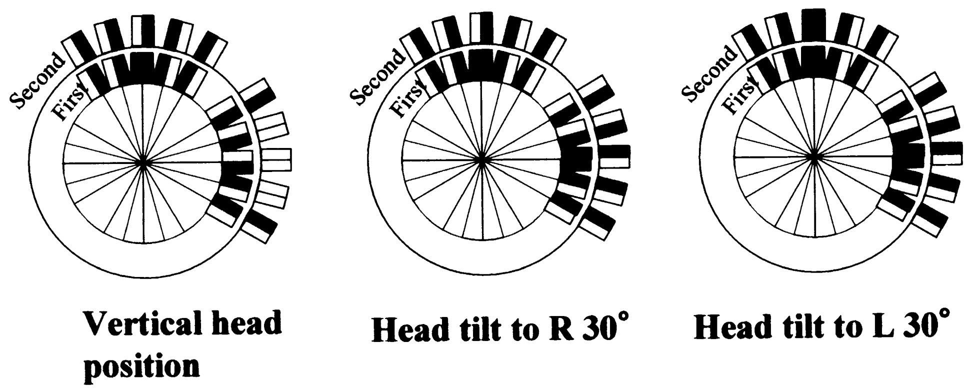

Figure 4. The test results of case 2. The performance at the first examination is shown in the inner circles. The second performance 2 months later, after the disappearance of cyclovertical deviation, is shown in the outer circles. In the second performance, the neutral zone is found in the horizontal direction with vertical head position, and the decline in hyperacuity was reduced even in the head tilt position.

reported that the position of the neutral zone changes with the head tilt[6]; similarly, the position of the decline may change with the head tilt. Table 6 shows that the decline in hyperacuity was observed in all subjects in the diplopia group. Two of the 5 patients in the cyclodeviation group showed vertical diplopia with the Hess chart and prism cover test. The decline was observed in both the vertical and horizontal directions in these 2 patients. Two of the remaining 3 patients complained of cyclodeviation only, and showed no decline in hyperacuity at any head position. Accordingly, it is conceivable that in patients with vertical diplopia the different stimuli from the 2 eyes confuses the visual information in the central nervous system and may trigger the decline in hyperacuity. On the other hand, in the cyclodeviation group, the hyperacuity did not decline as much as in the diplopia group.

Case 1, who complained about intermittent diplopia, had different results with the right and left eyes. The differences in the hyperacuity test when conducted monocularly and binocularly vary according to the conditions of the test target,[12] but in the normal vision subjects including all 5 self-tested subjects, we found no difference between the results with the left and right eyes and with monocular and binocular vision. In case 1, however, the result with the right eye was very different from that with the left eye and from the result with both eyes. The result with the right eye more clearly showed anisotropy and the neutral zone in the horizontal direction. These findings suggest that the patient used the paralyzed right eye dominantly[13,14] and closed the left eye so as not to disturb the visual information from the right eye. The difference in monocular and binocular hyperacuity (case 1) and the recovery of hyperacuity (case 2) would seem to be related to adaptation to cyclovertical deviation.

In a short time after the experiment started, an examinee's visual field became occupied by the white of the background and it was as if the frame of the display did not enter the visual field at all. This phenomenon is due to the concentration of attention on the target. A similar observation has been reported by Sullivan et al.[15] Even the frames of the display that entered the visual field did not play the role of visual clue, because of the following three reasons: the angle of the axis of the test target changed randomly; the direction of the displacement referred to the other test target; and the presentation time of the test target, 250 milliseconds, was shorter than the fixation movement. Thus, the neutral zone identified in this study reflects the difference between the vertical and horizontal lines subjectively observed at the examination and those lines that might have been observed previously. von Noorden[16] has reported that adult onset cyclovertical deviation patients use visual clues to adapt to the new environment. However, our patients complained that the objects to be used as a visual clue were tilted when viewed either monocularly or binocularly. We wonder in relation to what they felt the visual clue was tilted. As the anisotropy and the neutral zone were maintained better in the cyclodeviation group than in the diplopia group, these patients might feel the tilt compared with the neutral zone they used to have. Yagasaki[17] stated that the sense of cyclodeviation usually occurred when the angle was too large to be compensated by cyclofusion. However, in the present study using hyperacuity, cyclofusion could be detected at a

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smaller angle. In these 12 patients the complaint of cyclodeviation disappeared in 6 months, so the adaptation to cyclofusion and the positional change of the neutral zone could have occurred.

It was previously reported that the recognition of the horizontal axis is more stable than that of the vertical axis, and that this contributes to the sense of body balance.[1] Our investigation supports this idea based upon the following results. The number of people showing deviation from the absolute vertical axis was greater than the number showing deviation from the absolute horizontal axis. Moreover, the subjects showing little deviation from the absolute vertical axis showed even less deviation from the absolute horizontal axis.[6] The patients with cyclovertical deviation showed a more significant decline in hyperacuity in the vertical direction than the normal vision subjects, but not in the horizontal direction. In addition, an increase in hyperacuity was seen in the horizontal direction when the cyclovertical diplopia disappeared in case 2.

Our newly developed system can set the test conditions easily and be performed monocularly and binocularly. We could determine the recognition of the vertical and horizontal planes in cyclovertical-deviated patients using hyperacuity as an index. This analytical method may be useful in investigating the pathophysiology of cyclovertical deviation.

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