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Monocular Electronystagmographic Analysis of Caloric Nystagmus

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Abstract: We compared the horizontal component of nystagmus of the right and left eyes using monocular recording of electronystagmography. We examined the eye movements of 135 patients during bithermal caloric testing and those of 50 patients during the rotation test. We measured the number of nystagmic beats, the slow-phase velocities, and the amplitudes during 10 seconds of the culmination phase of caloric response. We also measured the number of nystagmic beats during the first 30 seconds in postrotatory nystagmus. The eye on the cold-irrigated side moved significantly more strongly than did the eye on the nonirrigated side, whereas a warm irrigation did not induce a significant difference between the irrigated and nonirrigated eyes. The summated activities of each eye during the four different stimulations under bithermal caloric testing did not show any significant differences. The activities of postrotatory nystagmus were almost equal in both eyes in 50 patients. We concluded that the inhibitory effect of cold caloric stimulation is probably transmitted more intensively to the eye on the irrigated side.

Key Words: caloric nystagmus; electronystagmography; human; monocular recording; vestibuloocular reflex

Both in Germany and in Japan, electronystagmography (ENG) is commonly recorded binocularly. However, the difference in the movement between the two eyes during physiological nystagmus, such as caloric or rotatory nystagmus, has not been fully discussed. Nagle [1,2] used caloric testing with 1 ml of ice-water and reported that 21 of 26 normal subjects showed a more vigorous nystagmus response in the eye on the irrigated side than in the other eye. Wolfe [3] used bithermal caloric stimulation with 250 ml of water at 30° and 44°C for 40 seconds and tested 25 normal subjects and 173 affected patients. He measured an average slow-phase velocity of 10 nystagmic beats for the left and right eyes during the period of maximum caloric response. He concluded that both in normal subjects and in patients, cold-water stimulation activated the eye of the irrigated side more intensely than the eye of the nonirrigated side, but warm-water stimulation caused almost identical responses in the two eyes.

We aimed to reevaluate Wolfe's results using caloric stimulation of 20 ml of water at 30° and 44°C for 30 seconds, which is clinically more frequently used. We recruited patients who had normal or very nearly normal functions of the peripheral and central vestibular systems as well as of the peripheral and central optic systems. We measured not only the slow-phase velocities but the number of beats and the amplitudes of nystagmus to compare the activities of the two eyes. We recruited patients who had normal or very close to normal functions of the peripheral and central vestibular systems and of the peripheral and central optic systems. We also attempted to clarify the underlying mechanism of the stronger activity of the eye of the cold-irrigated side with contemporary knowledge of neurophysiology.

PATIENTS AND METHODS

From 1999 to 2001, a total of 1,038 patients underwent ENG recordings for conventional bithermal caloric

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testing and the rotation test at the Neurootological Research Institute of the 4-G-F in Bad Kissingen. We then examined those recordings retrospectively.

For the analysis of caloric response, we included in our study those patients who fulfilled the following eight criteria: (1) caloric response recorded at least moderately in all four caloric stimulations, (2) absence of severe disorder in the central nervous system, (3) absence of spontaneous nystagmus with eyes closed, (4) age between 20 and 70 years, (5) absence of pathological eye movement, (6) normal visual evoked potentials, (7) visual acuity of at least 0.25, and (8) ENG in good condition. For the analysis of postrotatory nystagmus, we used the data of those patients who fulfilled these 2 conditions: (1) postrotatory nystagmus normally evoked in right and in left directions and (2) ENG in good condition.

We placed Ag/AgCl electrodes bilaterally on the outer canthi for recording the horizontal eye movements in both eyes and at the root of the nose for recording movements in the right and the left eyes independently. For vertical recording, we placed electrodes above and below the orbita of each eye on the vertical line running through the center of the pupil in a mideye position. We recorded the horizontal and vertical eye movements of each eye by ENG using AC recording with a time constant of 1.0 seconds. In this study we analyzed only the horizontal component of nystagmus.

Each patient underwent biological calibration by visually following a lighted target, which automatically swept horizontally from 15 degrees right to 15 degrees left. Before caloric testing, we checked spontaneous nystagmus in patients with their eyes closed.

We performed bithermal caloric testing in supine patients with their eyes closed and the head elevated at 30 degrees. We irrigated one ear with 20 ml tap water at 44° and 30°C for 30 seconds in the following order: right ear at 44°C, left ear at 44°C, right ear at 30°C, and left ear at 30°C. We recorded the provoked response for at least 3 minutes. A 3-minute interval elapsed after each test.

We identified 10 seconds of the culmination period at the binocular trace for each caloric response. During the same period, we measured the slow-phase velocities, the amplitude, and the number of all nystagmic beats in the monocular traces for the right and left eye. We defined the average of slow-phase velocities as *maximum slow-phase velocity*, average of amplitude as the *maximum amplitude*, and the number of nystagmic beats as *maximum frequency* for the response of each eye. Those three parameters were calculated for four caloric responses.

We performed the rotation test after the Claussen method [4]. We rotated the chair first to the right with a linear acceleration of 3 degrees/sec^2. When the speed reached 90 degrees/sec, we maintained it constantly for 3 minutes. Then we abruptly stopped the chair within one-third of a second. We recorded postrotatory nystagmus thus provoked for at least 40 seconds. After a 5-minute interval, we repeated the same procedure with a rotation to the left. For the postrotatory nystagmus, we evaluated the number of nystagmic beats during the first 30 seconds. We did not measure the slow-phase velocity and amplitude, because those values decreased rapidly such that measuring them accurately was technically difficult.

All data are presented as mean plus or minus the standard deviation (SD) unless stated otherwise.

RESULTS

For the analysis of caloric response, we qualified a total of 135 patients (68 male, 67 female; age range, 21–69 years; mean age, 48.0 years; SD, 11.7). For the analysis of postrotatory nystagmus, we qualified 50 patients (29 male, 21 female; age range, 23–75 years; mean age, 48.3 years; SD, 12.0).

Figure 1 illustrates the ENG recording of caloric nystagmus derived from a 60-year-old female patient. During warm calorization, the movement between right and left eyes was almost identical. With cold calorization, the eye on the cold-irrigated side responded more intensively than did the contralateral eye.

Figure 2 graphically depicts the average and SD of maximum slow-phase velocity, maximum amplitude, and maximum frequency for the right and left eyes during the four different caloric stimulations. During warm calorization, these three parameters showed no significant difference between a patient's two eyes. Conversely, during cold calorization, the eye on the cold-irrigated side responded significantly more vigorously than did the other eye. The maximum slow-phase velocities were 20.2 ± 12.0 (irrigated side) and 15.2 ± 9.5 degrees/sec (other side) during right-ear cold calorization ($p < .01$), and 20.4 ± 12.7 (irrigated side) and 16.6 ± 10.5 degrees/sec (other side) during left-ear cold calorization ($p < .01$). The maximum amplitudes were 9.2 ± 4.4 (irrigated side) and 7.0 ± 3.5 degrees during right-ear cold calorization ($p < .01$), and 8.4 ± 3.7 (irrigated side) and 7.4 ± 3.5 degrees (other side) during left-ear cold calorization ($p < .05$). The maximum frequencies were 12.5 ± 5.2 (irrigated side) and 11.1 ± 5.3 (other side) during right-ear cold calorization ($p < .05$), and 13.4 ± 5.5 (irrigated side) and 11.9 ± 6.2 (other side) during left-ear cold calorization ($p < .05$).

We compared the activities of right and left eyes by summating the maximum slow-phase velocities, maximum amplitudes, and maximum frequencies of each eye during all four caloric stimulations (Fig. 3). We

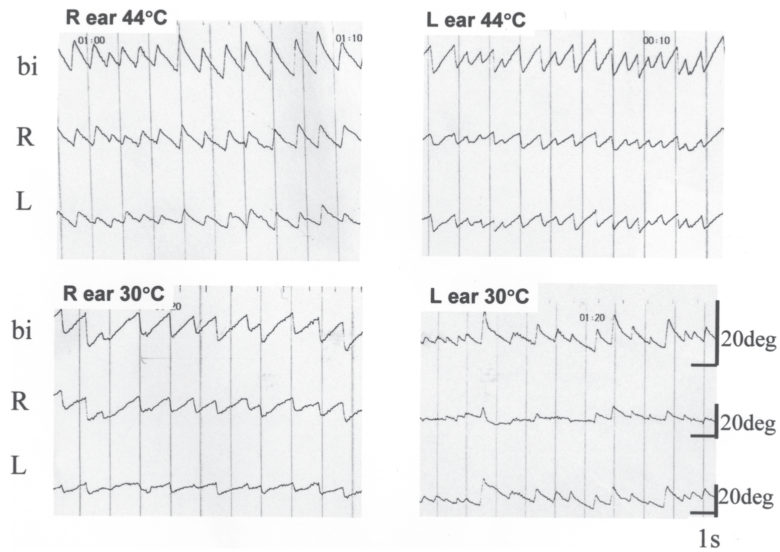

Figure 1. Electronystagmographic (ENG) recordings from a 60-year-old female patient. ENG was a horizontal recording with a time constant of 1.0 second. The traces were arranged such that info from both eyes (*bi*) appears at the top, followed by recording from the right eye (*R*) in the middle and then from the left eye (*L*) at the bottom. The upward deflection of the fast phase indicates right-beating nystagmus. With warm calorization, the responses were almost equal in both eyes, whereas with cold calorization, the response was remarkably greater in the eyes on the irrigated side.

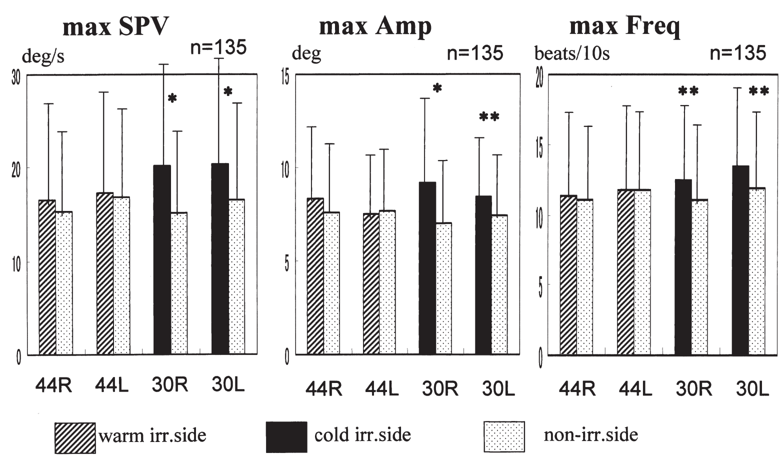

Figure 2. Analysis of caloric nystagmus: comparison between the eye on the irrigated side and the eye on the nonirrigated side in all four caloric stimulations (N = 135). Calorization was achieved with 44°C or 30°C water in the right (*R*) or left (*L*) ear. Maximum frequency (*max Freq*) represents the average of slow-phase velocities (*SPV*), amplitudes (*Amp*), and nystagmic beats during 10 sec of the culmination phase. Vertical lines in the bar indicate standard deviations. There was no significant difference between a patient's two eyes during warm calorization. During cold calorization, the eye on the irrigated side moved significantly more strongly than did the opposite eye (*$p < .01$; **$p < .05$).

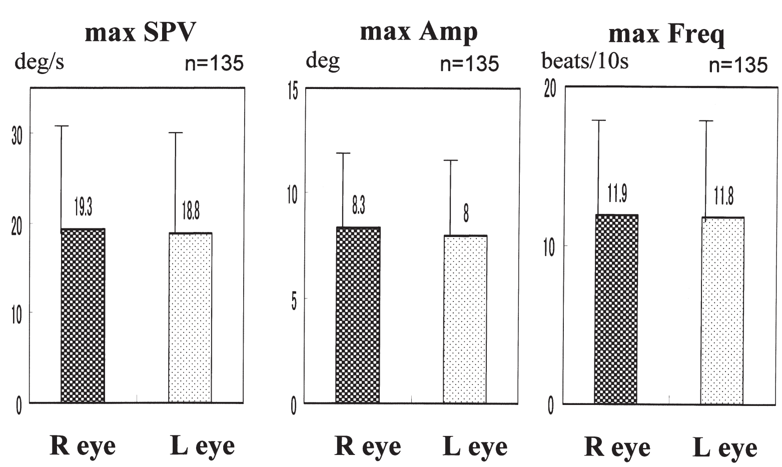

Figure 3. Analysis of caloric response: comparison between total response of the right and left eyes (N = 135). Maximum frequency (*max Freq*) represents the average of summated slow-phase velocities (*SPV*), amplitudes (*Amp*), and nystagmic beats during 10 seconds of the culmination phase in all four caloric stimulations of the right and left eye, respectively. Vertical lines in the bar indicate standard deviations. The average response is numerically demonstrated above each bar. There was no remarkable difference in movement between the two eyes of a single patient.

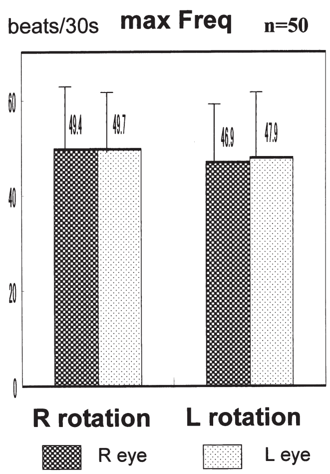

Figure 4. Analysis of postrotatory nystagmus: comparison between right eye and left eye. Maximum frequency (*max Freq*) represents the number of nystagmic beats during the first 30 seconds after cessation of chair rotation. No difference was found between the right and left eyes after rotation to the right (*R*) or left (*L*).

found no significant difference in the total activities of the two eyes. The number of beats of postrotatory nystagmus during the 30 seconds after cessation of the rotation to right or to left was almost equal between the two eyes (Fig. 4).

DISCUSSION

We evaluated nystagmus response during the bithermal caloric test for each eye separately in vertiginous patients. Using a large sample of normal volunteers would have been ideal for the investigation, but it is difficult in reality. Thus, we recruited for our study patients who had normal or very close to normal vestibular and optic functions. We found in our patients that cold caloric stimulation provoked a significantly larger response in the eye on the irrigated side, whereas warm calorization provoked almost similar activities in both eyes. We proved that tendency by measuring the slow-phase velocity, the number of beats, and the amplitude of nystagmus during the culmination phase.

What led to the stronger response of the eye on the cold-irrigated side as compared with that of the contralateral eye? Cold calorization of one ear causes decreased activity of the ampullary nerve of the horizontal semicircular canal on the irrigated side. That decreased activity is transmitted through an inhibitory pathway (Fig. 5A)—the neural pathway that includes inhibitory neurons in its linkage—to cause contraction of the extraocular muscles [5,6]. As shown in Figure 5A (i.e., the inhibitory pathway), a *three*-neuron pathway transmits the signals to the ipsilateral extraocular muscles, and a *four*-neuron pathway transmits them to the contralateral

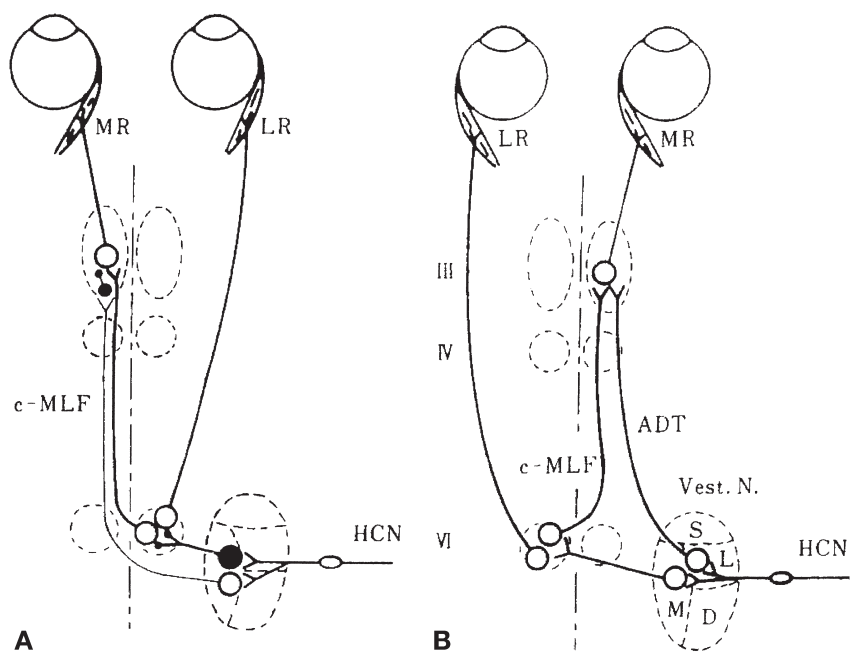

Figure 5. The vestibuloocular reflex: (A) inhibitory pathway and (B) excitatory pathway. Synaptic linkages from the ampullary nerve of the horizontal semicircular canal (*HCN*) to the extraocular motoneurons are depicted. (*ADT* = ascending tract of Deiters; *c-MLF* = contralateral medial longitudinal fasciculus; *D* = descending vestibular nucleus; *I* = inferior vestibular nucleus; *L* = lateral vestibular nucleus; *LR* = lateral rectus muscle; *M* = medial vestibular nucleus; *MR* = medial rectus muscle; *S* = superior vestibular nucleus; *Vest. N.* = vestibular nucleus; *III* = oculomotor nucleus; *IV* = trochlear nucleus; *VI* = abducens nucleus. White circles indicate the excitatory neurons and black circles, the inhibitory neurons.) Reprinted with permission from Uchino et al. [5].

side. As the ipsilateral inhibitory pathway contains one neuron less, we suspect that the efficacy of synaptic transmission might be greater in the ipsilateral side. When we suppose that the contraction of the extraocular muscles is the driving force of the slow phase of nystagmus and that the extraocular muscles of both eyes respond equally to the same amount of neuronal stimulation, we may expect that the eye on the cold-irrigated side will move more strongly than does the other eye.

Why did both eyes respond equally during warm calorization? Warm calorization causes an increase of activities in the ampullary nerve of the horizontal semicircular canal. The increased activity is transmitted through an excitatory pathway (see Fig. 5B)—the neural pathway that does not include inhibitory neurons in its linkage—to cause contraction of the extraocular muscles. As shown in Figure 5B, a *three*-neuron pathway transports the signals to the contralateral eye. To the ipsilateral eye, signals were carried partly by a *three*-neuron pathway (one that goes through the ascending tract of Deiters) and partly by a *four*-neuron pathway (one that goes through the medial longitudinal fasciculus). The neural linkages that connected the two eyes contain a *three*-neuron pathway. Therefore, no definitive evidence exists to indicate that the excitatory signals might be transmitted especially strongly to one eye, which would explain the almost equal responses of both eyes to warm calorization.

We compared the response of the right and left eyes in caloric nystagmus. In the beginning, we expected dominant activity in the right eye, as most of our patients are supposed to be right-handed. Dietrich et al. [7] used positron emission tomography and investigated cortical and subcortical activation during the bithermal caloric test. They demonstrated a significant right-hemispheric dominance for vestibular and oculomotor structures in right-handed volunteers and left-hemispheric dominance in left-handed volunteers. In our study, we did not detect any difference in the intensity of nystagmus between the right and left eyes. We suppose that the influence of a dominant hemisphere was not strong enough to cause a difference in right and left eye activation or that it was canceled out by another mechanism.

In postrotatory nystagmus after right rotation and after left rotation, no significant difference in intensity was evident between the two eyes. We presumed that the inhibitory neurons were stimulated to a saturated level during rotatory stimulation so that the responses of both eyes were equalized or that another central mechanism might have canceled the difference between the right and left eyes' activities.

CONCLUSION

We performed monocular ENG analysis during bithermal caloric testing in 135 patients who had presumably normal or very close to normal peripheral and central vestibular functions. We found that the eye on the cold-irrigated side moved more strongly than did the contralateral eye. We assumed that the inhibitory effect of cold calorization was transmitted more intensively to the eye on the irrigated side.

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