Effects of a Fixation Target on Torsional Optokinetic Nystagmus

Yasuo Suzuki,1 Yasubiro Shinmei,2 Hiroyuki Nara,3 and Tohru Ifukube3

PURPOSE. To investigate the effects of an imaginary and a visual target on torsional optokinetic nystagmus (tOKN) and directional symmetry of tOKN.

METHODS. Torsional OKN was induced by a rotating random dot pattern (52° in diameter, constant angular velocity: ±30 deg/sec to ±52 deg/sec) with an imaginary or a visual target in 11 eyes of 10 healthy humans by dual-search coil methods.

RESULTS. Intorsional OKN and extorsional OKN were symmetrical in their slow-phase gain. The mean slow-phase gain (0.057/0.041, intorsion/extorsion) of tOKN during fixation on a visual target at the center of the rotating random dot pattern was significantly (P < 0.002) smaller than that (0.051/0.052, intorsion/extorsion) during fixation on an imaginary target at the center of the rotating random dot pattern. The mean tOKN slow-phase beat duration (840 msec/724 msec, intorsion/extorsion) during fixation on the visual target was significantly (P < 0.002) longer than that (585 msec/543 msec, intorsion/extorsion) during fixation on the imaginary target. In seven eyes of six subjects, the mean slow-phase gain and beat duration (0.034 and 812 msec) of tOKN during fixation on a visual target 6.5° left or right from the center of the rotating random dot pattern were not significantly different from those (0.037 and 825 msec) with a visual target at the center of the rotating random dot pattern (P > 0.3).

CONCLUSIONS. A visual target spot suppresses tOKN by a nonpursuit visual system. Intorsional and extorsional OKNs were symmetrical. (Invest Ophthalmol Vis Sci. 2000;41:2954–2959)

Optokinetic nystagmus (OKN) is an eye movement to stabilize the retinal image during a movement of a large portion of, or of the entire, visual field. When the retinal image moves continuously in one direction, slow movements in the direction of the retinal image (slow phase) alternate with saccadic return movements (fast phase). OKN occurs not only in a horizontal or vertical direction but also in a torsional direction. When the visual field rotates around the maintained line of sight (direction of the gaze), OKN is induced around the line of sight.1 OKN consists of two parts that differ in their dynamics and rotational degrees of freedom. The early and latter parts of OKN have been considered to occur through the direct and indirect pathways2 that correspond to the pursuit and optokinetic systems,3 respectively. The degrees of freedom of OKN were investigated in the visual suppression of postrotational nystagmus of the three-dimensional vestibulo-ocular reflex (VOR) in rhesus monkeys. The latter part of OKN has three rotational degrees of freedom and contributes to the visual suppression of the postrotational nystagmus by decreasing the time constant of slow-phase velocity decay in three-dimensions.4 In contrast, the early part of OKN has only two rotational degrees of freedom and contributes to the visual suppression of the postrotational nystagmus by decreasing the peak slow-phase velocity in the horizontal and vertical directions.5 The early part of OKN is thought to be useful in stabilizing a moving object on the fovea, through the pursuit system, by increasing eye velocity to its maximum within 1 or 2 seconds at the onset of the optokinetic stimulus. Common stimuli for the horizontal and/or vertical pursuit systems are the target velocity on the retina and the target offset from the fovea.

Horizontal OKN is suppressed by fixating on a stationary visual target superimposed on the moving visual field.5,6 However, horizontal OKN is also suppressed by a visual target stabilized on the fovea7 or by an afterimage imposed on the fovea.8 In addition, the target stabilized on the retina could suppress horizontal OKN with no attempt to look (passive suppression), and the passive suppression of OKN declines with an increase in target eccentricity from the fovea by 15° to 20°.9 Because these targets when stabilized on the retina do not provide common stimuli for the pursuit system, it has been supposed that a visual target suppresses the horizontal OKN through a nonpursuit visual system as well. Furthermore, it has been determined that the horizontal OKN cannot be suppressed by voluntary effort (e.g., fixating on an imaginary target6). A stationary visual target, independent of moving retinal images, is necessary to suppress the horizontal OKN. Because the OKN operates in three dimensions, whereas the torsional pursuit system has yet to be demonstrated, the question arises of whether a stationary visual target superimposed on the rotating visual field can suppress torsional OKN (tOKN).

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through the nonpursuit visual system. Although gains of tOKN in humans with a visual target or an imaginary target at the center of rotating visual stimuli were reported in separate experiments (an imaginary target\(^1\); a visual target\(^2\)) gains of tOKN with these two kinds of target presentations have not yet been investigated in the same subjects with the same OKN stimuli. To clarify the role of the nonpursuit visual system on tOKN, we have investigated the slow-phase velocity gain and beat duration of tOKN during fixation on an imaginary or visual target superimposed on a rotating visual field in healthy humans by means of a dual-search coil system.

Although directional asymmetry of the slow-phase gain of the vertical and horizontal OKN has been reported in humans with binocular stimulation,\(^3\) clockwise and counterclockwise OKNs were reported to be symmetrical.\(^4\) To confirm the directional symmetry of tOKN, we analyzed intorsional OKN and extorsional OKN separately.

**METHODS**

**Subjects and Calibration**

Ten healthy subjects (8 men, 2 women, 20–40 years of age; mean age, 26 years) possessing normal visual acuity (better than 20/20 for each eye, with or without spectacle correction) gave informed consent to participate in this study. All experimental procedures conformed to the tenets of the Declaration of Helsinki for research involving human subjects. None of the subjects had any neurologic disorders on clinical examination. Refractive errors observed in these subjects were myopia or myopia with astigmatism and were not corrected by any devices during experiments. Eye movements were measured three dimensionally with two orthogonal magnetic fields (side length of cubic field coils was 89 cm) and a double-loop search coil (Skalar Medical, Delft, The Netherlands) on one eye. Four-channel coil signals were filtered (bandwidth for horizontal and vertical eye components was 0–200 Hz, and that for torsional eye components was 0–60 Hz) and digitized at 1000 Hz, written onto the computer hard disk, and processed offline. The double-loop search coil was calibrated before each experiment by mounting it on a protractor device that could be rotated in horizontal, vertical, and torsional planes (in vitro calibration).\(^1\) The in vitro calibration gave the lengths of the two coil vectors and their relative angles. The length of each coil vector represents the relative sensitivity of each coil in the two orthogonal magnetic fields. The sensitivity of the first coil wound in the horizontal plane is used to calibrate horizontal-vertical orientation of the eye, and the sensitivity of the second coil wound in the sagittal plane is used to calibrate the torsional orientation of the eye. Overall SD of position noise in this study was less than 0.1° for each component.

Each subject sat upright in a chair with his/her head fixed with a bite bar at the center of the cubic field coils. Five LEDs (0.2° in diameter, aligned vertically at intervals of 10°) fixed on a tangent board were presented at a distance of 100 cm in front of each subject during the in vivo calibration. After applying the coil, we calculated the orientation of both coil vectors and possible voltage offsets using the four-channel coil signals measured in the in vivo calibration during fixation of the vertically aligned five LEDs.\(^1\) We then carefully checked voltage offsets of the coil signals during each interval between recording sessions and compensated for them if necessary.

Calibrated three-dimensional eye positions were expressed as rotation vectors according to the right-hand rule.\(^4\) The direction and the length of the rotation vector represent the axis and the amount of rotation from a reference position, respectively. Eye position vectors were originally calculated in coil frame coordinates in which the torsional (x-axis) coincided with the direction of the LED when the subject looked straight ahead. Eye position vectors were rotated such that the null vector coincided with the primary position as defined by Listing’s law.\(^5\) The direction of the primary position (primary direction) was defined by spontaneous eye movements of approximately 100 seconds, recorded immediately after the in vivo calibration in each experiment. The cardinal axes of Listing coordinates point forward (x-axis), leftward (y-axis), and upward (z-axis). Rotations around the positive–negative x-axis, y-axis and z-axis yield extorsion-intorsion, depression-elevation, and adduction-abduction of the right eye, respectively.

The length of a rotation vector is given by \(|r| = \tan(\rho/2)\), where \(\rho\) denotes the amount of rotation: 0.005 \(\equiv 0.56^\circ\), 0.01 \(\equiv 1.1^\circ\), 0.05 \(\equiv 5.7^\circ\). Rotation angles in this study are shown in degrees for clarity.

**Experimental Protocol**

After the in vivo calibration, the tangent board with LEDs was replaced with a tangent screen. Thereafter, room lights were turned off, and the following sessions were performed in the dark. A round black pattern (52° in diameter) with randomly spaced white dots generated by graphic software (Superscope Visualizer; Superscope Inc., Hampshire, UK) was rear projected on the screen by an LCD projector (model XV-Z4000; Sharp, Osaka, Japan). Henceforth, we will refer to this form of visual stimulation as a random pattern. The random pattern could be rotated around its center with a constant angular velocity to induce tOKN. There was no white dot at the center of the random pattern that could act as a stable fixation target. The direction of the center of the random pattern coincided with the direction of the LED, while the subject gazed straight ahead during in vivo calibration. Similarly, a laser beam was rear projected on the screen as a visual target for fixation (a red-filled circle, 0.3° in diameter) by a servomotor-controlled mirror system that could change the position of the target.

**Experiment 1: Visual Target at the Center of the Random Pattern.** Both the random pattern and a visual target for fixation were rear projected onto the screen in this experiment. During the whole session, the visual target was presented at the center of the random pattern, and the subject was asked to fixate on it binocularly. At first, the random pattern was stationary for 30 seconds. Thereafter, the random pattern rotated for 30 seconds with a constant angular velocity (negative, counterclockwise rotation) and stopped. After an interval of 5 seconds, the random pattern rotated for 30 seconds with the same constant velocity but in the opposite direction (positive, clockwise rotation) and stopped. After a second interval of 5 seconds, the same presenting sequence of negative–positive rotation was repeated twice (in total, 90 seconds of negative rotation and 90 seconds of positive rotation).

**Experiment 2: An Imaginary Target at the Center of the Random Pattern.** Only the random pattern was rear projected on the screen in this experiment. During the whole session, the subject was asked to fixate on an imaginary target at the center of the random pattern binocularly. The rotating sequence of the random pattern was the same as in experiment 1.
Experiment 3: A Stepping Visual Target. This experiment was planned to test the effect of the stability of the visual axis on tOKN, because the stability of the visual axis observed in experiments 1 and 2 was different for each subject (see the Results section). The rotating sequence of the random pattern was the same as in experiments 1 and 2. A rear-projected target was moved in horizontal steps between 6.5° right and 6.5° left, passing through the center of the random pattern at 0.1Hz. The subject was asked to follow the stepping target as quickly as possible and to fixate on it binocularly. Three sessions of experiments 1 and 2 with a constant rotational velocity of 44 deg/sec were investigated in five subjects (five right eyes). Experiments 1, 2, and 3 were investigated sequentially with a constant rotational velocity of 52 deg/sec in four subjects (four right eyes) and with a constant rotational velocity of 30 deg/sec in two subjects (one right eye and two left eyes). Only the right eye of subject A was investigated, with two constant rotational velocities of 52 deg/sec (52AR) and 44 deg/sec (44AR).

Data Analysis

Three-dimensional (torsional, vertical, and horizontal) eye position traces were displayed on the computer screen for visual inspection. The onset and end of the slow phase of tOKN were identified manually, and periods with blinks were discarded. Thereafter, we calculated the mean coordinate velocity of the slow phase of tOKN [(torsional position at the end of the slow phase − torsional position at the onset of the slow phase)/duration] and the gain to the constant angular velocity of the random pattern. When the slow-phase velocity of tOKN was smaller than 1% of the rotational velocity of the random pattern, we discarded the data and did not include it in our database for further analysis. The mean percentages of discarded slow phases were 5.1% ± 5.4% (mean ± SD) in experiment 1, 1.8% ± 1.2% in experiment 2, and 3.7% ± 4.5% in experiment 3. The data from the left eye were converted to the right eye by changing the signs of the torsional and horizontal components.

The SDs of the horizontal and vertical components during fixation on an imaginary or a visual target at the center of the random pattern were used as an estimate to quantify the stability of the visual axis. In experiment 3, we calculated the SDs of the horizontal and vertical components during fixation on a target 6.5° to the right and left independently and averaged them out.

RESULTS

Figure 1 shows three components of the eye position during intorsional rotation of the random pattern with a constant velocity of 44 deg/sec (approximately 17 seconds) followed by no rotation of the random pattern (5 seconds) and extorsional rotation of the random pattern with a constant velocity of 44 deg/sec (approximately 28 seconds) in experiments 1 and 2 (44ER). Torsional OKN with a negative (intorsional) slow phase and positive (extorsional) fast phase was observed during intorsional rotation of the random pattern, and the signs of tOKN were the opposite during extorsional rotation of the random pattern in both conditions. However, the slope of the slow phase of tOKN (slow-phase velocity) in experiment 2 was steeper than that in experiment 1, and the tOKN slow-phase...
TABLE 1. Mean Slow-Phase Gain of Torsional OKN

<table>
<thead>
<tr>
<th>Exp. 1</th>
<th>Exp. 2</th>
<th>Exp. 3</th>
<th>Exp. 1</th>
<th>Exp. 2</th>
<th>Exp. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>4AR</td>
<td>0.052 ± 0.018</td>
<td>0.073 ± 0.022</td>
<td>0.075 ± 0.022</td>
<td>0.096 ± 0.031</td>
<td></td>
</tr>
<tr>
<td>4BR</td>
<td>0.025 ± 0.010</td>
<td>0.037 ± 0.011</td>
<td>0.036 ± 0.016</td>
<td>0.040 ± 0.014</td>
<td></td>
</tr>
<tr>
<td>4CR</td>
<td>0.028 ± 0.010</td>
<td>0.046 ± 0.017</td>
<td>0.026 ± 0.011</td>
<td>0.025 ± 0.009*</td>
<td></td>
</tr>
<tr>
<td>4DR</td>
<td>0.038 ± 0.012</td>
<td>0.046 ± 0.013</td>
<td>0.040 ± 0.012</td>
<td>0.048 ± 0.013</td>
<td></td>
</tr>
<tr>
<td>4ER</td>
<td>0.045 ± 0.015</td>
<td>0.056 ± 0.020</td>
<td>0.042 ± 0.014</td>
<td>0.062 ± 0.020</td>
<td></td>
</tr>
<tr>
<td>52AR</td>
<td>0.057 ± 0.022</td>
<td>0.059 ± 0.021*</td>
<td>0.043 ± 0.016</td>
<td>0.065 ± 0.026</td>
<td>0.068 ± 0.020*</td>
</tr>
<tr>
<td>52FR</td>
<td>0.022 ± 0.010</td>
<td>0.030 ± 0.012</td>
<td>0.023 ± 0.012</td>
<td>0.022 ± 0.007</td>
<td>0.032 ± 0.013</td>
</tr>
<tr>
<td>52GR</td>
<td>0.054 ± 0.013</td>
<td>0.045 ± 0.024</td>
<td>0.024 ± 0.010</td>
<td>0.047 ± 0.016</td>
<td>0.047 ± 0.018*</td>
</tr>
<tr>
<td>52HR</td>
<td>0.029 ± 0.012</td>
<td>0.035 ± 0.012</td>
<td>0.037 ± 0.006</td>
<td>0.027 ± 0.015</td>
<td>0.030 ± 0.012*</td>
</tr>
<tr>
<td>30IR</td>
<td>0.026 ± 0.009</td>
<td>0.053 ± 0.021</td>
<td>0.041 ± 0.013</td>
<td>0.053 ± 0.014</td>
<td>0.053 ± 0.025</td>
</tr>
<tr>
<td>30LL</td>
<td>0.042 ± 0.016</td>
<td>0.064 ± 0.028</td>
<td>0.031 ± 0.012</td>
<td>0.035 ± 0.019</td>
<td>0.061 ± 0.024</td>
</tr>
<tr>
<td>Grand mean</td>
<td>0.037 ± 0.014</td>
<td>0.051 ± 0.020</td>
<td>0.034 ± 0.012</td>
<td>0.041 ± 0.016</td>
<td>0.052 ± 0.018</td>
</tr>
</tbody>
</table>

Data are means ± SD.
* The difference between experiments 1 and 2 is not significant (P > 0.05).

beat duration in experiment 2 was shorter than that in experiment 1 (Fig. 1). Mean ± SD of the tOKN slow-phase gain for each subject in experiments 1 and 2 are summarized in Table 1. Similarly, Mean ± of the tOKN slow-phase beat duration for each subject in experiments 1 and 2 are summarized in Table 2. No significant difference in the slow-phase gain of tOKN was observed between experiments 1 and 2 during the session of subject A with a constant velocity of ±52 deg/sec (52AR). However, the slow-phase gain of tOKN in experiment 1 was significantly smaller than that in experiment 2 during each of the three sessions, when a constant velocity of ±44 deg/sec was used (44AR, P < 0.05, two tailed t test, assuming unequal variance).

In the other 10 eyes, the majority (10/12 for intorsional slow phase, 7/10 for extorsional slow phase) showed a significantly longer mean duration in experiment 1 than in experiment 2 (P < 0.05, two tailed t test, assuming unequal variance). The grand mean of the duration in experiment 1 was significantly longer than that in experiment 2 (840 msec/585 msec for intorsion, 724 msec/543 msec for extorsion, experiments 1/2, respectively; P < 0.0001, two-tailed paired t-test).

In experiments 1 and 2, horizontal and vertical positions were stabilized well at the center of the random pattern, but the stabilization of the visual axis in experiment 1 was better than that in experiment 2 (Fig. 1). The mean SDs of the horizontal/vertical components were 0.42°/0.57° (n = 12) in experiment 1 and 0.93°/1.02° (n = 12) in experiment 2, respectively. The differences in the mean SDs were significant between these two experiments (P < 0.001, two-tailed paired t test, n = 12). To test the effect of the stability of the visual axis on tOKN, we investigated tOKN during fixation on a visual target at 6.5° right or left from the center of the rotating random pattern in seven eyes (experiment 3). We averaged the

TABLE 2. Average Slow-Phase Beat Duration of Torsional OKN

<table>
<thead>
<tr>
<th>Exp. 1</th>
<th>Exp. 2</th>
<th>Exp. 3</th>
<th>Exp. 1</th>
<th>Exp. 2</th>
<th>Exp. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>4AR</td>
<td>676 ± 469</td>
<td>487 ± 300</td>
<td>577 ± 351</td>
<td>401 ± 222</td>
<td></td>
</tr>
<tr>
<td>4BR</td>
<td>790 ± 535</td>
<td>593 ± 314</td>
<td>691 ± 337</td>
<td>577 ± 282</td>
<td></td>
</tr>
<tr>
<td>4CR</td>
<td>752 ± 351</td>
<td>514 ± 244</td>
<td>855 ± 407</td>
<td>654 ± 334</td>
<td></td>
</tr>
<tr>
<td>4DR</td>
<td>645 ± 435</td>
<td>544 ± 286</td>
<td>587 ± 286</td>
<td>454 ± 194</td>
<td></td>
</tr>
<tr>
<td>4ER</td>
<td>884 ± 461</td>
<td>789 ± 430</td>
<td>787 ± 390</td>
<td>631 ± 363</td>
<td></td>
</tr>
<tr>
<td>52AR</td>
<td>494 ± 361</td>
<td>356 ± 226</td>
<td>453 ± 302</td>
<td>538 ± 304</td>
<td>316 ± 172</td>
</tr>
<tr>
<td>52FR</td>
<td>898 ± 598</td>
<td>714 ± 557</td>
<td>686 ± 522</td>
<td>675 ± 377</td>
<td>610 ± 431*</td>
</tr>
<tr>
<td>52GR</td>
<td>858 ± 529</td>
<td>629 ± 361</td>
<td>789 ± 300</td>
<td>578 ± 270</td>
<td>605 ± 332*</td>
</tr>
<tr>
<td>52HR</td>
<td>972 ± 640</td>
<td>583 ± 360</td>
<td>1121 ± 538</td>
<td>947 ± 609</td>
<td>530 ± 245</td>
</tr>
<tr>
<td>30IR</td>
<td>1143 ± 706</td>
<td>517 ± 262</td>
<td>834 ± 462</td>
<td>817 ± 320</td>
<td>551 ± 306</td>
</tr>
<tr>
<td>30LL</td>
<td>1023 ± 605</td>
<td>559 ± 354</td>
<td>1011 ± 659</td>
<td>857 ± 417</td>
<td>598 ± 391</td>
</tr>
<tr>
<td>30JL</td>
<td>949 ± 453</td>
<td>731 ± 486*</td>
<td>879 ± 385</td>
<td>799 ± 409</td>
<td>592 ± 347</td>
</tr>
<tr>
<td>Grand mean</td>
<td>840 ± 489</td>
<td>585 ± 346</td>
<td>825 ± 453</td>
<td>724 ± 373</td>
<td>543 ± 301</td>
</tr>
</tbody>
</table>

Data are mean milliseconds ± SD.
* The difference between experiments 1 and 2 is not significant (P > 0.05).
SDs of the horizontal-vertical components during fixation on a target at 6.5° right and left. Mean SDs were 0.60° and 1.02° (n = 7), respectively. Although the visual target superimposed on the rotating random pattern decreased vertical OKN in experiment 3, the stability of the visual axis in this condition was significantly lower than that in experiment 1 (with a visual, P < 0.05, two tailed paired t-test, n = 7).

Figure 2 shows three components of eye movements during experiment 3 (52AR). Torsional OKN with a positive slow phase was induced by the random pattern rotating with a positive constant angular velocity (52 deg/sec). Vertical OKN was not completely suppressed by the visual target superimposed on the rotating random pattern. Upward and downward slow phases of vertical OKN were observed during fixation on the target at 6.5° to the left and right, respectively. The mean gain of vertical OKN (vertical slow-phase velocity/vertical component of the random pattern velocity at the target) for each subject was less than 0.2. That was clearly lower than that reported without a visual target (0.817; 0.35–0.80 12). Mean slow-phase gain and beat duration of tOKN in experiment 3 are summarized in Tables 1 and 2, respectively. Grand means of the slow-phase gain (0.034) and beat duration (812 msec) of tOKN in experiment 3 were not significantly different from those (0.037 and 825 msec) in experiment 1 (P > 0.3, two-tailed paired t-test, n = 14) but were significantly different from those (0.051 and 564 msec) in experiment 2 (P < 0.002, two-tailed paired t-test, n = 14).

Four of 11 eyes showed directional asymmetry of the tOKN slow-phase gain in the same direction both in experiment 1 and experiment 2 (P > 0.05, two-tailed t-test, assuming unequal variance). The gain during the extorsional slow phase was larger than that during the intorsional slow phase in three of the four eyes, but the other eye showed the opposite asymmetry. The grand mean of the intorsional slow-phase gain was not significantly different from that of the extorsional slow-phase gain (P > 0.5, two-tailed paired t-test) for each condition (experiment 1, experiment 2). Only one eye (44AR) showed directional asymmetry of the tOKN slow-phase beat duration in the same direction, both in experiment 1 and experiment 2 (P > 0.05, two-tailed t-test, assuming unequal variance). Additionally, six eyes showed directional asymmetry of the tOKN slow-phase beat duration in either experiment 1 (three eyes) or experiment 2 (three eyes). In total, the mean intorsional slow-phase beat duration was longer than the mean extorsional slow-phase beat duration in four eyes in experiment 1 and in three eyes in experiment 2. However, the other eye in experiment 2 showed opposite directional asymmetry. Therefore, the directional asymmetry in the grand mean of tOKN slow-phase beat duration was observed in experiment 1 (P < 0.01, two-tailed paired t-test) but not observed in experiment 2 (P = 0.118, two-tailed paired t-test).

**Figure 2.** Three components of 10-second eye movements with the random pattern rotating at 52 deg/sec in experiment 3 (52AR). Fixations were moved in horizontal steps between 6.5° right and 6.5° left.

**DISCUSSION**

When tOKN was induced by the rotating random pattern during fixation on a visual target (experiment 1) or an imaginary target (experiment 2) at the center of the rotating random pattern, notable horizontal-vertical OKN was not observed. However, the stability of the visual axis at the center of the random pattern in experiment 1 was better than that in experiment 2. When the visual target was superimposed at 6.5° right or left from the center of the rotating random pattern (experiment 3), vertical OKN was suppressed well, in accordance with previous reports.5,6,8 Although the stability of the visual axis in experiment 3 was significantly lower than that in experiment 1, significant differences in the slow-phase gain and beat duration of tOKN were not observed between them (Tables 1 and 2). We think that the stability of the visual axis itself did not affect the slow-phase gain and beat duration of tOKN.

The mean gains of tOKN obtained in experiment 1 (range: 0.022–0.075) were extremely low and variable across subjects in comparison with those reported in the horizontal and vertical directions.12,17 However, the gains of tOKN in experiment 1 agree with the mean gains reported by Cheung and Howard11 with a stimulus condition similar to experiment 1. They reported that the mean gains of tOKN induced by randomly spaced black disks in the white background and a coaxial red fixated target decreased with an increase in stimulus velocity. The mean gains in their study were approximately 0.08, 0.06, and 0.05 with stimulus angular velocities of 30 deg/sec, 45 deg/sec, and 60 deg/sec, respectively. Similarly, the mean gains of torsional OKN obtained in experiment 2 in this study (range, 0.025–0.096) were close to the mean gains of tOKN reported by Collewijn et al.10 using an imaginary fixated target at the center of a rotating random pattern similar to experiment 2. They reported that the mean gain of tOKN was almost constant (0.035 with a stimulus angular velocity of 6 deg/sec and 30 deg/sec, 0.033 with a stimulus angular velocity of 12 deg/sec). Mean gains for each subject in this study showed a slight tendency to decrease with an increase in the velocity of the random pattern, but mean gain differences between individuals were much more prominent (Table 1).

The mean gain with a visual target (experiments 1 and 3) was significantly smaller than that with an imaginary target (experiment 2). Although we could not determine whether the imaginary target suppresses tOKN, our results agree with previous observations in horizontal OKN that a visual target stabilized on the retina can suppress horizontal OKN better than an imaginary target.7–9 Because a torsional pursuit system does not exist, our results strongly suggest that a visual target can suppress tOKN through the nonpursuit visual system.

Leigh et al.18 reported that the change in the gain of torsional VOR (tVOR) induced by a textured background stabilized in space or to the head is larger than the gain of tOKN and that a mental effort in the dark (imagineing a stationary...
scene in space or a rotating scene with the head) has little influence on the gain of tVOR. Therefore, they proposed that visual information could change the gain of tVOR by a mechanism that is not optokinetic or pursuit. Because the gain of tOKN is also subject to change through the nonpursuit visual system, the interaction between tVOR and tOKN may not be a simple linear summation as in the linear model for horizontal and/or vertical visual–vestibular interaction.19,20

Directional asymmetry of the slow-phase gain of vertical and horizontal OKN has been reported in humans with binocular stimulation.12 The gain of the upward slow phase was larger than that of the downward slow phase, whereas that of the adductive slow phase was larger than that of the abductive slow phase.12 However, clockwise and counterclockwise tOKNs were reported to be symmetrical.11 In our study, 4 of 11 eyes showed a directional asymmetry in the slow-phase gain of tOKN ($P < 0.05$), but the grand mean of the gain of tOKN did not show directional asymmetry ($P > 0.5$). Therefore, we confirm that tOKN gain, induced by binocular stimulation, is symmetrical.

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References