Perception of Motion Smear in Normal Observers and in Persons With Congenital Nystagmus*

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Purpose. Despite incessant motion of the retinal image, persons with congenital nystagmus (CN) usually do not report that targets are smeared. The authors investigated whether the brief stationary glimpses of a target that occur during foveation periods in the CN waveform contribute to the alleviation of perceived smear.

Methods. Retinal image motion simulating that in jerk nystagmus was produced in normal observers (N = 10) who monocularly viewed either a 5-minute or a 1° luminous disk reflected from a horizontally oscillating mirror. Contrast sensitivities to detect each target and to perceive the presence of motion smear were determined for two simulated CN waveforms; observers also estimated the length and brightness of perceived smear for several suprathreshold target luminances. One waveform was a 7°, 4-Hz ramp that included 120 msec zero-velocity intervals, simulating the foveation periods in the CN waveform. The second waveform lacked the zero-velocity simulated foveation periods. For comparison, estimates of perceived smear for physically stationary targets were obtained from three observers with CN.

Results. Normal observers' contrast sensitivities for perceiving smear were nearly identical for the simulated CN waveforms with and without a 120-msec foveation period. Estimated length and brightness of perceived smear for suprathreshold targets increased similarly with luminance for both waveforms. Observers with CN reported substantially less smear than did normal observers.

Conclusions. Glimpses of a stationary retinal image during simulated foveation periods do not attenuate the perception of motion-induced smear in normal observers. In persons with CN, the perception of smear may be reduced by the extraretinal signals that accompany their eye movements. Invest Ophthalmol Vis Sci. 1996;37:188-195.

Despite rapid rhythmic movements of their eyes, persons with idiopathic congenital nystagmus (CN) generally report that the visual scene is stable rather than oscillating in synchrony with the movements of their eyes. Perceptual stability apparently results, at least in part, from a neural cancellation of the retinal image motion by signals that represent the nystagmus eye movements.1-3 Recently, Dell'Osso et al4,5 and Abel et al6 suggested that the presence in the nystagmus waveform of well-developed foveation periods—intervals when the target of regard is imaged on or near the fovea with an eye velocity less than approximately 4°/second—may contribute to the prevention of oscillopsia. This suggestion was based on the observation that perceptual stability was disrupted in some patients when foveation periods were absent from the CN waveform or when the duration of foveation periods was brief.

The aim of this study was to examine the contribution of foveation periods to the reported absence of perceived smear in CN. In normal observers, rapidly moving targets produce the perception of smear,8 particularly in the absence of other nearby stationary9 or moving10,11 targets. A possible role of foveation periods in the elimination of perceived image smear is suggested by experiments by Smith and Gulick12,13 and Kaufman et al,14 who found that a moving target was less likely to appear smeared if, before and after the target moved, stationary glimpses of the...
target were provided at the end points of the motion trajectory. Also relevant is an experiment by Matin et al., who presented a bright target during a saccade and for varying intervals after the saccade was completed. When the target was exposed only during the saccade, observers perceived a smeared streak, the length of which corresponded closely to the target’s retinal image path. However, the length of the perceived smear decreased monotonically with the duration of the post-saccadic, stationary image of the target. Matin et al. concluded that the stationary retinal image of the target after the saccade backwardly masked perception of the smear that was produced by the retinal traverse of the target’s image during the saccade. In CN, the nearly stationary image of a target during foveation periods similarly could mask perception of the smear produced by the rapid motion of the target’s image during high-velocity components of the CN waveform. In our first two experiments, we tested this possibility by simulating the retinal image motion that exists in persons with CN in normal observers, thereby allowing us to control the durations of the (simulated) foveation periods as well as other nystagmus parameters. In the third experiment, we assessed the perception of smear in a sample of persons with idiopathic CN, using stimuli similar to those viewed previously by the normal observers.

METHODS

The target was an illuminated disk with a diameter of either 5 min arc or 1°, backprojected onto a 15° × 15° diffusing screen placed 67 cm from the observer. Target illumination was provided by a Kodak slide projector (Eastman Kodak, Rochester, NY), which could be attenuated by up to 4.9 log units in 0.1-log unit steps, using Tiffen (Hauppauge, NY) neutral density filters housed in a pair of filter wheels. The projector beam also passed through a broadband green filter (λmax = 530 nm) to eliminate most of the near-infrared light that was transmitted by the neutral filters. A second light source, placed remotely behind the diffusing screen and controlled by additional neutral filters, provided a homogeneous white background with a luminance of 32 cd/m². With the background field extinguished, the maximum luminance of the target was 440 cd/m².

Observers viewed the target and background field monocularly after reflection from a pair of front-surface mirrors. A head rest and chin cup minimized head movements. The mirror located closer to the observer’s right eye was mounted on a galvanometer (General Scanning, Watertown, MA), which, when rotated about its vertical axis, caused the observer to see simultaneous horizontal motion of the target and background field. Motion of the mirror was produced by voltage signals from a 3314A Hewlett-Packard (Marysville, WA) programmable function generator, operating under computer control.

Signals used to drive the mirror simulated the image motion from two different horizontal jerk nystagmus waveforms, each with an amplitude of 7°. Both waveforms consisted of an accelerating ramp (composed of three segments of increasing velocity, with an average velocity of 58°/second and a total duration of 120 msec) and a rapid (10 msec) flyback in the opposite direction to simulate the fast phase of jerk CN (Fig. 1). The two waveforms differed in the duration of the simulated foveation period. One waveform included a 120-msec, zero-velocity simulated foveation period just after the simulated fast phase, whereas the other included no simulated foveation period at all. Because the two waveforms were otherwise identical, the frequency of the waveform with the 120-msec simulated foveation period was 4.0 Hz, and the frequency of the waveform with no simulated foveation period was 7.7 Hz. In all experiments, the target and background field were visible continuously.

In experiment 1, we determined the contrast necessary to just detect each target and the contrast at which smear just became visible for each of the simulated CN waveforms. Contrast thresholds (ΔL/L) were determined by the method of ascending limits. While the observer viewed the repetitively moving display with his or her right eye, the experimenter increased the target luminance in 0.1-log unit steps until the observer could just detect the target against the
background field. The observer was then asked whether he saw the target as smeared. If the target was not seen as smeared at the detection threshold, the experimenter continued to increase the luminance of the target until the observer first reported smear. Observers were instructed that their criterion for smear should be the perception of any horizontal streak or horizontal elongation of the target. In addition, they were instructed to maintain fixation at the location corresponding to the target's position after the simulated fast phases of the waveform. Accurate tracking was impossible because of the high temporal frequencies of target motion used, however, eye movement recordings in two observers indicated that motion of a suprathereshold target induced an intermittent fine nystagmus (average amplitude = 0.65°, average slow phase velocity = 0.62°/second). For each observer, two consecutive measures of the thresholds for detecting the target and for perceiving smear were obtained for each combination of target size and waveform. Across observers, the testing order for the four conditions (two target sizes × two simulated CN waveforms) was varied pseudorandomly. Results of the experiment are expressed in terms of log contrast sensitivity, i.e., the logarithm of the inverse of the average threshold.

In experiment 2, observers estimated the length and brightness of the perceived smear produced by the targets used in experiment 1, presented at the detection threshold, the threshold for perceiving smear, and at several suprathereshold contrasts. For each combination of target size and motion waveform, target luminance first was increased to the detection threshold, as in experiment 1. The observer then made separate magnitude estimates, on a scale of 0 to 10, to indicate the length and brightness of any perceived smear. Additional estimates of the length and brightness of perceived smear were obtained subsequently when the luminance of the target was equal to the threshold for perceiving smear (if different from the detection threshold) and at two or three higher luminances. Observers were instructed to use a magnitude estimate of 0 when there was no detectable smear and a magnitude estimate of 10 when the length or brightness of the perceived smear was equal to that of a 440 cd/m² target, viewed with a motion amplitude of 7°, and a frequency of 7.7 Hz, produced by a constant-velocity ramp waveform. Magnitude estimates between 0 and 10 were to be assigned based on the fraction of the maximum smear length and brightness perceived. As in experiment 1, observers were told to maintain fixation at the position of the target after the simulated fast phases of the waveform. For each observer, one magnitude estimate for the length and brightness of perceived smear was obtained at each tested luminance level for the two target sizes and the two simulated CN waveforms. Because magnitude estimates were not obtained at equal luminance increments above the detection threshold for each observer, length and brightness estimates for the different observers were binned (0.3 log units/bin) and then averaged.

Ten observers with normal ocular motility and corrected visual acuity of 20/20 or better participated in experiments 1 and 2, after review of the experimental protocol by the University of Houston Committee for the Protection of Human Subjects and after voluntary written informed consent was obtained in accordance with the tenets of the Declaration of Helsinki. With the exception of the two authors, the observers were naive with respect to the hypotheses tested.

For comparison to the normal results, detection thresholds, thresholds for perceiving smear, and estimates of the perceived length of smear were obtained for three observers with idiopathic CN in experiment 3, again after obtaining voluntary, written, informed consent. Visual acuity, refractive errors, and parameters of these observers' nystagmus (assessed using infrared scleral reflection) are provided in Table 1. Sample traces of each observer's predominant nystagmus waveform are shown in Figure 2. The detection threshold and the threshold for perceiveing smear were measured as for the normal observers in experiment 1, except that retinal image motion of the target was produced by the observer's nystagmus eye movements instead of by oscillating the galvanometer-mounted mirror. Unlike the normal observers in experiment 2, the observers with CN estimated the length of perceived smear directy in millimeters, using an illuminated scale mounted below the target and background field but at the same viewing distance. By converting estimates of smear length to degrees, the perceived length of smear could be expressed as a fraction of the CN amplitude. Estimates of smear length were obtained for the observers with CN using the 5-minute and 1° targets against the bright (32 cd/m²) background field. To extend the range of suprathereshold luminances for which smear length could be estimated using the 5-minute target, this target was also presented against a dim background field of 0.8 cd/m². Observers with CN were not asked to estimate the brightness of the smear they saw because of the lack of a common reference.

RESULTS

Experiment 1

Normal observers' sensitivity for detecting the targets was considerably higher when the simulated CN wave-
Smear Perception

TABLE 1. Characteristics of Observers With Congenital Nystagmus

<table>
<thead>
<tr>
<th>Observer</th>
<th>Refractive Error</th>
<th>Visual Acuity (logMAR)</th>
<th>Predominant Waveform</th>
<th>Amplitude (°)</th>
<th>Frequency (Hz)</th>
<th>Foveation Duration (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFN</td>
<td>RE: +0.25–0.50 × 080 LE: +0.25 sphere</td>
<td>0.114</td>
<td>Pendular</td>
<td>4.7</td>
<td>2.8</td>
<td>60</td>
</tr>
<tr>
<td>AJ</td>
<td>RE: -3.00–1.75 × 005 LE: -3.00–1.00 × 003</td>
<td>0.159</td>
<td>Jerk left</td>
<td>7.7</td>
<td>5.0</td>
<td>64</td>
</tr>
<tr>
<td>FR</td>
<td>RE: +5.50–3.75 × 180 LE: +5.75–4.50 × 168</td>
<td>0.803</td>
<td>Pendular</td>
<td>10.8</td>
<td>3.0</td>
<td>36</td>
</tr>
</tbody>
</table>

form included a 120-msec foveation period than when it did not, as can be seen by comparing the leftmost and rightmost bars in Figure 3. This difference in contrast sensitivity for the two waveforms is not surprising because the waveform without a simulated foveation period provides only a limited opportunity for spatio-temporal integration.\(^{18,19}\) Contrast sensitivity was approximately 0.15 log units higher than shown in the leftmost bars of Figure 3 when the targets were presented without any motion. For the waveform that included a 120-msec foveation period, observers first saw the target as a stationary dot or disk and reported smear only when the contrast of the target was increased by an additional 0.80 (5-minute target) or 0.55 (1° target) log units, indicated by the lower contrast sensitivity for the center than for the leftmost bars in Figure 3. In comparison, when the waveform did not include a foveation period, observers perceived a streak or smear as soon as the target was detected. To assess whether the presence of the stationary target image during foveation periods attenuates the visibility of image smear, the appropriate comparison is between the contrast sensitivities for perceiving smear with and without a simulated foveation period. Comparison between the center and rightmost bars in Figure 3 indicates that the sensitivity for perceiving smear differs by only approximately 0.1 log units for the two waveforms. These small differences in contrast sensitivity for the two simulated CN waveforms were not significantly different for either the 5-minute (\(t_{0.05}=0.99, P > 0.30\)) or for the 1° (\(t_{0.05}=1.39, P \approx 0.20\)) target.

Experiment 2

Magnitude estimates pooled across the 10 normal observers for the length of perceived smear increase with target luminance over approximately the first 1.5 log units above the threshold for perceiving smear and then level off (Fig. 4, top). On the other hand, the estimated brightness of perceived smear increases essentially linearly with log target luminance over the range examined (Fig. 4, bottom). For a 5-minute target, the estimated length and brightness of perceived smear are less for the waveform that includes 120-msec foveation periods than for the waveform with no foveations. However, these differences are small; a shift along the luminance axis of 0.3 log units or less would bring the average estimates for the perceived length and brightness of the smear for the two waveforms into agreement. Statistical analyses indicated that only the estimates of perceived length for luminances less than 0.6 log units above the threshold for perceiving smear differ significantly for the two waveforms (Wilcoxon’s rank sum test; \(z = 2.42, P = 0.015\)). For a 1° target, the pooled estimates of the length and brightness of perceived smear are indistinguishable for the two simulated CN waveforms over the range of suprathreshold luminance levels tested. In general, then, even when the repetitively moving target is bright enough to produce a clear perception of smear, the length and brightness of the perceived smear depend little on whether the simulated CN waveform includes a foveation period.

Experiment 3

Contrast sensitivities for detecting the stationary 5-minute and 1° targets in the three observers with CN fall within the range of sensitivity of the normal observers for the two conditions of retinal image motion (Table 2). Observer CFN did not perceive smear of either target over a 2.5 to 3.5 log unit range of suprathreshold luminances against the 32 cd/m² background but did report smear when the 5-minute target was presented at 3.4 log units above its detection threshold on the 0.8 cd/m² background. Against the brighter background, observers AJ and FR first perceived smear when the 5-minute target was, respectively, 0.8 and 0.1 log units above the detection threshold and when the 1° target was 0.9 and 0.3 log units above the detection threshold. Results were similar for these two observers when the 5-minute target was presented against the dimmer background. However, the length of the smear reported by the three observers with CN was considerably less than reported by
FIGURE 2. Sample traces of horizontal eye position are shown for the three observers with congenital nystagmus (CFN, top; AJ, middle; FR, bottom). Each trace is positioned arbitrarily with respect to the associated vertical scale. Upward and downward deflections of the traces represent rightward and leftward eye movements, respectively. The time scale at the bottom applies to all three traces. The small fluctuations on CFN’s trace are noise.

the normal observers. This generalization is supported by the data shown in Figure 5, in which the estimates of perceived smear (in millimeters) of each person with nystagmus were converted to degrees of visual angle, normalized to the average amplitude of his or her nystagmus, and then multiplied by 10 to produce values on a scale comparable to that used by the normal observers. Note that the length of the smear perceived by the observers with CN never exceeded 15% of the nystagmus amplitude (i.e., 0.3° to 1.3°), even for target luminances that are more than 3 log units above the detection threshold.

DISCUSSION

Results of experiment 3 provide quantitative support, at least for three observers with CN, for the assertion made in the introduction that persons with CN typi-

FIGURE 3. Normal observers’ log contrast sensitivities (1/contrast threshold) are shown for detection and for the perception of smear in 5-minute (top) and 1° (bottom) targets moving in accordance with two simulated congenital nystagmus waveforms. Note that the sensitivities for detection and for perceiving smear were identical for the waveform without a simulated foveation period (rightmost bar). Each bar represents average data for 10 observers; error bars = 1 SD.
observers perceive is alleviated substantially if the motion of the retinal image contains intervals of near-zero velocity, simulating the foveation periods of the CN waveform. It is noteworthy that the normal observers perceived this extensive smear despite our using a simulated CN waveform with very long foveation periods, which we chose to maximize the opportunity for masking of image smear to occur. The small-amplitude, low-velocity eye movements that normal observers made when viewing the moving targets (see Methods) should have had little effect on our simulation; in fact, they probably resulted in a better approximation of the retinal image motion in CN than that produced by the highly regular motion of the mirror. We conclude, therefore, that the mere presence of foveation periods in the CN waveform is inadequate to account for the lack of perceived image smear in persons with CN.

What accounts for the apparent difference between our results and those of previous studies on normal observers, which indicated that the perception of motion-induced smear is alleviated by stationary targets? Smith and Gulick\textsuperscript{12,13} and Kaufman et al\textsuperscript{14} demonstrated that the velocity of motion at which smear was first perceived increases when stationary glimpses of the target are also provided before and after it moves. However, in Smith's and Gulick's experiments, adding 100-msec glimpses of a stationary target before and after each motion interval raised the velocity threshold for perceiving smear only from approximately 14°/second to 18°/second. In contrast, the image velocities in our simulated CN waveform, as in persons with CN,\textsuperscript{20} are much higher, averaging more than 50°/second during the nonfoveating portions of the slow phases. Further, unlike typical CN waveforms that contain only one foveation period per cycle, Smith and Gulick\textsuperscript{12,16} and Kaufman et al\textsuperscript{14} presented glimpses of a stationary target before and after each motion interval. In a subsidiary experiment, Smith and Gulick\textsuperscript{13} showed that when one of these stationary glimpses was reduced or eliminated, smear was perceived at a lower target velocity, although not

TABLE 2. Log Contrast Sensitivity to Detect 5-Minute and 1° Targets

<table>
<thead>
<tr>
<th>Observer</th>
<th>Log Contrast Sensitivity 5-min Target</th>
<th>Log Contrast Sensitivity 1° Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFN</td>
<td>1.46</td>
<td>2.36</td>
</tr>
<tr>
<td>AJ</td>
<td>1.16</td>
<td>2.36</td>
</tr>
<tr>
<td>FR</td>
<td>0.46</td>
<td>1.86</td>
</tr>
<tr>
<td>Normals (120 msec)</td>
<td>1.32 ± 0.27</td>
<td>2.14 ± 0.18</td>
</tr>
<tr>
<td>Normals (0 msec)</td>
<td>0.52 ± 0.17</td>
<td>1.59 ± 0.15</td>
</tr>
</tbody>
</table>
Smear Length: 5' Target Nystagmats

Smear Length: 1° Target Nystagmats

FIGURE 5. Estimated length of perceived smear is shown as a function of target luminance above the detection threshold for three observers with congenital nystagmus (indicated by different symbols). Estimates were converted to degrees and normalized to the average amplitude of each observer's nystagmus, equivalent to a value of 10 on the vertical axes. Results are for 5-minute (top) and 1° (bottom) targets against a 32 cd/m² background and for a 5-minute target against a 0.8 cd/m² background.

as low as when no stationary target was presented. In separate experiments, we have observed that the perceived length of smear for a target in nonrepetitive, constant-velocity motion is reduced considerably when a stationary image of the target is presented before and after the motion and very little when a stationary image is presented only before the motion.

Finally, we note that in the experiment of Matin et al., the retinal image motion resulted from a saccadic movement of the eyes rather than from motion of the target, as in the experiments of Smith and Gulick, Kaufman et al., and in our experiments 1 and 2. Extraretinal signals are known to accompany normal eye movements as well as the involuntary rhythmic eye movements in CN. We speculate that these extraretinal signals may help to suppress or alleviate the perception of smear that would otherwise be produced by the consequent motion of the retinal image. Altered processing of visual information in persons with CN, adaptation to the more or less continuous motion of the retinal image, or both, also may contribute.

Key Words
congenital nystagmus, contrast sensitivity, motion smear, visual masking

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References


