Reflexive Optokinetic Nystagmus in Younger and Older Observers under Photopic and Mesopic Viewing Conditions

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PURPOSE. To investigate the effect of age on optokinetic nystagmus (OKN) in response to stimuli designed to preferentially stimulate the M-pathway.

METHOD. OKN was recorded in 10 younger (32.3 ± 5.98 years) and 10 older (65.6 ± 6.53) subjects with normal vision. Vertical gratings of 0.43 or 1.08 cpd drifting at 5°/s or 20°/s and presented at either 8% or 80% contrast were displayed on a large screen as full-field stimulation, central stimulation within a central Gaussian-blurred window of 15° diameter, or peripheral stimulation outside this window. All conditions apart from the high-contrast condition were presented in a random order at two light levels, mesopic (1.8 cdm^{-2}) and photopic (71.5 cdm^{-2}).

RESULTS. Partial-field data indicated that central stimulation, mesopic light levels, and lower temporal frequency each significantly increased slow-phase velocity (SPV). Although there was no overall difference between groups for partial-field stimulation, full-field stimulation, or low-contrast stimulation, a change in illumination revealed a significant interaction with age: there was a larger decrease in SPV going from photopic to mesopic conditions for the older group than the younger group, especially for higher temporal frequency stimulation.

CONCLUSIONS. OKN becomes reflexive in conditions conducive to M-pathway stimulation, and this rOKN response is significantly diminished in older healthy adults than in younger healthy adults, indicative of decreased M-pathway sensitivity. (*Invest Ophthalmol Vis Sci.* 2006;47:5288–5294) DOI:10.1167/iovs.06-0539

Visual abilities decline as part of the normal aging process because of changes in central neural pathways and degradation in the optics of the eye.[1-3] Perception of coherent motion of central stimuli declines significantly with age,[4-9] particularly at slower speeds (less than 2°/s),[10] with reports of older women undergoing significantly more decline than men.[11] Peripheral motion processing also declines with age.[5,12] However, the evidence is not conclusive regarding whether any significant decline with age occurs in motion sensitivity for small, centrally located stimuli.[8,13] Most of these findings suggest an age-related decline in the magnocellular neural (M) pathway in vision.[14] In support of this, direct evidence indicates reduced neural responses to speed and flicker processing within areas 17 and 18 of rat cortex in the aged animal.[15]

In the present study, we examined the decline in the response to motion because of age. Rather than using direct measures of motion sensitivity as in previous studies, we measured changes in involuntary, reflexive optokinetic nystagmus (rOKN) to explore putative differences in M-pathway functioning in older and younger groups. rOKN, or Stier-nystagmus, occurs when observers do not actively follow specific features in the moving visual field but rather attempt to stare straight ahead.[16,17] rOKN is characterized by more frequent and smaller amplitude beats of lower "gain" than those recorded in voluntary "pursuit" OKN,[16,18] in which gain is slow-phase eye movement velocity (SPV) divided by the velocity of the moving stimulus.

A second feature of our study is that we recorded OKN under different ambient light levels because evidence suggests that vision under low light conditions is likely to favor M-pathway over P-pathway functioning. Purpura et al.[19,20] have shown in monkey that the M-pathway is the predominant conveyor of contrast information under mesopic/scotopic illumination, and this is supported by human data from simultaneous psychophysical and electrophysiological recording.[21] At scotopic light levels, these low spatial frequencies accentuate a significant diminution in average sensitivity with age.[22] In the present study, we tested our subjects at mesopic light levels, at which differences in sensitivity at the low spatial frequencies between the older and younger groups were smaller and the effect of senile miosis was minimized.[23] We also compared the rOKN with peripheral versus central stimulation: the absence of cones in the periphery ensures predominant M-pathway response even though the central visual field is more important in generating OKN.[24-26]

Finally, we studied rOKN in younger and older groups because a recent review of the literature on the effects of aging on eye movements[27] revealed a lack of data on rOKN and age. There is clear evidence that the SPV in pursuit OKN decreases with increasing age beginning at 30, but these differences only become marked with stimuli velocities greater than 50°/s and may not exist at slower speeds.[28-30] Such declines have tended to follow similar losses in smooth pursuit accuracy[31,32] and may be attributed to the fact that SPV in older people "saturates."[28,29] Older people with ocular disease also show reduced OKN responses compared to healthy controls.[27,33] The present study measured OKN in older and younger people and compared the results under photopic and mesopic light levels contrasting high-gain OKN data with low-gain rOKN.

METHODS

Participants

Participants were recruited from staff and students at Queensland University of Technology (QUT), the University of Queensland, and the wider community. Mean age of the younger group (five men, five women) was 32.3 years (SD, 5.98; range, 26–42), and mean age of older group (four men, six women) was 65.6 years (SD, 6.53; range, 53–75). All had normal or corrected-to-normal vision and were free of ocular disease. All participants were screened at the School of Optometry clinic at QUT, except for a 67-year-old woman who was tested by a private optometrist.

A clinical examination and a brief screening battery of tests were administered to ensure that all participants fulfilled the inclusion criterion of normal ocular health. These assessments consisted of biomicroscopy and ophthalmoscopic examination and measurement of intraocular pressure (Goldmann applanation tonometry), Bailey-Lovie MAR, Pelli-Robson contrast sensitivity, and perimetry with the Humphrey Field Analyser program 24–2 tested in each eye of each participant. Only participants with normal ocular health and visual acuity, and with contrast sensitivity and visual fields within the normal range were included in the study. Our research adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained from the subjects after explanation of the nature and possible consequences of the research. The QUT Human Research Ethics committee approved the research.

Stimuli

Achromatic vertical sine wave gratings were projected onto one wall of a darkened laboratory by a ceiling-mounted digital projector (808S; Barco, Kortrijk, Belgium), and a graphics computer (Onyx 300; SGI, Mountain View, CA) generated all stimuli. The observers viewed the stimuli binocularly at a viewing distance of 1.5 m, and the center of the image was indicated by a small fixation cross. The image size was 2.33 m high and 3.12 m wide and subtended $75.7° \times 92.2°$. Two light levels were used—a photopic light level of 71.5 cdm^{-2} and a mesopic light level of 1.8 cdm^{-2}. These levels were measured at the center of the image and represented the mean luminance of the grating. To ensure that the mean luminance for the photopic condition was at an appropriate level (>60 cdm^{-2}),[34] two arc lamps with diffusers (to avoid hotspots) were positioned 4 m apart and illuminated the wall at a distance of 3.5 m.

The gratings drifted from left or right at either slow (5°/s) or fast (20°/s) velocities, with a spatial frequency of either 0.43 or 1.08 cycles per degree (cpd) of visual angle. They were presented at two levels of Michelson contrast under mesopic conditions: low (8%) and high (80%), with only the low-contrast level possible under photopic conditions because the augmented background light level prevented sufficient modulation in the projected image to attain the high contrast. To ensure the visibility of our spatially coarse gratings for all participants in both age groups, the low-contrast condition was set at 8% contrast. This is, at the very least, five times threshold for our older group[23] and most probably greater than this given that slow movement at these spatial frequencies enhances contrast sensitivity.[35]

The gratings were presented as full-field stimulation across the entire image or as either central or peripheral (partial-field) stimulation. In central stimulation, a software mask was used such that the drifting gratings with full-contrast modulation appeared in a central circular region of 6° radius around the fixation cross. From a radius of 6° to 9°, the contrast modulation of the gratings diminished to zero following a Gaussian function, and the image was a uniform background gray beyond the central region of 18° diameter. Peripheral stimulation was the inverse of this: the central region was filled with uniform gray, and the periphery was filled with drifting gratings of full-contrast modulation.

Eye Movement Recording and OKN Analysis

Eye movements were recorded with a head-mounted system (Eye-Link I; SensoMotoric Instruments GmbH, Berlin, Germany) that records horizontal and vertical movement using video-oculography with infrared illumination of the eye. This system consists of binocular miniature cameras (with built-in infrared illuminators) attached to a lightweight padded headband. Eye position and relative pupil size data were recorded. Eye position data were acquired from each eye at a rate of 250 Hz, with a gaze accuracy less than 0.5° and with an eye rotation precision of 0.01°, as claimed by the manufacturer. Van der Geest and Frens[36] compared the performance of this system with a scleral coil system, and they found it to be remarkably accurate and precise, with average position discrepancy between the systems of less than 1° over a range of $40° \times 40°$ for saccadic velocities up to 300°/s. In some cases, heavy antireflection coatings on spectacles prevented recording of reliable, accurate eye position, and those participants were not included in this study. Our system consisted of a host computer containing a card (Eye-Link I; SensoMotoric Instruments GmbH) that acquired and stored the eye movement data and controlled the presentation of stimuli generated by the graphics computer (Onyx 300; SGI).

Eye movement record was calibrated automatically at the beginning of each session using the provided software (Eye-Link I; SensoMotoric Instruments GmbH). Raw data files of horizontal and vertical eye position for each trial were analyzed. The signal of only one eye was used because the eyes were yoked. The horizontal signal was displayed graphically on a position-versus-time *x-y* plot. A highly trained operator, masked to both the condition and the participant's identity, positioned a cursor at the beginning and end of the slow-phase of each candidate OKN beat and the end of the fast phase. The operator's scoring was highly reliable when tested against rescoring of a sample of the same data by another operator. A computer program then determined the slow phase velocity (SPV) of each beat that corresponded to the slope of a linear regression through all data points constituting the slow phase, the duration of that slow phase, and the amplitude of the fast phase in each beat. The program also discarded suspect beats if they failed to meet one of the following criteria: slow-phase duration greater than 150 msec, SPV greater than 0.5°/s,[37] fast-phase amplitude greater than 1°, and SPV within 3 SD of the average SPV in a particular trial.

Procedure

Participants were fitted with the headpiece (Eye-Link I; SensoMotoric Instruments GmbH), and their horizontal and vertical eye movements were calibrated. Trials were blocked by each of the two light levels: 24 trials were presented in random order under mesopic lighting conditions and 12 under photopic conditions. Each combination was tested: fast or slow drifting gratings, presented as full-field, peripheral, or central stimuli, at low or high contrast (if possible) at each of the two spatial frequencies. A 10-minute rest period was taken between the mesopic and photopic trial blocks, and the order of these blocks was randomized. All participants were dark adapted before viewing under mesopic conditions.

A 25-second OKN rest period was included between trials during which the participant viewed a uniform gray field. A trial began with the participant fixating the cross for 5 seconds. This was replaced with the drifting gratings for 20 seconds. During this period, participants were instructed to keep their gaze straight ahead, where the fixation cross had been, and not to track specific stripes. Eye movement data were acquired for the 20 seconds of the trial when the stimulus was visible and then for 10 seconds immediately after the removal of the stimulus. The entire experimental session lasted no more than 50 minutes.

RESULTS

Average pupil sizes for all participants were obtained under the mesopic and photopic conditions. A precise calibration of

these sizes in square millimeters for each participant was not possible because of differences in the working distance from the miniature camera to the pupil for each observer. However, a ratio of the pupil sizes (mesopic/photopic) was calculated for each participant, and analyses of variance (ANOVAs) were performed on these data for both groups. Mesopic pupil size was clearly larger than photopic (ratio >1; $F(1, 18) = 96.15$; $P < 0.0001$), but no effect of age group on the ratios ($F(1, 18) = 0.172$; NS) was observed.

OKN was analyzed from the last 15 seconds of each trial. The first 5 seconds of recording were discarded to ensure that only steady state OKN SPV was used.[17] Only 11 of the 960 trials analyzed did not produce OKN as defined by our criteria, and most of these trials were from younger participants spread across the mesopic, partial-field conditions. These data were excluded from further analysis. The eye movement record was also analyzed for optokinetic afternystagmus (OKAN) in the 10 seconds after extinction of the stimulus. Few OKAN beats fulfilled our criteria, and this precluded statistical analyses of these data. Clearly, the short duration of the OKN stimulation and the small size of the OKN beats were unable to sufficiently charge the brain stem velocity storage mechanism to yield OKAN.[38]

ANOVAs were performed on the OKN SPV data that were log-transformed because of the high level of positive skew in their distributions. Because of our inability to test high-contrast gratings under photopic conditions (see Methods), our experimental design was not completely balanced. For this reason, separate ANOVAs were performed on high- and low-contrast data, and an additional ANOVA was performed to test the interaction of contrast with the other factors. For ease of interpretation, analysis of partial-field data was conducted separately from the analysis of full-field data.

Partial-Field Analysis

Age group (older vs. younger) $\times$ stimulation (central vs. peripheral) $\times$ light level (mesopic vs. photopic) $\times$ spatial frequency (0.43 vs. 1.08 cpd) $\times$ drift velocity (slow vs. fast) mixed ANOVA was conducted on each of the low-contrast and high-contrast SPV partial-field data (the factor light level was dropped in the latter). These ANOVAs revealed significant main effects (all $P < 0.01$ or greater) for light level (low-contrast data: mesopic > photopic), for spatial frequency (0.43 > 1.08 cpd), for drift velocity (slow > fast), and for stimulation (central > peripheral). Mean $\pm$ SE representing these main effects, collapsed across all levels of the other factors, are presented in Table 1.

Full-Field Analysis

Full-field stimulation clearly produced faster SPVs in all conditions compared with their partial-field equivalents (Table 1).

Again, the ANOVAs revealed significant main effects (all $P < 0.005$ or greater) for light level (low-contrast data: mesopic < photopic) and for spatial frequency (0.43 > 1.08 cpd). There was no main effect for drift velocity resulting from the low-contrast data analysis; however, this main effect did reach significance for high-contrast data (fast > slow, $F(1,18) = 5.93$; $P = 0.026$). Mean $\pm$ SE representing these main effects collapsed across all levels of the other factors is also presented in Table 1.

Interactions with Contrast at Mesopic Light Levels

To test the interaction of contrast with the other factors, an age group $\times$ stimulation $\times$ contrast $\times$ spatial frequency $\times$ drift velocity mixed ANOVA was conducted on the mesopic SPV data for each of the partial-field and full-field data, dropping the stimulation factor in the latter. In both analyses, high-contrast conditions produced consistently higher SPVs than similar low-contrast conditions ($P < 0.0001$; Table 1). These analyses produced only one significant three-way interaction with contrast.

Interactions with Temporal Frequency

In consideration of interactions among factors, the spatial frequency $\times$ drift velocity interaction reached significance ($P < 0.005$ or greater) in every ANOVA, and this interaction is plotted for each of the high- and low-contrast, full- and partial-field conditions in Figure 1. Given that temporal frequency is the product of spatial frequency and drift velocity, the interaction was clearly the result of greatly reduced SPV in the highest temporal frequency conditions (i.e., 1.08 cpd drifting at the fast velocity). For the ANOVA conducted on mesopic, full-field data, a significant three-way interaction occurred—contrast $\times$ spatial frequency $\times$ drift velocity ($F(1, 18) = 4.86$; $P = 0.041$)—that subsumed significant interactions between frequency and contrast and between velocity and contrast in each instance. Even though photopic data were included (Fig. 1c), mesopic and photopic SPV means were similar; hence, the nature of this three-way interaction emerged (compare Figs. 1c and 1d). Here the highest temporal frequency stimulus caused a large diminution in SPV, but this diminution was much greater (almost to the extinction of OKN) for low-contrast than for high-contrast gratings.

In each of the partial-field analyses, there was a significant stimulation $\times$ drift velocity interaction (low contrast: $F(1, 18) = 23.64$; $P < 0.0001$; left-hand plot; high contrast: ($F(1, 18) = 8.49$; $P = 0.009$; right-hand plot; Fig. 2) where diminution in SPV for the faster velocity was greater with the central-field stimulation than with the peripheral-field stimulation. (Some of this diminution may be due to the fact that the image of the stimulus was projected onto a flat wall so spatial fre-

TABLE 1. Mean SPVs for Main Effects Collapsed across All Other Factors in Each of the Partial Field Stimulation Analyses and the Full-field Stimulation Analyses

Factor	Level	Partial Field		Full Field	
		Low Contrast	High Contrast	Low Contrast	High Contrast
Light level	Mesopic	2.51 ± 0.16	2.52 ± 0.25	4.03 ± 0.47	7.15 ± 0.59
	Photopic	2.42 ± 0.14	NA	4.76 ± 0.41	NA
Spatial frequency	0.43 cpd	2.79 ± 0.17	2.92 ± 0.25	5.59 ± 0.52	8.42 ± 0.89
	1.08 cpd	2.13 ± 0.14	2.10 ± 0.20	3.21 ± 0.30	5.89 ± 0.73
Drift velocity	Slow	2.63 ± 0.14	2.68 ± 0.21	3.88 ± 0.20	5.00 ± 0.19
	Fast	2.13 ± 0.14	2.34 ± 0.26	4.91 ± 0.56	9.31 ± 1.06
Stimulation	Central	3.06 ± 0.17	3.13 ± 0.25	—	—
	Peripheral	1.87 ± 0.12	1.89 ± 0.19	—	—

Values are mean ± SEM. NA, not available. High-contrast photopic stimulus could not be tested.
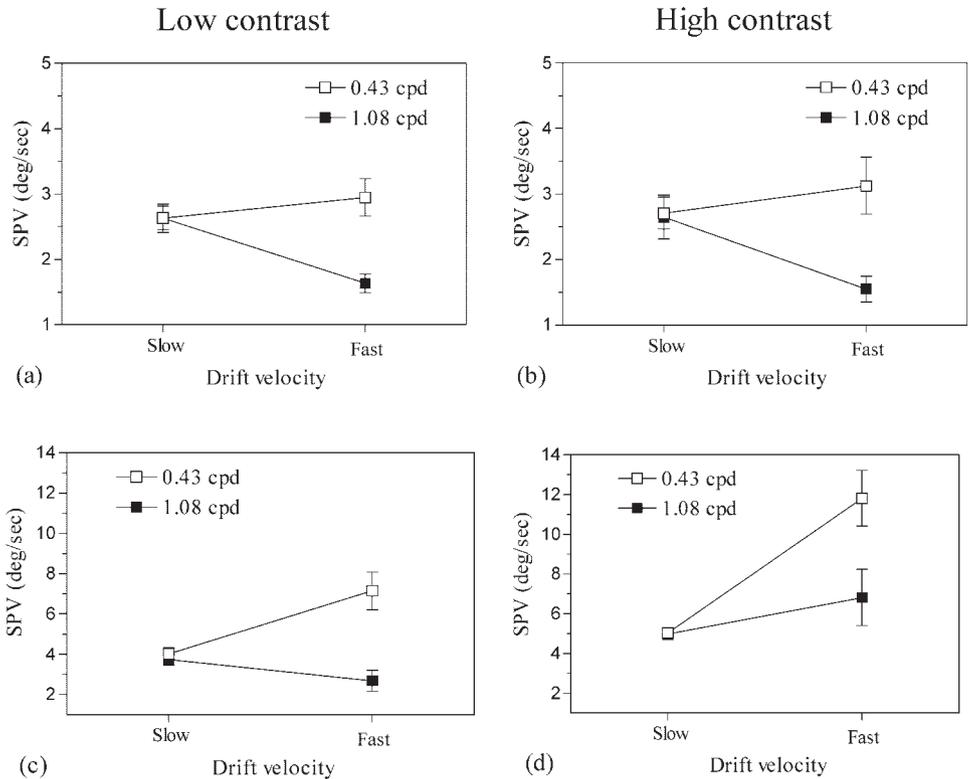
Low contrast

High contrast

FIGURE 1. Mean SPVs for interactions caused by temporal frequency in partial-field and full-field conditions. (**a**) Low-contrast, partial-field conditions. (**b**) High contrast, partial-field conditions. (**c**) Low contrast, full-field conditions. (**d**) High-contrast, full-field conditions. Error bars represent ± 1 SEM.

quency and velocity are geometrically distorted as a function of eccentricity, especially in the far periphery. For example, at 30° velocity is about 0.75× the value at 0° and spatial frequency is 1.33× the value. No correction for this was made in the software. Note that counteracting this artefact is the result from the partial field data analysis: *slower* drift velocity produced *higher* OKN gains but the *finer* spatial frequencies generated *lower* OKN gains.) Finally, in the low-contrast, full-field data analysis, there was a significant three-way interaction of light level × spatial frequency × drift velocity interaction ($F(1, 18) = 7.458$; $P = 0.014$; Fig. 3). OKN for the highest temporal frequency was virtually nonexistent under mesopic conditions but was restored by an increase in light level, whereas 0.43 cpd grating data were not affected by light level.

Interactions with Age

Although age group did not emerge as a significant main effect, some interesting interaction effects with age did emerge. For the low-contrast, partial-field analysis, there was a significant three-way interaction of age group × spatial frequency × drift velocity ($F(1, 18) = 7.460$; $P = 0.014$). An examination of the mean data revealed that this interaction was caused by the

older group having a significantly lower mean SPV than the younger group for the highest temporal frequency condition, whereas no between-group differences were observed for 0.43-cpd slow- or fast-velocity conditions.

With full-field analyses, significant interaction was observed for the low-contrast data age × light level ($F(1, 18) = 6.76$; $P = 0.018$). A larger drop-off was observed in SPV (photopic vs. mesopic) for the older group than for the younger group. This interaction was particularly prominent in the 1.08-cpd conditions, and an ANOVA on this condition alone revealed a main effect for light level ($F(1, 18) = 12.07$; $P = 0.003$) and a significant age group × light level interaction ($F(1, 18) = 6.87$; $P = 0.017$), as shown in Figure 4. This last result is also seen in the raw eye movement traces presented in Figure 5. It should be noted that in the older group, high-velocity, 1.08-cpd stimulation under mesopic conditions produced by far the lowest mean SPV of the entire experiment (0.85°/s).

DISCUSSION

Participants in both age groups performed rOKN rather than pursuit OKN in most of the stimulation conditions. OKN beats
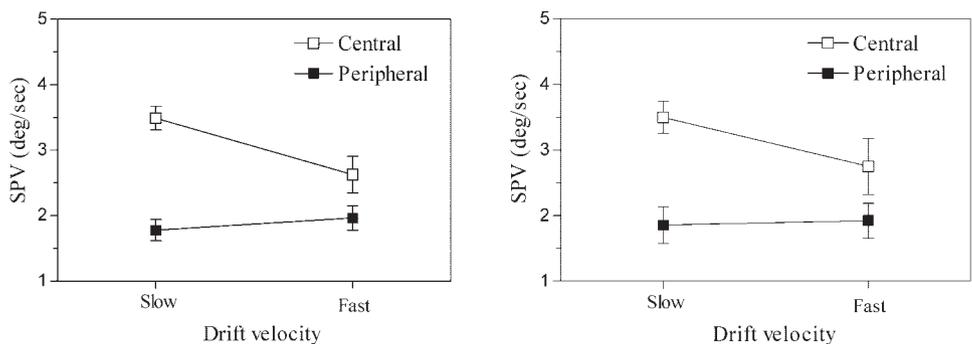

FIGURE 2. Mean SPVs for interactions between stimulation location and drift velocity for partial-field conditions. Plot on the *left* illustrates the interaction for low-contrast conditions, and plot on the *right* illustrates the interaction for high-contrast conditions. Error bars represent ± 1 SEM.
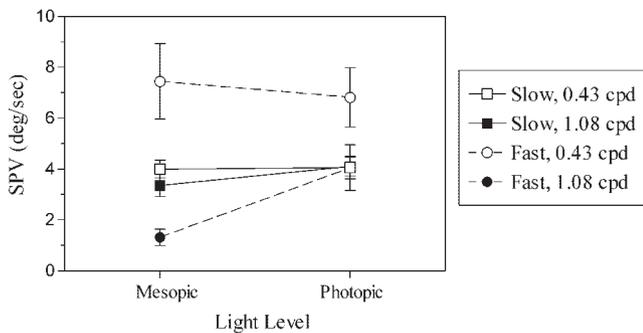
FIGURE 3. Mean SPV for full-field conditions, low-contrast gratings. Plots illustrate the interaction between light level × spatial frequency × drift velocity. Data for slow (5°/s) gratings were plotted with *solid lines*, and data for fast (20°/s) gratings were plotted with *broken lines*. Error bars represent ± 1 SEM.

were rapid, and there were no long, tracking slow phases or large excursions of gaze from the straight-ahead position, where participants were instructed to stare (Fig. 5).[16,37] In addition, except for slow-velocity, full-field conditions in which OKN gain was near unity (Figs. 1c, 1d), gains were lower than 0.7, which is indicative of rOKN.[16,39] In fact, the fastest SPVs for the entire experiment were recorded in the full-field, high-contrast, mesopic, 0.43-cpd conditions at the fast velocity with mean SPVs (±1 SEM) of 10.02° ± 2.15°/s for the older group and 13.59° ± 1.70°/s for the younger group. Gains here were still lower than approximately 0.7.

We believe our partial-field rOKN data provide new insights into the reflexive response of the M-pathway to motion. rOKN seems to be similar to pursuit OKN with partial-field stimulation, except that the OKN response is weaker and the gains are considerably lower. Modest increases in SPV were observed as contrast increased, and larger increases were observed as stimulation was changed from the peripheral field (where the area of stimulation is much larger) to the central field.[24–26,40] Unlike previous findings, we found that when we increased the velocity of the drifting gratings from 5°/s to 20°/s (a modest increase in the context of usual OKN stimulus velocities), a small *decrease* occurred in SPV for central stimulation (Fig. 2). Previous work on so-called passive OKN with partial-field stimulation at stimulus velocities of 20°/s and greater has shown modest increases in SPV with increasing velocity.[41] However, Abadi et al.[41] used low spatial frequency gratings of 0.25 cpd; therefore, the temporal modulation of most of their stimuli was lower than in the present experiment. Our SPVs and, hence, OKN gains seem to have been limited by the temporal modulation of the stimulus, even though the temporal frequency of the stimulus with the highest modulation (21.6 Hz) was lower than the limit (24 Hz) for optimal OKN,[39] but this limit might have been even lower under conditions of low light or low contrast.[40]

The interaction effects in our eye movement data among the different stimulus parameters— contrast, temporal frequency, and light level—strongly suggest rOKN is driven by the M-pathway and, hence, is indicative of the level of functioning of that system.[39,42] A recent fMRI study in humans has shown that unlike pursuit OKN, rOKN does not activate cortical oculomotor structures associated with planned eye movements[42]; rather, it strongly activates the traditional motion-processing cells in the medial temporal (MT) area of the macaque[43] and human[42] cortex. In addition, Crognale and Schor[37] have shown that the gain of rOKN in human observers is severely reduced compared with pursuit OKN, but only when the drifting patterns inducing the OKN are isoluminant (to which the M-pathways are unresponsive) rather than lumi-

nance modulated. In macaques, lesions interrupting M-pathway functioning have been shown to reduce the response to low-contrast gratings at high temporal frequencies, and this in turn is linked to deficits in motion perception.[44] These reductions and deficits become more prominent in low-contrast stimulation,[44] and M-pathway predominates over P-pathway functioning at low light levels.[19] Similarly, our mean SPVs and gains were reduced—that is, the OKN is clearly more reflexive[39] with higher temporal frequency stimulation, but more so in low-contrast than in high-contrast conditions (compare Figs. 1c and 1d for full-field stimulation). SPVs were actually slightly higher with mesopic than with photopic light levels with low gain OKN in partial-field stimulation.

The three-way interaction between light level and temporal frequency with full-field stimulation at low contrast shown in Figure 3 could also have been caused by M-pathway functioning. Note that the lowest SPVs occurred with high temporal, mesopic stimulation and that increasing the light level reduced the differences produced by high temporal versus low temporal stimulation (right-hand graph). Conversely, there was no effect of temporal frequency or light level for OKN gains over 0.7 (left-hand graph) corresponding to pursuit OKN. This connection between M-pathway and rOKN seems to have been stronger using central rather than peripheral stimulation, but it was best tested using full-field stimulation.

These interactions in the rOKN data were greater in the older group than in the younger group. In the partial-field, low-contrast conditions, the older group differed from the younger group in mean SPV but only with high temporal frequency stimulation. Such differences were even clearer with full-field, low-contrast stimulation. In Figures 4 and 5, the low-contrast, higher temporal frequency stimulation revealed differences between the groups but only with mesopic (vs. photopic) light levels. However, a potential problem may exist when comparing visual function in younger and older groups at low light levels because of the reduction in retinal illumination in older persons, caused by senile miosis, and the increased intraocular light scatter.[1,23,45] Such optical factors do not affect contrast thresholds at high levels of illumination and low spatial frequencies (below approximately 1.5 cpd), which are similar for subjects in their 20s and 70s.[10,35,46–49] We believe the age differences in our data cannot be attributed to reduced contrast sensitivity at low light levels in the older group given the light levels and contrast levels we have chosen, nor can they be attributed to differences in retinal illuminance caused by senile meiosis. No difference was observed in pupil size ratios between different light levels for the older and younger groups. Clearly, our mesopic light level was not dark enough to reveal the limitations in pupil dilation attributed to age.
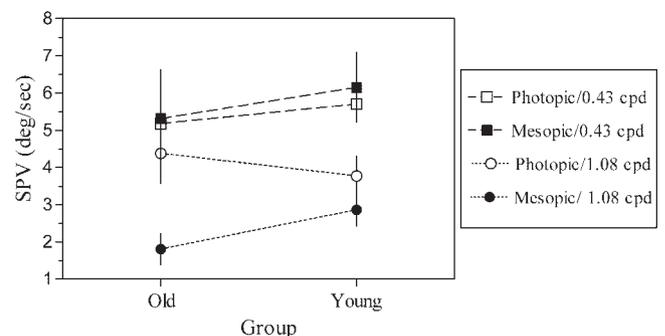

FIGURE 4. Mean SPV for full-field, low-contrast gratings, demonstrating interactions with age group and light level. Error bars represent ± 1 SEM.
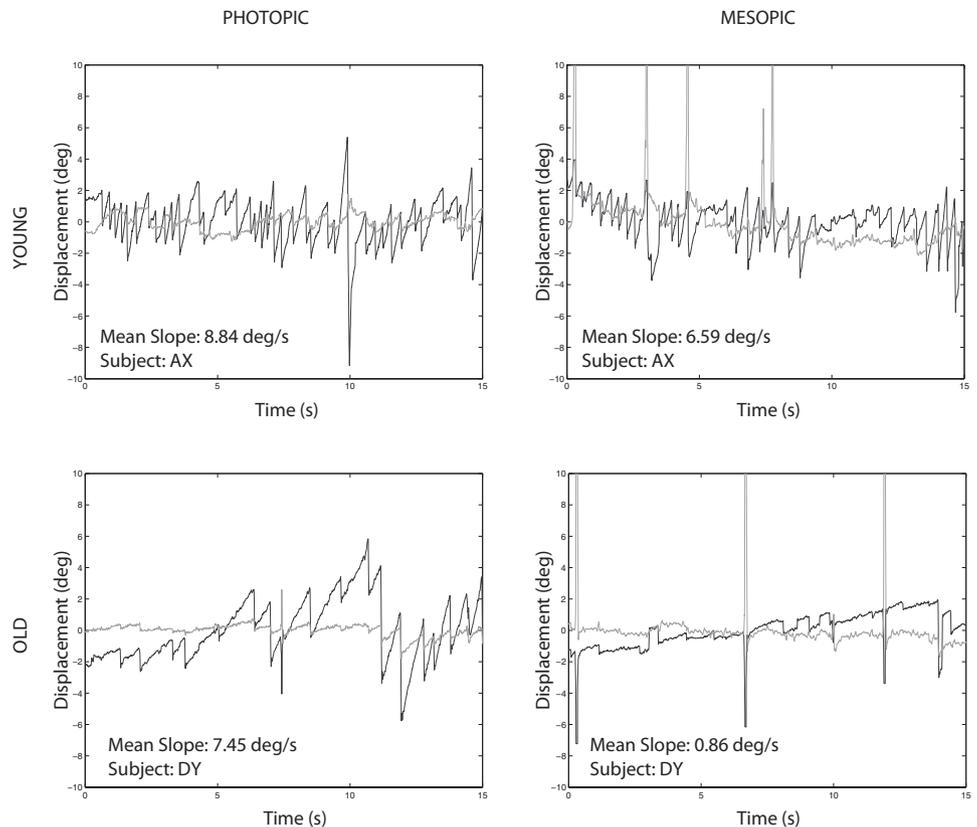
FIGURE 5. Typical raw eye movement data from the last 15 seconds of a trial: full-field, low-contrast, mesopic conditions, 1.08-cpd gratings drifting at the fast velocity of 20°/s. *Darker trace* is horizontal left eye movement, and *lighter trace* is vertical left eye movement. The residual vertical OKN seen during vigorous horizontal OKN (*left*) is probably an artifact of a slight misalignment between the horizontal direction of stimulus movement and the putative horizontal axis of eye movement recording. Participant AX (*upper traces*) is a 42-year-old man. Participant DY (*lower traces*) is a 74-year-old woman.

A motivation for doing this work was to record changing visual function in older persons who have normal scores on traditional clinical tests yet often report visual difficulties in day-to-day life. For example, as light levels decline and contrast decreases, research indicates that older drivers have greater difficulty with moving hazards than younger drivers.[50–52] Our rOKN age group differences occurred at low light levels, low contrast, and higher temporal frequencies, suggesting a reduction in M-pathway functioning in the older group compared with the younger group. This decline is exaggerated under mesopic light levels, a decline that may begin with reduced rod numbers and sensitivity in the healthy, but aging, macula.[53] However, one must be cautious in interpreting these results as a decline in all motion perception because it has recently been shown that for high-contrast stimulation (independent of light level), an older group performed better on a motion direction discrimination task than a younger group.[54]

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