Using Two Preferred Retinal Loci for Different Lighting Conditions in Patients With Central Scotomas

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Purpose. Using a scanning laser ophthalmoscope, it was found that some patients with relative central scotomas reliably used two different preferred retinal loci (PRLs) at different stimulus illuminances. This article describes adaptations in a patient’s PRL for fixation when dimming the stimulus increased the relative scotoma size.

Methods. Twenty-eight patients with macular diseases had their dense and relative macular scotoma borders mapped with the scanning laser ophthalmoscope. The high-illuminance PRL (PRLhi) and low-illuminance PRL (PRLlo) were operationally defined as the PRLs that patients used to fixate a high or low illuminance stimulus, respectively. The PRLs’ abilities to do visual tasks and their characteristics at the corresponding illuminances were assessed.

Results. The PRL consistently shifted between the PRLhi and the PRLlo as the stimulus illuminance was changed. Brightness permitting, the visual system prefers to use the PRLhi with generally better performance in visual function such as fixation stability. There were no significant differences between the PRLhi and the PRLlo in pursuit and saccadic abilities, when assessed by subjective ratings. The illuminances that induced shifting ranged from 106 to 3437 trolands. The PRLhi was always located within an area of relative scotoma, usually at the fovea or just outside a dense scotoma. The PRLlo was located in relatively healthy retinal area, and usually below or to the left of the PRLhi in the visual field.

Conclusions. In the visual system, two well-defined PRLs can develop when visual function is adapting to maculopathy, with the use of each depending on the brightness of objects used in visual tasks. Rehabilitation and treatment strategies should consider the existence of multiple PRLs. Invest Ophthalmol Vis Sci. 1997;38:1812-1818.

The preferred retinal locus (PRL) is the preferred retinal location used to perform visual tasks. Previous research has produced results demonstrating that in most patients with central vision loss affecting all of the fovea, an eccentric PRL will develop in the visual system that will be used to accomplish visual tasks, including fixation, reading, and tracking, that otherwise would be undertaken by the normal fovea.1-10

The use of the fovea and an eccentric retinal loca-
to the stimulus illuminance, the current study investigates the characteristics of these two PRLs developed for different lighting conditions during the adaptation to a central relative scotoma.

METHODS

Patients

Using the SLO, we examined 288 patients referred to a low-vision rehabilitation center. Thirty-one eyes from 28 patients (9.7%) used two PRLs, depending on the target’s brightness. Among them, 22 eyes had age-related macular degeneration, 7 had presumed ocular histoplasmosis syndrome, 1 had traumatic subretinal hemorrhage, and 1 had Stargardt’s disease. The median visual acuity of the 31 study eyes was 20/108 (range, 20/22 to 20/440). Most of the fellow eyes also had macular diseases with decreased vision. The median age of the patients was 70.5 years (range, 24 to 88 years). The median time since onset was 2 years (range, 2 months to 30 years). Tenets of the Declaration of Helsinki were followed, informed consent obtained, and institutional review board committee approval granted.

Scanning Laser Ophthalmoscope

The confocal SLO is a monocular testing device that, with graphics capabilities, allows the investigator to determine directly on the retinal image in real time the precise retinal location employed for visual tasks. The SLO obtains retinal images continuously with a near-infrared laser (780 nm) while simultaneously scanning graphics onto the retina with a modulated visible HeNe laser (633 nm). The stimuli are thus observed by the patients and on the patients’ retina by the investigator. A series of built-in filters can be used to change the overall HeNe laser power (target and background) in 12 illuminance levels. The retinal illuminance of the stimulus is adjustable by 256 steps. To calibrate the stimulus intensity, a power meter (Coherent Fieldmaster with LD-2 detector) was used to measure the output power at the position corresponding to the patient’s entrance pupil. The calibration of the retinal illuminance function is similar to the calibration of the luminance function of a monitor driven by a digital-to-analog converter. The SLO provides two image fields: a 32° × 24° image of the retina (labeled 20° field of view) with a minimum resolution of ~3.6 minutes of arc and a 16° × 12° image of the retina (labeled 20° field of view) with a minimum resolution of ~1.8 minutes of arc for measurement of the retinal areas and the positioning of targets.

Scanning Laser Ophthalmoscope Tests

To determine the location of the PRLhi and the PRLlo and their relationship to the target’s brightness, each patient was asked to look at a 1° cross with retinal illuminance initially at 45,000 trolands; then the stimulus illuminance was gradually reduced. The PRLs were operationally defined as the location where the cross is located on the fundus. The PRL used when the stimulus illuminance is relatively high or bright (before the PRL shift occurs) is the PRLhi; the one used when the stimulus illuminance is relatively low or dim (after the PRL shift occurred) is the PRLlo. Conversely, the PRLhi and the PRLlo were also determined by increasing the retinal illuminance from low to high. The results were then averaged to yield the critical stimulus illuminance corresponding to when the PRL shifted from one retinal location to another.

To illustrate the differences between these two PRLs regarding visual function and performance, the following visual tasks were assessed at the PRLhi and the PRLlo: threshold illuminance, visual acuity, fixation stability, pursuit ability, and saccadic ability. Except for the measurement of threshold illuminance, in all visual task assays, stimuli illuminances were set at 20,000 trolands for the PRLhi and at a level below the PRLhi’s threshold illuminance for the PRLlo.

Threshold Illuminance. Threshold illuminances were measured for both PRLs on a fixed, dark background. A 1° cross was placed at either the PRLhi or the PRLlo, which can be confirmed by viewing the SLO monitor. The illuminance of the cross was initially set to the minimum and then gradually increased until the patient pressed a button indicating the cross was just visible. This procedure was repeated three times to obtain an average for each PRL.

Visual Acuity. Visual acuity was assessed by SLO for the PRLhi and the PRLlo by displaying letters on the center of screen. The starting letter size was chosen according to the patient’s visual acuity, measured with a standard chart of the Early Treatment Diabetic Retinopathy Study (ETDRS). The patient read the perceived letters, and the investigator recorded the responses. An adaptive staircase Up-Down Transform Rule–Maximum Likelihood was used to determine the letter size for 75% confidence and for 95% confidence. Letter size with 75% confidence was then converted to log minimum angle of resolution (LogMAR) for statistical analysis.

Fixation Stability. The size of a PRL was measured to indicate fixation stability. The patients were asked to fixate as steadily as possible on the center of a 1° cross. A graphics circle was overlaid on the retinal image and a landmark selected—for example, vessel bifurcations or features of the retinal lesions on the fundus. The size of the circle was adjusted to encompass the maximum extent of landmark movement during 30 seconds of fixation, which is commensurate to the size of a PRL.

Pursuit Ability. The patient was instructed to follow
a moving target (12 minutes of arc square target). The target was moved vertically, horizontally, and circularly while the moving speed was varied from low to high until it could not be maintained by the patient. The PRL's ability to pursue was then determined by the speed of the pursued target and was scored subjectively from 0 (no ability) to 4 (normal ability to follow a fast-moving target) using the previously described scoring criteria.14

Saccadic Ability. Two 1° squares set 10° apart from each other were displayed vertically and horizontally. The patient was instructed to look at each in turn and the PRL ability for saccade was scored subjectively from 0 (no ability) to 4 (normal ability) using the previously described scoring criteria.14

The SLO hybrid macular perimetry technique that combines elements of static and kinetic methods was used to identify scotomas.15–17 Fixation was maintained on a 1° stationary cross. Dense scotoma was defined as consistent absence of response to the brightest stimulus (12 minutes of arc square target) with a retinal illuminance of 45,000 trolands. Relative scotoma was defined as consistent absence of response to a relative brightness (the PRLlo threshold illuminance was used in this study).

Other Tests

Binocular Preferred Retinal Locus Test. An SGI Crimson Elan (Mountain View, CA) graphics computer system was used to display stereo pairs sequentially on the screen at 120 Hz. The electronic eyewear or stereo view, a liquid crystal viewing device synchronized with the monitor, determines which eye sees each frame of the stereo pair. The test procedure has been described previously.18

Visual Acuity and Contrast Sensitivity. Visual acuity and contrast sensitivity with best correction were measured for both eyes with the ETDRS charts and Pelli-Robson chart, respectively, following a standard letter-by-letter scoring protocol.

RESULTS

Preferred Retinal Locus Shift

Figure 1 shows the results produced by SLO of a 45-year-old patient with presumed ocular histoplasmosis syndrome who had a PRL shift in the left eye. In the initial examination, SLO testing demonstrated that when stimulus illuminance was above 170 trolands (the threshold illuminance of the PRLhi in this patient), the PRLhi was used to perform fixation and other visual tasks. Otherwise, another retinal location, a PRLlo with a threshold illuminance of 42 trolands would be used. The patient underwent submacular surgery shortly after initial examination, which might have caused the change in the location and shape of scotomas. Nine months later, in a follow-up examination, the SLO confirmed that the patient still used two PRLs corresponding to the different stimulus illuminances. Both PRLs remained at the same locations and the PRL shift occurred at approximately the same illuminance. Binocular PRL testing revealed that the patient possessed monocular perception with left-eye dominance. An example of patients who had PRL shifts in both eyes is shown in Figure 2. The PRL shifts occurred at ~250 trolands in both eyes. The PRLhi and the PRLlo were used alternatively, depending on the stimulus illuminance. Binocular PRL testing indicated that the patient had binocular perception.

In all 31 eyes the PRL shift occurred reliably when the stimulus illuminance was changed to a certain level, either from high to low or from low to high.
Using Two Preferred Retinal Loci

FIGURE 2. A 67-year-old patient with age-related macular degeneration showing preferred retinal locus shifts in both eyes. The PRLhi and the PRLlo were used alternatively depending on the target brightness. DS = dense scotoma; RS = relative scotoma; T = threshold illuminance; PRLhi = preferred retinal locus with high luminance; PRLlo = preferred retinal locus with low luminance.

That is, when the target's brightness dropped below the threshold illuminance at the PRLhi, the shifts from the PRLhi to the PRLlo occurred; and vice versa. Therefore, the PRLhi's threshold illuminance was the important brightness that determined when the PRL shift occurred, which in our patients ranged from 106 to 3437 trolands (Fig. 3). For a given patient, the PRLhi's threshold could be sharply defined to several trolands or relatively noisy up to 20 trolands.

In 21 eyes the PRL appeared to shift immediately and directly between the PRLhi and the PRLlo, whereas the remaining 10 eyes appeared to wander for a few seconds before the shift was completed. However, there was no statistically significant difference between the two groups in age, time since onset of vision problem, scotoma type, binocular perception, and direction or distance of PRL shifts (one-way analysis of variance; contingency-table analysis). The shift pattern of PRLs in both groups is shown in Figure 4.

The distribution of the PRLlo appears always to be away from the fovea relative to the PRLhi. There was never an overlapping of the PRLhi and the PRLlo on the fundus in any case. The distance and direction of shift varied from patient to patient. The distances of PRL shifts ranged from 2.2° to 17° (median 4.6°). In most of the eyes observed, the PRL shifted either downward (14 eyes, 45.2%) or leftward (14 eyes, 45.2%) from the PRLhi to the PRLlo in the visual field. In only one eye (3.2%), the PRL shifted upward in the visual field (Fig. 5). In other words, in the majority of patients the PRLlo was located on the inferior, or the left, part of the visual field in relation to the central relative scotoma. Statistical analysis (multivariate ANOVA) indicates that neither the distance nor the direction of PRL shifts has significant correlation with age, visual acuity (determined by ETDRS chart), and contrast sensitivity (determined by Pelli-Robson chart). Three patients shifted their PRLs in both eyes: One patient had binocular perception, and the other two had monocular perception. Twenty-five patients shifted their PRLs in only one eye; two patients had binocular perception and, the rest had monocular perception. Of those 25 patients, 13 used the shift eye's PRL as the dominant PRL, and nine used the fellow eye's PRL as the dominant PRL. A binocular PRL test was not performed in 1 patient. Nevertheless, no statistical correlation was found between the PRL dominance and the type of PRL shift (contingency-table analysis).

Characteristics of Preferred Retinal Loci and Scotomas

Macular perimetry results showed that 20 eyes had dense central scotomas (of these, 16 eyes had only partial involvement within approximately the central...
The pattern of preferred retinal locus shifts in the visual field. (A) In these eyes, the preferred retinal loci shifted immediately and directly between PRLhi and PRLlo. (B) Eyes that usually wandered for a few seconds before the preferred retinal locus shifts were completed. The origins of the two plots are approximately the foveal location. PRLhi = preferred retinal locus with high illuminance; PRLlo = preferred retinal locus with low illuminance.

3°) surrounded by relative scotomas; one eye had dense paracentral scotomas and relative central scotomas; seven eyes had dense ring scotomas and relative central scotomas; and three eyes had no dense scotoma, only relative scotomas. The PRLhi was located within the area of the relative scotoma, usually at the fovea or just outside the dense central scotoma. In contrast, the PRLlo appeared to be located within an area of relatively healthy retina, immediately outside the relative scotoma area. As might be expected, the PRLhi provided better visual acuity than the PRLlo (differences between the visual acuities ranged from 0.08 to 0.58 LogMAR). The differences were significant except in two eyes (significant difference was defined as greater than 0.1 LogMAR). The PRLhi also had smaller fixation size (Student's t-test, p < 0.001). Based on subjective ratings of PRL ability, there were no significant differences between the PRLhi and the PRLlo in pursuit ability and saccadic ability (contingency-table analysis). The threshold illuminance of the PRLlo was always lower than that of the PRLhi (by definition) and the differences in threshold illuminances ranged from 89 to 2020 trolands.

DISCUSSION
The results of this study demonstrate that in some patients with central scotomas two well-defined PRLs can develop in the visual system, depending on the brightness of visual objects. These two PRLs probably develop naturally as the visual system attempts to adapt to central scotomas during activities of daily living. Brightness permitting, the visual system appears to prefer to use the PRLhi to take advantage of its better visual function (acuity and fixation stability) even though there was no significant difference in pursuit and saccadic abilities. However, when the target brightness is below the PRLhi's threshold illuminance, the system is constrained to the use of PRLlo.

The PRL shift always occurred in the eyes which had a relative central scotoma (never found in an eye without decreased visual sensitivity), but not all eyes...
with relative central scotomas demonstrated a PRL shift. The PRLhi was located within the area of the relative scotoma, usually at the fovea or just outside the dense central scotoma. Conversely, the PRLlo appeared to be located within an area of relatively healthy retina, immediately outside the relative scotomatosus area. The area of central scotoma and the depth of reduced visual sensitivity seem to determine the PRL shift. The light levels at which the PRL shift occurred in our participants ranged from 106 to 3437 trolands—well above the rod–cone break of the normal dark-adaptation curves. Therefore, the PRL shift is not related to the rod–cone shift. Rather, it appears to happen because the relatively healthy cones at the PRLlo have better visual sensitivity compared with that of the partially damaged cones at the PRLhi, which perform poorly when the target’s brightness falls below the higher threshold caused by macular disease.

In most of the eyes observed, the PRL shifted either downward or leftward from the PRLhi to the PRLlo in the visual field. In the majority of patients, this meant that the PRLlo was located to the left or below the central relative scotoma in the visual field. This leftward or inferior shift agrees with observations reported in previous investigations of PRL placement in relation to a central scotoma. However, the mechanism that govern the preference of PRL location in relation to central scotomas should be investigated further.

To understand the practical significance of the development and use of the PRLhi and the PRLlo in a patient’s normal daily lighting conditions, the brightness of a number of everyday objects was measured (in candelas per square meter) indoors and outdoors. The measured brightness was converted into trolands by using an idealized estimate of pupil area. In a low-vision rehabilitation center, the brightness of black-and-white reading materials ranged between 25 and 268 cd/m² (158 to 928 trolands); of human faces, between 14 and 67 cd/m² (102 to 334 trolands); and of the stairway, between 18 and 25 cd/m² (123 to 158 trolands). Outdoors under clear skies in the daytime, the brightness of human faces ranged between 106 and 254 cd/m² (468 to 880 trolands); of wristwatches, between 105 and 338 cd/m² (465 to 1171 trolands); and of traffic signs, between 186 and 856 cd/m² (702 to 2965 trolands). Some objects’ brightness measured in normal surroundings are comparable to the range of target luminance levels at which a PRL shift occurred in our patients. This implies that in everyday life such patients would use the PRLhi and the PRLlo alternatively to perform visual tasks under different lighting conditions. When lighting is optimal the PRLhi would be used, and the patient’s visual function and performance could be quite satisfactory. However, in low-light environments, compensatory visual performance might be made at the PRLlo in such activities as reading restaurant menus or walking after dusk, although the visual function would be less satisfactory. For these reasons, environmental conditions and lighting are much more critical for patients who use two PRLs.

Knowledge of the existence of dual PRLs and their individual characteristics is useful in guiding clinical treatment and is especially valuable in determining residual visual capacities, predicting functional difficulties, and planning appropriate adaptive strategies. By taking into account the lighting conditions corresponding to the use of different PRLs, predictions can be made of which daily activities are likely to be challenging, and different rehabilitation and treatment strategies can be formulated appropriately, according to each lighting condition.

**Key words**
illuminance, low vision, macular scotoma, preferred retinal locus (PRL), scanning laser ophthalmoscope (SLO)

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