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PURPOSE. To study normative ranges, learning effect (LE), test–retest variability (TRV), and influence of blur and cataract in normal subjects by using rarebit perimetry (RBP).

METHODS. Seventy-five normal subjects underwent visual field (VF) testing with standard automated perimetry (SAP) and RBP. LE and TRV for RBP were assessed in repeated examinations conducted on four different days. LE was evaluated by comparing results from the first with those of the other three sessions. TRV was studied by calculating differences between retest for each combination of single tests. The blur effect was evaluated by repeated tests with spherical lenses added to the optimum refractive correction (±1.00 to ±6.00 D). The cataract effect was studied in 23 subjects who underwent RBP 1 week before and 1 month after cataract surgery. Mean hit rate (MHR) and mean miss rate (MMR) were analyzed for single areas and test duration.

RESULTS. The mean MHR was 91% ± 5.7% (range, 78%–99%); the mean MMR ranged from 4.0% to 13.8%. MHR significantly decreased with age (mean, 0.21%/year). Mean test time was 265 ± 34.1 seconds. No significant LE was observed. TRV was significantly higher in the central VF zone and in elderly subjects. MHR increased with refractive blur and significantly decreased after cataract surgery. Effects of blur and cataract extraction were significantly higher in the central VF zone, especially in elderly subjects.

CONCLUSIONS. RBP is a rapid and easily accessible VF test. RBP testing did not show a significant LE; however, inter- and intrasubject variability were consistent. Blur and media opacities may give false-positive results in RBP, especially in the central VF, and should be considered. (Invest Ophthalmol Vis Sci. 2007;48:5320–5331) DOI:10.1167/iovs.06-1495

Rarebit perimetry (RBP) is a new perimetric method developed by Frisén in 2002,1 designed to detect subtle visual field (VF) damage. It utilizes spatially and temporally minute test stimuli (microdots or “rare bits”) to avoid the simultaneous stimulation of numerous retinal receptive fields, which tends to cause an underestimation of the VF defect. RBP has shown promising preliminary results in the early detection of VF damage in patients with neurologic disorders12 and glaucoma.3 RBP is simple, rapid, and inexpensive. Studies have shown that RBP is an interesting alternative technique for glaucoma screening and VF defect detection when compared with standard automated perimetry (SAP),3 frequency-doubling technology (FDT),4 and high-pass resolution (HRP)5 perimetry. Proper interpretation of RBP results and comparison with other types of perimetry, however, should consider RBP normative parameter ranges, learning effect, variability, and the influence of optical opacities and refractive correction.

Variability is inherently part of any VF testing, which is mainly due to factors that include fatigue, learning effect, visual artifacts, measurement errors, and the psychophysical test procedure itself.16 The learning effect has been reported in many studies of perimetry,7–9 which is normally manifested as an improvement in VF sensitivity and reduction in test result variability and is mainly due to a better understanding of the test procedure.8,10 VF test variability, encompassing both within-test and between-test components, tends to be greater in patients with sensitivity loss due to such ocular diseases as glaucoma, especially in areas of the VF that show relative or absolute defects.12 Variability within a dataset can be examined by a test–retest analysis, which quantifies the degree of scatter between measurements made on two or more data sets at different test sessions.13,14 The test–retest analysis can be regarded as a compound measure of within- and between-test variabilities.14 Test–retest variability (TRV) has been studied widely in various types of perimetry,14,15 especially regarding progression of VF loss.

Several studies have been conducted to investigate the effects of optical defocus on perimetric results.16,17 Refractive errors can be corrected by using the patient’s spectacles or trial lenses during testing, which can at times cause rim artifacts in the periphery, thus leading to diagnostic errors. It is therefore important to differentiate optical causes of neural VF loss and artifacts. The importance of refractive correction in RBP testing can be assessed by examining the effect of various degrees of refractive blur on testing.

The effect of cataract on each type of perimetry must be considered in interpreting VF results, especially considering the growing number of elderly subjects who undergo VF testing. It has been demonstrated that cataracts can give rise to pseudoglaucomatous VF defects or general reductions in sensitivity in SAP18 and that progressive lens opacity may mimic progressive glaucomatous field loss.19

The purpose of our study was to define a normative range for RBP parameters, and to examine thoroughly the learning effect, test–retest variability, and effects of optical defocus and cataract on RBP in a group of normal subjects and patients undergoing cataract surgery.

METHODS

Normal Range of RBP Testing

This observational study included 75 consecutive healthy adult subjects recruited as volunteers. The study abided by the principles of the Declaration of Helsinki and was approved by the Ethics Committee of our institution. Informed consent was obtained from each subject before enrollment. All subjects underwent a complete ophthalmic
examination (including best-corrected visual acuity [BCVA] evaluation, slit lamp examination, Goldmann applanation tonometry, and fundus biomicroscopy), SAP, and RBP testing within a 3-month period. Only one eye per patient was randomly selected for analysis when both eyes satisfied the inclusion criteria. Inclusion criteria were BCVA ≥0.8, open anterior chamber angle, absence of any ocular pathology, intraocular pressure (IOP) <21 mm Hg, normal optic disc appearance, and normal SAP results. Exclusion criteria included refractive error with a spherical equivalent > ±5 D, astigmatism ≥2 D, pupil diameter <3 mm, history of intraocular surgery, glaucoma family history, diabetes mellitus, neurologic or cognitive disorders, and medications that could alter the VF.

Optic disc and RNFL appearance were analyzed by an expert ophthalmologist with slit lamp indirect ophthalmoscopy and a 78-D lens. Normal optic disc and RNFL appearance was clinically defined as intereye vertical cup/disc asymmetry <0.2, cup-to-disc ratio <0.6, and the absence of diffuse or focal rim thinning, cupping, localized pallor, optic disc hemorrhage, or RNFL defects.

SAP testing was performed with the 30-2 program (Humphrey Field Analyzer [HFA] II 750; Carl Zeiss Meditec Inc., Dublin, CA), SITA standard strategy. Only reliable SAP results were considered, defined as false-positive and false-negative responses <33% and fixation loss <20%. The criteria for normal SAP results were defined as not having a cluster of three or more points with P ≤ 5% in the pattern deviation probability plot and pattern standard deviation (PSD) and glaucoma hemifield test (GHT) results within normal limits.10

The RBP procedure has been described elsewhere.1 In brief, RBP (ver. 4.0) is performed on a standard computer with a 15-in. liquid crystal display. The software (Windows format; Microsoft, Redmond, WA) is available free of charge from the author (lars.frisen@neuro.gu.se). The test stimulus is composed of two microdots with a size of the SAP stimulus), spaced 4° apart and simultaneously shown for 200 ms. The paired dots are oriented either horizontally or vertically and appear on the screen at random positions within each of 24 rectangular test areas. The tested areas were divided into three zones: 4 central areas, midperipheral (7 areas around the central ones), and peripheral (remaining 12 external areas).

**Learning Effect and Test–Retest Variability**

The learning effect and TRV were evaluated in 29 subjects selected at random from the 75 subjects to undergo four repeat RBP tests on four

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**FIGURE 1.** Size and distribution representation of the 24 test areas in RBP. The test areas were divided into three zones: 4 central, 7 midperipheral, and 12 peripheral areas.
different days within a 3-month period. To evaluate the learning effect, the test results obtained in the first session were compared with those obtained in other sessions. TRV was studied by calculating the mean, SD, and 95% CI of the differences at retest for each combination of single tests. TRV was calculated for both global and local indices. The effect of age on learning effect and TRV was assessed by allotting subjects according to age to three groups: under the age of 46 years (group 1), between 46 and 60 years (group 2), and over 60 years (group 3).

**Effect of Optical Defocus**

Tolerance to blur was tested in 27 subjects selected at random from the 75 subjects. Autorefractometer measurements were taken for each subject, and the spherical equivalence was used, whereby an additional +0.50-D sphere reduced the subject’s distance acuity by one line on the Snellen chart.21 Subjects underwent the first RBP test with their individual optimal refractive corrections using full-aperture (38-mm diameter) trial lenses, adjusted for a testing distance of 50 cm and 1 m, respectively. The test was repeated under refractive blur by the addition of positive and negative spherical lenses to the optimal refractive correction (+6, +5, +2, +1, −1, −2, −3, and −6 D, in random order). The effect of age on optical defocus was assessed in the three age groups.

**Effect of Cataract**

The effect of cataract extraction was determined in a separate group of 23 consecutive patients scheduled for cataract surgery, recruited prospectively from the Department of Ophthalmology of the S. M. Miserocordia Hospital of Udine from January to April 2006. All patients underwent slit lamp ophthalmic examination with dilation, in which the cataract was graded according to the Lens Opacities Classification System (LOCS) III criteria.22 In brief, a reference set of LOCS standard photographs was used as a comparison to define the extent (in the cortical, posterior subcapsular, and nuclear areas of the lens) and intensity of opacification and color of nuclear opacities. All patients underwent cataract grading by a single experienced ophthalmologist (MLS). Based on the structure of the lens, cataracts were defined as nuclear (N), cortical (C), posterior subcapsular (PSC), and mixed (a combination of two or more types in the same eye). After a brief RBP training and practice session, all patients were tested 1 week before and 1 month after surgery. RBP was repeated twice at each session, and only the second test was taken into consideration. Inclusion criteria were BCVA before surgery between 0.2 and 0.7, no ocular disease other than senile cataract, and IOP <21 mm Hg. Exclusion criteria included refractive error with spherical equivalent > ±5 D; astigmatism >2 D; pupil diameter <3 mm; history of intraocular surgery, diabetes mellitus, neurologic disorders, and medication that could affect vision; cataract surgery complications; and family history of glaucoma. The cataract surgical technique involved a small corneal incision, lens phacoemulsification, and insertion of an acrylic foldable intraocular lens (IOL) in the capsular bag by a single experienced surgeon (PB). The analysis included differences in RBP global and local indices before and after surgery.

Normality of the data distribution was assessed with the Kolmogorov-Smirnov test. Differences between test results were calculated using the paired t-test and the analysis of variance for variables that showed a normal distribution and the Wilcoxon and Friedman tests for those that did not. The Duncan multiple-range test was used for multiple comparisons. Comparisons between age groups were assessed using the unpaired t-test and analysis of variance for variables that showed a normal distribution and the Mann-Whitney and the Kruskal-Wallis tests for those that did not. The statistical analysis was performed with commercial software (SPSS 11.0; SPSS, Chicago, IL). Statistical significance was defined as $P < 0.05$.

**RESULTS**

**Normal Range of RBP Testing**

Seventy-one of the 75 subjects enrolled completed the study: 4 subjects were excluded because of lack of familiarity with the use of a computer mouse. The group was composed of 33 men and 38 women, with a mean age of 52.9 ± 13.7 years, ranging from 24 to 79 years (Fig. 2). The mean SAP-MD was −0.68 ± 0.71 dB and the SAP-PSD was 1.48 ± 0.44 dB. The mean SAP testing time was 433 ± 58 seconds.

The mean, SD, 95% CI and range for all the RBP global parameters analyzed are listed in Table 1. No differences were found in the mean MMR between the three different zones of eccentricity (Table 1; Friedman test, $P = 0.9$).

The distribution of the #MR (grouped as 10% increments as shown on the printout) for the different zones of the VF is shown in Figure 3. The average #MR at 0% was slightly lower (not significantly) in the central zone (44.2%) compared with the midperipheral (53.8%) and peripheral zones (56.0%; $\chi^2$ test).
test, \( P = 0.29 \). The average #MR in the 10% to 30% range were slightly higher (not significantly) in the central zone (52.7%) than in the midperipheral (41.5%) and peripheral zones (40.3%; \( \chi^2 \) test, \( P = 0.28 \). The #MR ranging between 40% and 60% were 2.0%, 4.1%, and 3.5% in the central, midperipheral, and peripheral zones, respectively (\( \chi^2 \) test, \( P = 0.33 \)). All tested areas in the normal subjects showed an MR <70%.

Figure 4 shows MMRs and SDs (\( n = 71 \)) at each of the 23 test areas. The Duncan multiple-range test was used to analyze the differences between test areas, which are shown as homogenous subset groups using gray-scale symbols (whereby areas having the same symbols do not show significant differences). MMRs ranged from 4.0% to 13.8%, showing a nonhomogeneous distribution (Friedman test, \( P = 0.001 \)). The test areas near the blind spot gave the highest MMR, whereas the midperipheral areas immediately above and below the nasal horizontal meridian gave the lowest values. MMRs were significantly different between the superior-nasal and superior-temporal quadrants (data not shown; Friedman test, \( P = 0.02 \)) and between the nasal and temporal hemifields (Wilcoxon test, \( P = 0.02 \)); however, they were not different between the superior and inferior hemifields (Wilcoxon test, \( P = 0.1 \)).

There was a significant decrease in MHR as age increased, showing a mean decrease of 0.21% per year (Fig. 5A; linear regression analysis, \( P < 0.01 \)). The MHR significantly increased with age (Fig. 5B; linear regression analysis, \( P < 0.01 \)), showing a mean increase in MHR at a rate of 0.29%, 0.23%, and 0.14% per year, respectively, in the central, midperipheral, and peripheral VF zones. The increase in MHR with age in the central zone was significantly higher than in the peripheral zone (Fig. 5B; \( F \) test, \( P = 0.03 \)). The average RBP test duration (268 ± 34.1 second) was significantly shorter than the SAP test duration (433 ± 58 seconds; paired \( t \) test, \( P < 0.01 \)).

### Learning Effect and Test–Retest Variability

Twenty-eight of the 29 enrolled subjects completed the series of four tests. One subject failed to complete all the tests and was excluded. The subjects included 13 men and 15 women (mean age, 50.8 ± 14.8 years; range, 24–79). The subjects were allotted to three groups according to age: 10 patients were included in group 1 (<46 years), 10 in group 2 (46–60 years), and 8 in group 3 (>60 years). The mean SAP-MD and SAP-PsD were −0.78 ± 0.75 and 1.63 ± 0.56, respectively.

Table 2 lists the means and SDs of all the RBP global parameters for the four repeated tests, including the mean of the differences (expressed in absolute values) between tests for each possible combination as a measure of TRV. None of the parameters showed significant differences between the four repeated tests (Table 2; analysis of variance and Friedman test, \( P > 0.05 \)). The mean TRV was 2.9% ± 2.1% for MHR, 2.6% ± 2.2% for MHR-SD, and 2.2 ± 1.9 for #MHR <90% (Table 2). The TRV for MMR were not significantly different in the three eccentric zones (Table 2; Friedman test, \( P = 0.6 \)). The means, SDs, and 95% CIs of the differences of the MMR for each tested area, as a measure of TRV, are shown in Figure 6. The Duncan multiple-range test was used to analyze the differences between test areas. TRV ranged between 4.9% ± 7.4% and 11.4% ± 9.2%, showing a nonhomogeneous distribution (Friedman test, \( P = 0.001 \)). The test areas near the blind spot gave the highest TRV, whereas the midperipheral inferior-nasal area gave the lowest TRV. All parameters did not show any statistically significant differences between the four repeated tests in the three age groups (analysis of variance and Friedman test, \( P > 0.05 \)). There was, however, a slightly higher but nonsignificant increase in MHR between the first and second tests in group 3 (Fig. 7). The mean TRV for MHR and MHR-SD did not show any significant differences between age groups (Fig. 8A; analysis of variance, \( P > 0.05 \)). The TRVs for MMR were similar in the three VF eccentricities in groups 1 and 2 (Fig. 8B; Kruskal-Wallis test, \( P > 0.05 \)); however, they appeared significantly higher in the central zone for group 3 (Fig. 8B; Kruskal-Wallis test, \( P = 0.03 \)). The TRV for MMR was significantly lower in group 1 than in group 2 in the central and midperipheral zones (Fig. 8B; Mann-Whitney test, \( P < 0.015 \)) and significantly lower

### Table 1. Rarebit Perimetry Global Indices in the Normal Group

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean (SD)</th>
<th>95% CI</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHR (%)</td>
<td>91.3 (5.7)</td>
<td>80.9–98.2</td>
<td>78–99</td>
</tr>
<tr>
<td>MHR-SD (%)</td>
<td>10.2 (4.1)</td>
<td>4.0–17.9</td>
<td>3.4–18.8</td>
</tr>
<tr>
<td>#MHR &lt; 90%</td>
<td>5.7 (4.4)</td>
<td>0–15.6</td>
<td>0–21</td>
</tr>
<tr>
<td>Central zone MMR (%)</td>
<td>9.2 (7.3)</td>
<td>0–28</td>
<td>0–32.5</td>
</tr>
<tr>
<td>Midperipheral zone MMR (%)</td>
<td>8.6 (6.9)</td>
<td>0–22.6</td>
<td>0–30</td>
</tr>
<tr>
<td>Peripheral zone MMR (%)</td>
<td>8.3 (6.2)</td>
<td>0.8–20.8</td>
<td>0.8–28.3</td>
</tr>
</tbody>
</table>

\( n = 71 \). MHR, mean hit rate; MMR, mean miss rate; #MHR < 90%, number of test areas with hit rate < 90%.
than group 3 in all VF zones (Fig. 8B; Mann-Whitney test, \( P < 0.01 \)). The TRV of MMR tended to be significantly higher in group 3 than in group 2 in the central zone (Fig. 8B; Mann-Whitney test, \( P = 0.048 \)).

**Effect of Optical Defocus**

Twenty-three of the 27 enrolled subjects completed the test. Four of the subjects failed to complete all the tests and were thus excluded from the analysis. The subjects included 10 men and 13 women (mean age, 51.7 ± 15.4 years; range, 24–77). The subjects were allotted to the three age groups: seven in group 1; eight in group 2; and, eight in group 3. The mean SAP-MD and SAP-PSD were \(-0.75 \pm 0.69\) and \(1.61 \pm 0.48\), respectively.

Refractive blur caused a decrease in MHR and an increase in MHR-SD in the three age groups (Fig. 9). With regard to refractive blur obtained with positive lenses, MHR decreases, and MHR-SD increases were statistically significant for lenses: \(+6 \text{ D in group 1}; \geq +2 \text{ D in group 2}; \text{and,} \geq +1 \text{ D in group 3}\). Similar results were found for refractive blur obtained with negative lenses using \(-6 \text{ D in all groups}\) (Fig. 9; Wilcoxon test, \( P < 0.05 \)). Figure 10 shows the effect of the refractive blur on the MMR for the three VF zones in the three groups. The increase in MMR caused by positive lens blur was statistically significant (Wilcoxon test, \( P < 0.05 \)) according to VF zone as follows: central zone for blur \(\geq +3 \text{ D in group 1}\) and for blur \(\geq +1 \text{ D in groups 2 and 3}\) (Fig. 10A); midperipheral zone for blurs of \(+6, \geq +3, \text{ and} \geq +1 \text{ D, respectively for groups 1, 2, and 3}\) (Fig. 10B); peripheral zone for blurs of \(+6, \geq +3, \text{ and} \geq +2 \text{ D, respectively, in groups 1, 2, and 3}\) (Fig. 10C). The increase in MMR caused by negative lens blur was statistically significant in group 1 for all VF zones with a \(-6 \text{ D lens blur and in groups 2 and 3 a blur of} \geq -3 \text{ D in the central zone and} -6 \text{ D in the midperipheral and peripheral zones}\) (Fig. 10; Wilcoxon test, \( P < 0.05 \)). RBP parameters seemed to be more affected by myopic blur (induced by positive-diopter lenses) than hyperopic blur in all three groups (Figs. 9, 10).

![Effects of Optical Defocus](image)

**Effect of Cataract**

A total of 23 patients were enrolled in the analysis of the effect of cataract extraction on RBP results. Three patients failed to complete the postoperative RBP testing. The subjects in the final analysis (\( n = 20 \)) included 8 men and 12 women, with a mean age of 65.6 ± 8.2 years (range, 45–75 years). The distribution of the patients based on cataract type was: nine nuclear, three cortical, two PSC, and six mixed opacification. The degree of the cataract severity ranged from II to IV. All patients were free of intra- and postoperative complications. The mean VA before surgery was 0.49 ± 0.2 (range, 0.3–0.7), which significantly increased after surgery to 0.91 ± 0.02 (range, 0.8–1.0; Wilcoxon test, \( P < 0.0001 \)). The mean MHR significantly improved from 67.5% ± 15.4% (range, 42.4%–87%) to 87.6% ± 6.6% (range, 78%–96.5%) after cataract surgery (Fig. 11A, paired \( t \)-test, \( P < 0.001 \)). MHR-SD significantly decreased from 26.7% ± 7.7% to 12.8% ± 4.3% after surgery (Fig. 11A, paired \( t \)-test, \( P < 0.001 \)). The average \#MMH < 90% also significantly decreased after surgery (from 14% ± 5.5% to 7.9% ± 5.2%; data not shown, paired \( t \)-test, \( P < 0.001 \)). MMR showed a statistically significant postoperative decrease in all 4 areas of the central zone, 5 of 7 areas in the midperipheral zone, and 4 of 12 areas in the peripheral zone (data not shown; Wilcoxon test, \( P < 0.05 \)). The postoperative reduction in MMR was statistically significant for the three zones, which tended to be significantly higher for the central zone compared with the midperipheral and peripheral zones (Fig. 11B; Duncan multiple-range test, \( P < 0.05 \)).

**Discussion**

The detection of early VF damage is of great clinical interest. RBP VF testing has shown encouraging results in the detection of subtle defects.\(^1\)\(^–\)\(^3\) The integrity of the visual system determined with RBP is based on the proportion of observed responses versus the total number of microdot presentations. The basic assumption behind RPB is that although the total number of ganglion cells may differ in the general population,
the neuroretinal architecture in most normal eyes should be complete, thus permitting the detection of paired dots of opportune size, contrast, and separation in the VF. A depleted neural matrix may cause “holes” in the VF, giving rise to the detection of just one or no targets in these areas and thus a reduction in hit rates. Some misses can be explained by factors such as the blind spot, angioscotomatas, age-related neuroretinal architecture depletion, blinks, and attention lapses. The new version of the RBP (version 4) has been available since 2005, differing from the former version in number and shape of tested areas. The clinical use of RBP requires a correct interpretation of results, keeping the limitations of the method in mind. To the best of our knowledge, this is the first study that deals with the learning effect, test–retest variability, and influence of blur and cataract on RBP on a considerable number of normal subjects (Fig. 2). All the subjects recruited in the study gave good reliability results with RBP. The mean MHR, MHR-SD, and average #MHR were comparable to those reported by Frisén in a cohort of slightly younger patients. #MR mostly ranged from 0% to 30% in our group of normal subjects (Fig. 3). All normal subjects, with the exception of one, showed MHR ≥ 80% and MR < 70% (Table 1, Fig. 3). There were no significant differences between MMR for the three VF zones or between the superior and inferior hemifields. The temporal hemifield MMR, however, appeared significantly higher than the nasal hemifield MMR. As shown in Figure 4, the pattern of distribution of the MMRs for the single areas was not homogeneous. The differences in MMR between areas could be due to several factors, including the influence of the blind spot’s position, artifacts related to head movements or fixation mark losses during the test, physiologically different distribution densities of neural matrix within normal individuals, and different patterns of age-related neural channel depletion shown in VF testing. The intersubject variability, expressed by the SDs and the 95% CI for both global and local parameters (Table 1, Fig. 4) appeared to be relatively high. The areas exhibiting higher intersubject variability tended to be those located closest to the blind spot. A possible explanation for the wide intersubject variability results found in RBP is that an internal normative database is not available in the software.

Individual test results (both global and local indices) are not automatically corrected for age; however, MHR has been shown to be affected by age. Our results show a significant inverse linear relationship, in which MHR decreased with age (Fig. 5A). This is in accordance with other VF studies that
report age-related VF sensitivity loss detected by SAP,\textsuperscript{27} SWAP, FDT,\textsuperscript{28} and HRP.\textsuperscript{29} Our data also show that MMR tended to increase with age at a faster rate in the central VF zone than in the peripheral zone (Fig. 5B). This trend does not seem apparent in SAP.\textsuperscript{27} The decline in visual function with age has been attributed to deterioration in optical quality, decrease in neural elements, or a combination of both.\textsuperscript{30} Previous studies have reported that light scatter and optical aberrations tend to increase with age and contrast sensitivity decreases, which may be due to age-related corneal and lens changes.\textsuperscript{31–33} Other authors have shown structural age-related reductions in optic nerve axons counts\textsuperscript{34} and progressive retinal nerve fiber layer thinning with age.\textsuperscript{35}

The learning effect can generally be seen up to the second or third testing session,\textsuperscript{7} which tends to be greater in those VF areas with eccentric locations farther from fixation\textsuperscript{7} and in areas showing a greater relative loss.\textsuperscript{36} The presence of a learning effect has been well documented in both normal and glaucomatous subjects for SAP,\textsuperscript{7,36,37} FDT,\textsuperscript{9,38} and SWAP.\textsuperscript{8} As shown in Table 2, none of the parameters showed significant differences in repeated tests, even if the older subjects showed a slight improvement between the first and second tests (Fig. 7). These results give compelling evidence that normal subjects with experience in SAP generally do not show a significant learning effect for RBP, providing that a training session is given, as recommended.\textsuperscript{38} Our results are in agreement with Frisen\textsuperscript{1} on a smaller group of normal naïve subjects, in which “learning effects were occasionally considerable but generally small.”

TRV must be considered when interpreting results, especially when determining whether the VF changes over time with age.

### Table 2. Rarebit Perimetry Parameters for the Four Repeated Tests in Normal Subjects

<table>
<thead>
<tr>
<th>MHR (%)</th>
<th>MHR-SD (%)</th>
<th>#MHR &lt; 90%</th>
<th>Central Zone (%)</th>
<th>Midperipheral Zone (%)</th>
<th>Peripheral Zone (%)</th>
</tr>
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<tbody>
<tr>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
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<tr>
<td>(95% CI)</td>
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<td>(95% CI)</td>
<td>(95% CI)</td>
<td>(95% CI)</td>
</tr>
</tbody>
</table>

| Test 1 | 91.4 ± 4.9 | 10.6 ± 4.0 | 5.7 ± 3.3 | 10.5 ± 9.6 | 8.2 ± 6.4 | 8.2 ± 4.7 |
| Test 2 | 93.0 ± 4.0 | 9.6 ± 4.1 | 4.6 ± 3.1 | 8.1 ± 8.7 | 8.1 ± 5.6 | 6.1 ± 4.0 |
| Test 3 | 93.0 ± 4.2 | 9.5 ± 4.0 | 4.6 ± 3.8 | 8.3 ± 6.4 | 7.6 ± 5.8 | 6.8 ± 4.7 |
| Test 4 | 93.3 ± 4.8 | 9.6 ± 3.9 | 4.8 ± 4.1 | 8.6 ± 6.3 | 8.0 ± 5.5 | 6.4 ± 5.5 |

| Test comparison (P) | 0.20* | 0.64* | 0.44* | 0.44† | 0.88† | 0.29† |
| Mean of the four tests | 92.7 ± 4.4 | 9.8 ± 4.0 | 5.0 ± 3.4 | 8.9 ± 8.1 | 7.8 ± 5.8 | 7.0 ± 4.5 |
| Mean of the differences at retest | 2.9 ± 2.1 | 2.6 ± 2.2 | 2.2 ± 1.9 | 8.5 ± 6.1 | 7.9 ± 4.4 | 7.9 ± 5.7 |

\( n = 28 \) MHR, mean hit rate; MMR, mean miss rate; #MHR < 90%, number of test areas with a hit rate < 90%.

* Analysis of variance.
† Friedman test.

![Figure 6](image-url)  
**FIGURE 6.** TRV of the MMR for each of the 23 test areas (\( n = 28 \)). TRV is expressed as the mean, standard deviation, and 95% CI (shown in parentheses) of the differences at retest for each combination of single tests. Groups of tested areas of homogeneous subsets according to the Duncan multiple-range test are also shown.
corresponds to variability or progression. Studies have shown that increased TRV in SAP is associated with the patient’s age, pupil size, intersubject variation, eccentric location of the testing, and severity and extent of the VF defect. SWAP showed a higher TRV than SAP in both normal subjects and subjects with glaucoma. The TRV for FDT seems to be larger in patients with glaucoma than in normal subjects and less than that found in SAP. FDT TRV is more evident as defect severity increases, yet is not affected by eccentricity. In HRP, TRV increases with eccentricity but not with the threshold level. The mean TRV found in the present study was moderate for MHR (Table 2; 2.9% ± 2.1%) and consistent for the MMR of the single tested areas (Fig. 6; between 4.9% and 11.4%). TRV for MMR was not related to the preceding test MMR results or to eccentricity; the areas with the highest TRV were those nearest to the blind spot (Fig. 6). It is difficult to compare the TRV between RBP (that is based on detection) and other perimetric techniques (that give sen-
sitivity or resolution thresholds). Moreover, RBP comparisons with SAP and other methods are limited because of the different measuring scales (percent versus decibel). Chauhan and Johnson reported that in a group of normal subjects having a mean threshold sensitivity of 30 dB, the TRV 90% CI for a baseline threshold sensitivity deviation of 0 dB was 5.7 and 3.6 dB for SAP and FDT, respectively. Our RBP results show that in the tested area having the lowest MMR (4.0%), the 90% CI for TRV was 20%. TRV for MHR was comparable in the three age groups (Fig. 8A), whereas TRV for MMR appeared significantly higher in subjects older than 60 years, especially in the central VF zone (Fig. 8B). TRV in RBP (Fig. 6) may be due to several factors. RBP does not provide continual monitoring of fixation throughout the test; instead targets are occasionally projected in the blind spot to test for this (Heijl-Krakau method). Unmonitored eye movements may thus falsely lead to enhanced peripheral sensitivity, as well as increased fluctuations at more than one of the test points. Head movements during testing can also play a role in this variability, due to the instrumentation’s lacking a head or chin rest. An incorporated monitoring fixation device and chin rest may prove to be beneficial in reducing TRV. Variability is also brought on by fatigue during the test, but this is probably minimal in RBP because of the short test duration and simple response task. The use of five test runs causes MRs for the 23 areas to be given in 10% increments; the use of more than five runs could probably reduce RBP TRV. Moreover, RBP gives topographical representation of defects in the form of large test areas, similar to FDT (which uses a larger stimulus), which may in part explain the minimal effects of defect depth and eccentricity on variability. Further studies are needed in a larger group of patients with glaucoma with a long follow-up to compare SAP, FDT, and RBP in monitoring progression, especially considering that TRV seems to increase with severity and extent of damage.

The effect of optical defocus has already been reported for other perimetric techniques. Previous studies with SAP have shown that small stimuli are more affected by blur than larger targets and that test areas located near fixation are more affected than those in the periphery. With regard to FDT, blur-induced sensitivity reductions tend to be smaller
than SAP and exhibit a similar effect in the central and peripheral VF. Optical defocus in normal subjects tends to cause an increase in MD (without influencing PSD) for both SAP and FDT. The optical blur induces a simultaneous decrease in luminance and an increase in diameter of a stimulus image on the retina, according to the point-spread function (PSF). It has been suggested that the microdots used in RBP are small enough to stimulate single receptive fields. Under conditions of optical blur, a large retinal image may cause more than one receptive field to be stimulated, thus falsely enhancing RBP performance, even in the presence of neuroretinal architecture depletion. Increases in optical defocus, however, reach a point where the luminance of the stimulus is below perception threshold, thus causing a significant decrease in performance. This fact is in accordance with our data, considering that the decrease in MHR and increase in MHR-SD were moderate for refractive blur and significantly higher for blur at 3 D and higher (Fig. 9). In agreement with previous studies with SAP, the central areas appear to be more influenced by blur than peripheral areas (Fig. 10), which can be expected considering that the receptive fields are of different sizes. Elderly subjects appeared to be more sensitive to blur in all three VF zones, especially in the central zone (Figs. 9, 10). Considering that our patients did not undergo cycloplegia, the different optic blur effects found in the three age groups (Fig. 9) may be partly due to age-related decline in accommodative amplitude and neuroretinal matrix depletion. Pupil diameter tends to get smaller with age and may give rise to a slight increase in depth of focus; however, this did not appear to be large enough in our subjects to counteract the optical defocus performance in the elderly group. RBP parameters seemed to be more affected by myopic blur (induced by positive dioptric lenses) than hyperopic blur in all three groups. This finding may be due to the effects of accommodation in reducing image blur induced by negative lenses and the different type of PSF caused by hyperopic and myopic defocus. RBP seems to be robust to blur in young subjects, but less in the elderly, and thus refractive errors should be corrected before running RBP tests (especially in elderly subjects).

For any perimeter, the influence of lens opacity on test results should be determined, to provide a proper clinical interpretation of the VF results. Light scatter induced by the cataract is thought to cause reduced retinal sensitivity and contrast. The type and amount of light scatter (forward and backscaer) has been shown to be influenced by cataract type and severity. Several SAP, SWAP, and FDT studies conducted in normal subjects demonstrated that cataracts primarily cause a general reduction in sensitivity. These studies reported that postoperative subjects who underwent cataract extraction and IOL insertion showed an improvement in MD, yet unchanged PSD in the VF results. In HRP perimetry, visually impaired cataracts tended to cause increased mean thresholds and local VF defects. Our data show that cataract extraction and IOL insertion caused an increase in MHR (especially in the central area) and a decrease in MHR-SD. The significant improvement in the central zone may be a reflection of how lens opacities cause light-scattering, distortion, and reduced central sensitivity, especially in cases of...
nuclear cataracts. This notion is in agreement with previous studies involving SAP. Moreover, a relatively high intersubject variability was noted both before and after surgery, as shown by the MHR-SD and 95% CI results. Our study is limited in addressing this question because of the relatively small number of subjects within each subgroup classified according to both cataract type and severity. Furthermore, our analysis did not include a spatial correlation of cataract topography with RBP depressions. It is important to note that although the learning effect was minimized (brief training session and discarding initial test results), a slight improvement in the post-operative results may be due in part to subjects' having a bit more experience. Our results indicate that visually significant cataracts may influence RBP test results, especially by causing increased MMR in the central locations and determining possible false positives. Caution should thus be taken when interpreting RBP results in eyes with cataracts.

Most of the subjects enrolled in this study did not show any particular problems in performing RBP, with the exception of very elderly subjects who tend not to be familiar with using a computer mouse. With regard to duration, RBP appeared to be significantly faster than HFA 30-2 SITA testing.

In conclusion, RBP is a rapid and easily administered perimetric test. It is widely accessible, free of charge and requires a only standard computer with an LCD monitor. It appears to be a valid VF testing method alternative, especially when other forms of perimetry are not applicable (i.e., in bedridden patients and settings where there are limited clinical resources). RBP seems to be robust to the learning effect; however, it did show considerable inter- and intrasubject variability. RBP tended to be influenced by refractive blur and cataract (especially in the central zone of the VF and in elderly subjects), and this must be considered in interpreting test results properly. Further studies are needed in ocular hypertensive subjects and patients with SAP-detected defects, to confirm our data regarding the learning effect in naive subjects, test variability, and the impact of blur and lens opacity.

References


