Test–Retest Reliability of the CSV-1000 Contrast Test and Its Relationship to Glaucoma Therapy

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Purpose. To determine the relationship between changes in contrast sensitivity, if any, after glaucoma therapy and the test–retest reliability of the CSV-1000 contrast sensitivity test.

Methods. Patients with primary open angle glaucoma (N = 16) were retrospectively evaluated to determine changes in visual function, as measured by contrast sensitivity, after beta-blocker therapy. A control group (N = 24) of normally sighted patients was tested and retested on contrast sensitivity. For the control group, the coefficients of repeatability (95% confidence interval for test–retest variability [COR]) were calculated for each spatial frequency. The CORs were compared to the changes in vision found after therapy in the patients with glaucoma.

Results. The group with glaucoma showed a significant improvement (P < .01) in contrast sensitivity at all spatial frequencies. The test–retest variance for normals, as measured by the COR, was smaller than the mean differences in contrast sensitivity before and after therapy at all spatial frequencies, except 18 cyc/deg.

Conclusions. Visual function in patients with glaucoma, as measured by contrast sensitivity, does improve after beta-blocker therapy. Further, the CSV-1000 is a clinically reliable tool for monitoring these changes.

Contrast sensitivity testing is becoming widely used as a routine clinical tool.1 Considerable interest has recently been shown in using contrast sensitivity to track the progression of ocular pathology, particularly glaucoma.

Interestingly, several studies have shown improvements in central vision after both medical and surgical glaucoma therapy. Nordmann et al conducted a 3-year study in which they used contrast sensitivity in conjunction with other measures to track the progression of glaucomatous vision loss. They concluded that contrast sensitivity was not useful for monitoring visual changes in patients proven to have glaucoma because the changes in visual fields did not correlate well with changes in contrast sensitivity.2 Their data did, however, show improvements in contrast sensitivity in certain patients after laser trabeculoplasty. Others have also found improvements in central vision after pharmacologic therapy. Tytla and colleagues showed increases in temporal sensitivity in a subgroup of patients with ocular hypertension after beta-blocker therapy.3 Most recently, Piltz and colleagues demonstrated significant improvement in spatial contrast sensitivity in patients with normal tension glaucoma after therapy using a calcium-channel blocker.4

These studies suggest that improvements in central vision do occur in conjunction with glaucoma therapy and that using contrast sensitivity testing to track patients over time could be helpful in providing proper therapy for patients with glaucoma. To determine the usefulness of a specific contrast test for tracking a disease, the test–retest reliability of the particular test must be examined. Bland and Altman5 suggested that for normally distributed data, the coefficient of repeatability (COR: 1.96 times the standard deviation of the test–retest difference) provides a useful metric for test reliability because it describes the 95% confidence interval for the variability in test–retest data. Reeves et al6 further suggested that a decision criterion could be established for each test in which the COR could be used to determine the minimum change necessary to indicate a significant change in vision on a particular test.

Here we determined changes in contrast sensitiv-
ity in patients with glaucoma after beta-blocker therapy. We also determined the test–retest reliability of the CSV-1000 contrast sensitivity instrument in terms of the COR. We compared the CORs for each spatial frequency to any changes in vision found before and after beta-blocker therapy in patients with glaucoma.

SUBJECTS AND METHODS

Subjects
Research followed the tenets of the Declaration of Helsinki, and all subjects consented to participate only after the nature and possible consequences of the study were explained. A retrospective study of patients with primary open angle glaucoma was conducted at the Plaza Eye Center in Chattanooga, Tennessee. Before and after beta-blocker therapy contrast sensitivity scores, using either timolol, levobunolol, or betaxolol, were evaluated. For inclusion in the retrospective sample, patients had to have significant visual field loss as measured by the Humphrey Visual Field Testing Instrument (Model 630) and analyzed by STATPAC 30-2 (Humphrey Instruments, San Leandro, CA) program. Patients had to have been tested by contrast sensitivity at least twice between January 1, 1991 and September 1, 1992, have 20/40 or better visual acuity, and be free of significant progressive disease other than glaucoma. Further, there could be no change in patients’ visual fields or cup–disc ratios between the before and after therapy visits, nor could there be any changes in patients’ medications. Thirty-five eyes met these criteria. The sample was further refined to include only one eye per patient and to include only patients whose test–retest intervals matched those of the normally sighted group (i.e., between 1 and 5 months). (If both eyes from the same patient met the original criteria, then only the right eye was used in the final retrospective sample.) The mean age was 69.98 years old (7.18 years SD) and the mean test–retest interval was 2.68 months (.901 months SD). The final sample included test–retest data on 16 eyes. Contrast sensitivity scores of the group undergoing glaucoma therapy were not evaluated until after the final sample was determined.

Test–retest subjects were solicited from among normally sighted visitors at the Plaza Eye Center. (These normal subjects were solicited from the escorts of patients with cataract who were scheduled for examination before and after surgery.) All subjects were free of ocular disease as determined by one author (GNP). Twenty-four subjects were recruited. The mean age was 63.9 years (12.17 years SD) and the mean test–retest interval was 2.65 months (.588 months SD).

Methods
At the Plaza Eye Center, every patient who either has or is suspected of having glaucoma is tested for contrast sensitivity upon entering the examination room before being seated in the examination chair and before dilation. The test is conducted by a technician who has no knowledge of the previous contrast sensitivity score, if there was any, or of the status of the patient’s glaucoma medication.

Each patient was led into one of four examination rooms by one of three ophthalmic technicians. Acuity and contrast sensitivity were tested monocularly. Acuity was assessed with an American Optical (Buffalo, NY) slide projection system. Contrast sensitivity was assessed with the CSV-1000E Contrast Testing Instrument (VectorVision Dayton, OH) shown in Figure 1. On the second test visit, the same testing procedure was used. No attempt was made to regulate which ophthalmic technician or which examination room was used for each subject retest. The same testing technicians and instructions were used for both the normally sighted group and the patients with glaucoma.

Contrast Sensitivity Testing
The CSV-1000 provides a fluorescent luminance source that retro-illuminates a translucent chart. The instrument houses a series of photocells that automatically monitor and calibrate the instrument light level to 85 candelas per square meter ± 0.1 log unit. The testing light levels were measured at the beginning and during the course of the study. The testing light levels were all within ±0.1 log unit on each spatial
TABLE 1. Pretherapy, Posttherapy, and Difference Scores for Patients With Glaucoma (n = 16)

<table>
<thead>
<tr>
<th>Spatial Frequency</th>
<th>Pretherapy</th>
<th>Posttherapy</th>
<th>Test–Retest Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 cyc/deg</td>
<td>1.203 ± 0.269</td>
<td>1.389 ± 0.211</td>
<td>0.186 ± 0.246</td>
</tr>
<tr>
<td>6 cyc/deg</td>
<td>1.427 ± 0.381</td>
<td>1.594 ± 0.340</td>
<td>0.167 ± 0.298</td>
</tr>
<tr>
<td>12 cyc/deg</td>
<td>1.038 ± 0.458</td>
<td>1.333 ± 0.414</td>
<td>0.295 ± 0.382</td>
</tr>
<tr>
<td>18 cyc/deg</td>
<td>0.709 ± 0.374</td>
<td>0.901 ± 0.455</td>
<td>0.191 ± 0.350</td>
</tr>
</tbody>
</table>

Values are mean ± SD.

frequency from instrument to instrument and from the start to the end of the study.

At the testing distance of 8 feet, the translucent chart presents four spatial frequencies: 3, 6, 12, and 18 cyc/deg. Each spatial frequency is presented on a separate row of the test. Each row presents 17 circular patches 1.5 inches in diameter. The first patch in the row presents a very high contrast grating (sample patch) in the far left of the row. The remaining 16 patches appear in eight columns presented across the row. In each column, one patch presents a grating, the other patch is blank. The patches that present gratings decrease in contrast moving from left to right across the row. The patient is directed to observe the first sample patch and is told to look for the grating pattern in each column. While reading across the row, that patient indicates whether the grating appears in the top patch or the bottom patch for each column. If the grating is not visible in either patch, the patient responds “both blank.” It is important to note that the patient is encouraged to guess if a grating is at least partially visible as the threshold is approached. However, the patient is cautioned that if no gratings are visible, then the response should be “both blank.” The contrast level of the last correct response is taken as the contrast threshold.

Contrast sensitivity levels in each row range from .70 to 2.08, .91 to 2.29, .61 to 1.99, and .17 to 1.55 log units for 3, 6, 12, and 18 cyc/deg, respectively. Contrast levels diminish in a uniform logarithmic fashion in steps of 0.15 log units for contrast levels 3 through 8 and 0.17 log units for steps 1 through 3. The contrast change between the sample patch and level 1 is 0.3 log units.

RESULTS

The before therapy, after therapy, and difference contrast sensitivity scores for the patients with glaucoma are shown in Table 1. A repeated measures analysis of variance showed a statistically significant improvement in contrast sensitivity after the initiation of glaucoma therapy ($P < .0005$). A post hoc test across all spatial frequencies using Scheffe’s multiple comparison test showed that the change in vision was significant at all spatial frequencies ($P < .01$). A $t$-test showed that the drop in intraocular pressure from 20.5 mm Hg to 18.2 mm Hg was significant ($P < .01$). No significant change in acuity was found.

Only the right eye of those in the normally sighted group was used for evaluation. All subjects had 20/20 or better acuity. The mean and standard deviation for each spatial frequency and the test–retest mean differences and standard deviations are shown in Table 2. A repeated measures analysis of variance showed that the slight improvement in contrast sensitivity found on the retest was not statistically significant ($P < .05$).

For COR to be used to evaluate the difference scores, the scores must be normally distributed. The distributions of difference scores (test 2 − test 1) for each spatial frequency were plotted to determine normality. Visual inspection showed that none of the distributions were significantly skewed from the normal. (This result was anticipated because, as noted by Reeves et al,6 difference scores of test–retest data are typically normally distributed.) Table 3 shows the COR for each spatial frequency, the test–retest mean differences for patients with glaucoma, and their ratios.

Figure 2 shows the improvements in contrast sensitivity at each spatial frequency for the group with glaucoma versus the normal test–retest changes and the 95% confidence interval for the test–retest variability (COR).

DISCUSSION

For the group with glaucoma, the improvements found with therapy agree with previous reports showing upward shifts in contrast sensitivity after the initiation of therapy.2,4 Comparison of the CORs to the mean test–retest differences show that the COR is less than the average change induced by therapy at 3, 6, and 12 cyc/deg. That is, the ratio calculated by dividing the test–retest differences by the COR is greater than 1. This result suggests that the CSV-1000 can be used as a clinically reliable tool for measuring the changes in vision induced by glaucoma therapy, except at 18 cyc/deg, where the ratio between COR and mean difference is less than 1.
TABLE 2. Test, Retest, and Difference Scores for Normally Sighted Group (n = 24)

<table>
<thead>
<tr>
<th>Spatial Frequency</th>
<th>Test</th>
<th>Retest</th>
<th>Test–Retest Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 cyc/deg</td>
<td>1.55 ± 0.155</td>
<td>1.57 ± 0.149</td>
<td>0.018 ± 0.048</td>
</tr>
<tr>
<td>6 cyc/deg</td>
<td>1.76 ± 0.178</td>
<td>1.84 ± 0.158</td>
<td>0.078 ± 0.074</td>
</tr>
<tr>
<td>12 cyc/deg</td>
<td>1.49 ± 0.226</td>
<td>1.50 ± 0.152</td>
<td>0.013 ± 0.116</td>
</tr>
<tr>
<td>18 cyc/deg</td>
<td>0.913 ± 0.300</td>
<td>0.951 ± 0.231</td>
<td>0.038 ± 0.151</td>
</tr>
</tbody>
</table>

Values are mean ± SD.

The average COR for the CSV-1000 (.191) compares favorably with those published for the Pelli–Robson Contrast Test (.18) and is much lower than the CORs for Vistech FDT (.36) and Miller-Nadler Glare Tester (.36). A comparison of the individual CORs for each frequency also provides interesting information. The Pelli–Robson test measures sensitivity to the peak of the contrast sensitivity function. Combining the two CORs from spatial frequencies on the CSV-1000 that test the peak sensitivity (i.e., 3 and 6 cyc/deg) shows that the average COR for this range (.12) is below that of the Pelli–Robson (.18). The Vistech FDT tests 6 cyc/deg. A direct comparison of the COR for 6 cyc/deg on the CSV-1000 (.145) again shows the CSV-1000 test–retest variance to be well below that of the Vistech (.36). The COR for 18 cyc/deg is approximately .3 log units. At this high level of test–retest variance, 18 cyc/deg can only be reliably used to measure large changes in vision.

It may seem contradictory that the CORs for the CSV-1000 are much lower than that for the Vistech test because both tests are similar. However, several important differences exist between the tests.

The Vistech test incorporates an unequal contrast interval that ranges from .36 to .11 log units (129% to 28% change), averaging approximately .25 log units (78% change). The CSV-1000 uses a uniform log step of .15 log units (40%) across contrast steps 3 to 8 and .17 log units (50%) from steps 1 to 3. As noted by Elliott and Bullimore, a larger contrast step increases test–retest variance.

The Vistech test incorporates an orientation task that poses two difficulties in terms of reliability. First, determining grating orientation is a two-part task in which the patient must not only detect the grating but must also identify its orientation. This two-part task injects an additional criterion level into the test, compared to a “true detection” task of inspecting two circles to determine the presence of a grating pattern. Second, oriented gratings can confound with astigmatism. A patient may be unable to identify a higher contrast grating in an orientation that coincides with his or her astigmatism and yet be able to identify a lower contrast grating of a different orientation. Although a test with only one grating orientation, such as the CSV-1000, is also affected differently by different axes of astigmatism, this has little impact on test reliability because, in a given patient, the axis of astigmatism is fixed and all contrast levels are affected equally.

The CSV-1000 uses a criterion-dependent paradigm in which the patient has three choices: to deter-

TABLE 3. CORs for Normals and Test–Retest Mean Differences for Glaucoma Patients and Ratios

<table>
<thead>
<tr>
<th>Spatial Frequency</th>
<th>Normal COR</th>
<th>Glaucoma Mean Difference</th>
<th>Ratio COR/Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 cyc/deg</td>
<td>0.094</td>
<td>0.186</td>
<td>1.98</td>
</tr>
<tr>
<td>6 cyc/deg</td>
<td>0.145</td>
<td>0.167</td>
<td>1.15</td>
</tr>
<tr>
<td>12 cyc/deg</td>
<td>0.227</td>
<td>0.295</td>
<td>1.30</td>
</tr>
<tr>
<td>18 cyc/deg</td>
<td>0.296</td>
<td>0.191</td>
<td>0.64</td>
</tr>
</tbody>
</table>

FIGURE 2. Improvements in contrast sensitivity for patients with glaucoma after beta-blocker therapy versus changes in normal patients due to retest. The heavy solid line shows the improvement for patients with glaucoma, and the heavy dashed line shows the retest change for normal patients. The lighter dashed line shows the 95% confidence interval for the normal test–retest variability. Note that the improvement in contrast sensitivity for the patients with glaucoma is above the upper limit of the 95% confidence interval for normal test–retest variance, except at 18 cyc/deg.
mine whether the gratings are in the top circle or the bottom circle or whether both are blank. Criterion-dependent tests have been shown to be less reliable than forced-choice tests. Given the criterion dependence of the CSV-1000 test, it is tempting to attribute the improvements in sensitivity for the patients with glaucoma as the result of such testing factors as learning or familiarity. However, the control group, which was matched for age and test–retest interval, showed only minor improvement that was not close in magnitude when compared to the group with glaucoma and was not statistically significant. Further, Woo and Bohnsack found a similar learning effect with the Vistech test, that again was much smaller in magnitude than the changes we found before and after therapy and that was not statistically significant at the .05 level.

Test–retest reliability can be artificially improved by the inclusion of truncated data, i.e., data from patients who are unable to see a grating of a particular spatial frequency, even at the highest contrast level. Because all the patients who participated in this study had good acuity (20/40 or better), no truncation occurred.

The mechanism for the improvement in vision with beta-blocker therapy, as measured by contrast sensitivity, remains unknown. An initial explanation could be a miotic effect of the pharmacologic agents. This is unlikely, however; Nordmann et al found improvements after laser surgery that had no effect on pupil size. Perhaps ganglion cells gain sensitivity as the intraocular pressure is reduced. Because we also found a significant decrease in intraocular pressure after treatment, this is a possible explanation. However, the correlation between changes in intraocular pressure and improvements in contrast sensitivity was not significant at any spatial frequency.

Another possible explanation is that contrast sensitivity improves with improved ocular blood flow. Studies have demonstrated increased retinal blood flow after beta-blocker therapy (timolol) in both animals and human eyes. Further, Sponsel and colleagues demonstrated a high correlation between asymmetry in retinal leukocyte velocity and contrast sensitivity in patients with glaucoma and those with ocular hypertension. However, in a study using an acute dose of a calcium-channel blocker, an association between improvements in contrast sensitivity and macular blood flow after therapy was not evident. We think the shifts in contrast sensitivity were related to increased ocular blood flow. As noted above, however, current data are inconclusive and further studies are needed to confirm this hypothesis.

Our results indicate that contrast sensitivity does improve with beta-blocker therapy and that the CSV-1000 contrast testing instrument has sufficient reliability to measure these improvements. Perhaps the evaluation of the short- and long-term effects of beta-blocker therapy on visual function in patients with glaucoma can be augmented by the use of contrast sensitivity testing.

Key Words
contrast sensitivity, test reliability, glaucoma therapy, beta-blocker, visual function

References