The Impact of Acuity on Performance of Four Clinical Measures of Contrast Sensitivity in Alzheimer’s Disease

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Investigations of contrast sensitivity losses in Alzheimer’s disease (AD) have yielded mixed findings, with some investigators reporting deficits and others not. Potential reasons for these discrepancies include differences between samples and assessments utilized and the failure of some investigators to account for acuity differences between groups. To investigate these issues, we administered four clinical contrast sensitivity assessments to the same group of AD patients and elderly control participants and examined the impact of acuity on performance for each assessment. Results revealed group differences across the spatial frequency range. Further, group acuity differences significantly affected performance on two of the four measures (the Regan and the Vistech but not on the Pelli-Robson or Freiburg assessments). Information regarding the availability of established age norms, test–retest reliability data, and other factors including the time, cost, and training needed to administer each measure is provided to aid clinicians and researchers in their search for an effective measure of contrast sensitivity.

ALZHEIMER’S disease (AD) is associated with impairments in a variety of visual abilities. One ability, contrast sensitivity, is the most extensively examined because it has been associated with deficits in daily function in elderly individuals (Dargent-Molina, Hays, & Breat, 1996; Elliott, Bullimore, Patla, & Whitaker, 1996; Elliott, Hurst, & Weatherill, 1990; Ross, Bron, & Clarke, 1984). The possibility that contrast sensitivity is more impaired in AD patients than in healthy elderly adults has significant implications for patients’ cognitive abilities and daily function. Research to date, however, has yielded mixed results across laboratories. Some investigators report deficits in contrast sensitivity in AD patients (Bassi, Solomon, & Young, 1993; Cronin-Golomb, Corkin, & Growdon, 1995; Cronin-Golomb et al., 1991; Cronin-Golomb et al., 2000; Gilmore & Levy, 1991; Gilmore & Whitehouse, 1995; Lakshminarayanan, Lagrave, Kean, Dick, & Shankle, 1996; Mendola, Cronin-Golomb, Corkin, & Growdon, 1995; Nissen et al., 1985; Rizzo, Anderson, Dawson, & Nawrot, 2000), whereas others report relatively normal performance (Neargarder & Oross, 1999; Schlotterer, Moscovitch, & Crapper-McLachlan, 1983).

Potential explanations for these mixed findings include differences between participant samples, differences between contrast sensitivity assessments used, and the fact that investigators have not examined the role of acuity differences in their findings. In view of these observations, it becomes evident that attempts to resolve discrepancies in findings via comparisons of previously published research studies are futile. A more direct approach to addressing this issue is to examine contrast sensitivity performance with multiple assessments in the same group of AD patients and to measure the impact of acuity on performance for each assessment. This approach has not been previously used. We have adopted it in the present study with the goal of resolving the methodological issues that keep investigators from fully understanding the nature and extent of contrast sensitivity deficits in AD.

A second goal of this project is to examine the clinical utility of each assessment. The assessments are commonly used by optometrists and ophthalmologists to examine the presence of possible contrast sensitivity losses, which directly affect everyday behaviors such as reading, eating, and driving (Akutsu, Legge, Ross, & Schuebel, 1991; Dunne, Neargarder, & Cippolloni, 2002; Koss & Gilmore, 1998; Owlsley, Sekular, & Boldt, 1981). A number of factors determine which tests of contrast sensitivity a clinician will choose. These factors include time, cost, and training needed to administer various measures. Review of these factors supplemented with information regarding the availability of established norms and test–retest reliability data associated with each assessment may aid clinicians and researchers in their search for an effective measure of contrast sensitivity.

METHOD

Participants

The study compared the performance of 15 patients with probable AD (8 men, 7 women) and 15 healthy elderly control participants (EC; 9 men, 6 women). Analyses (t tests for homogeneous variances) revealed that groups were comparable in age, t(28) = 1.35, p = .19, and level of education, t(28) = 0.70, p = .49. Mean AD age was 76.9 (SD = 7.7) years and EC age was 72.6 (SD = 9.6) years. Mean AD
education level was 13.4 ($SD = 3.2$) years and EC education was 14.1 ($SD = 2.5$) years. Dementia severity in the AD group was measured by the Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975). Total scores on the MMSE can range from 0 to 30, with lower scores being indicative of higher levels of dementia. The mean MMSE score of our sample was 18.0 ($SD = 5.3$) with scores ranging from 6 to 26, indicative of a wide range of dementia severity.

AD patients were recruited through area hospitals and day programs and all met NINCDS-ADRDA criteria for probable AD (McKhann et al., 1984). All participants were free of confounding conditions such as depression or other psychiatric disorders as well as ocular abnormalities including glaucoma, cataracts, and macular degeneration as determined from medical reports.

EC participants were recruited through area retirement communities. All were free of any signs of dementia as assessed by the MMSE as well as ocular abnormalities determined by health history screening.

Assessments

Assessments consisted of four clinical measures of contrast sensitivity: the Vistech VCTS 6500 Chart, the Pelli-Robson Chart, the Freiburg Visual Acuity Test, and the Regan Low Contrast Letter Acuity Charts. The presentation order of the assessments was counterbalanced across participants. Each assessment was administered from a distance of 10 feet and was untimed. Luminance for each assessment exceeded 100 cd/m$^2$ as determined via a hand-held light meter. Standard procedures associated with each measure were followed. Each assessment was preceded by training conditions as a means of ensuring comprehension.

Vistech VCTS 6500 Chart.—The Vistech Chart (Vistech Consultants, Dayton, OH) consists of 5 rows and 9 columns of circular grating patches, each of which subtend 1.4° of visual angle when viewed from a distance of 10 feet. Each row presents a single spatial frequency. The represented frequencies are 1.5, 3.0, 6.0, 12.0, and 18.0 cycles per degree (cpd). Contrast decreases in 0.12 log unit steps from left to right across rows. Each grating is either oriented vertically, slanted 15° to the left, or slanted 15° to the right. The last patch in each row is blank. Proceeding from left to right, participants were asked to identify the orientation of each grating either verbally or through matching hand posture (a forced-choice procedure was used). Participants were required to guess the orientation if they could not see a grating; “blank” was not a response option. A contrast level, defined as the last correctly identified grating in a given row, was determined for each spatial frequency. If, however, two consecutive correct responses followed an incorrect response, the threshold was taken as the second incorrect response. This scoring method has been shown to increase the test–retest reliability of the Vistech Chart (i.e., average intraclass correlation for various patient groups increases from 0.60 to 0.69; Rubin, 1988).

For the training condition, participants were shown nine high-contrast grating patches of 6 cpd and were asked to identify the orientation of each grating (i.e., vertical, slanted left, or slanted right). Individuals unable to get 7 out of 9 correct were excluded from this assessment. Only 1 participant with AD failed to meet this criterion.

Pelli-Robson Chart.—The Pelli-Robson Chart (Clement Clarke Inc., Columbus, OH) consists of eight rows of six uppercase Sloan letters. Each letter subtends 1.13° of visual angle when viewed from a distance of 10 feet. Letters are arranged in groups of three. Each group decreases in contrast by approximately 0.15 log units. Contrast values range from 100% (the upper left triad) to 0.9% (the lower right triad). Participants were asked to name each letter until they missed two out of three letters in a given triad. The contrast level was defined as the last triad in which at least two of the three letters were correctly identified.

For the training condition, participants were presented with 10 trials of high contrast Sloan letters and were asked to name them. Those participants unable to get 8 out of 10 correct were excluded from this assessment. All participants met this criterion.

Freiburg Visual Acuity Test.—The Freiburg (Bach, 1996) is a computerized contrast sensitivity test wherein the gap of a Landolt C is presented in one of four orientations (up, down, left, or right). The size of the C (1.13° of visual angle when viewed from a distance of 10 feet) remains constant across trials while the contrast varies according to a maximum likelihood procedure. On each trial participants were asked to indicate the direction of the Landolt C. A total of 24 trials was administered. Threshold was determined by means of the best PEST algorithm (Pentland, 1980), in which an S-shaped psychometric function was fit to the data.

The program was calibrated via the dialog “File/Preferences” by entering information pertaining to the monitor size, observer distance, and the width of the active display area (in this case 235 mm). Corrections for the linearity of video voltage were made by equating a line pattern of space averaged one half maximum luminance with a homogeneous area where video voltage was adjusted to the same brightness.

For the training condition, eight high-contrast Landolt Cs were presented. Participants were instructed to indicate the direction of each C. Those individuals unable to get 6 out of 8 correct were excluded from this assessment. One AD participant (the same mentioned previously for the Vistech) was excluded based on this criterion.

Regan Low Contrast Letter Acuity Charts.—The Regan assessment (Regan, 1988) consists of five separate charts, each measuring acuity thresholds for a different contrast level. These levels include high (96%), intermediate (50% and 25%), and low (11% and 4%) contrast. Each chart is composed of 10 different letters (8 letters per row) that decrease in size across rows. The largest and smallest letters on the 96%, 50%, 25%, and 11% charts subtend visual angles of 0.42 and 0.04° when viewed from a distance of 10 feet which roughly correspond to Snellen acuities of 20/100 and 20/10, respectively. For the 4% chart, these visual angles are .83 and .04°, which correspond to Snellen acuities of 20/200 and 20/10, respectively. Starting from the bottom of the chart, letter size increases by a constant ratio of 1.26
to 1; letter size doubles every third line. Participants were asked to name each letter until 4 or more errors were made in a given row. Contrast acuity levels for each chart were determined by using the following formula: \((N - 1) + n/8\), where \(N\) refers to the first line in which 4 or more errors were made, whereas \(n\) refers to the number of letters read correctly on that line (Regan, 1988).

For the training condition, 10 high contrast letters were presented and participants were instructed to name the letters. Those individuals unable to get 8 out of 10 correct were excluded from this assessment. All participants successfully completed the training condition.

**RESULTS**

Analyses of covariance (ANCOVAs) using acuity as a covariate were conducted to examine the effect of acuity differences on performance for each contrast sensitivity assessment. These acuity values were obtained using the 96% Regan Chart. The average acuity for AD patients was 20/27 and for EC participants was 20/19. Because four separate analyses were conducted on a single group of subjects, familywise error rate was controlled by setting \(\alpha_{\text{test}}\) to 0.0127 for each analysis. To effectively demonstrate the influence of acuity on performance for each assessment, initial analyses ignoring group differences in acuity were conducted to serve as a comparison. For each assessment, missing data points (a total of 2.3%), which are discussed below, were replaced with the mean of the respective group.

A range of dementia severity levels were represented by the AD patients, with MMSE scores ranging from 6 to 26. Performance on each assessment did not correlate with either age or dementia severity as determined via Pearson product-moment correlations \((p > 0.26\) for all correlations). For the Pelli-Robson Chart, when ignoring group differences, an independent groups \(t\) test revealed a significant difference between AD patients and EC participants, \(t(28) = -6.87, p < .00\). When accounting for group differences in acuity, an independent groups \(t\) test revealed a significant difference between AD patients and EC participants, \(t(28) = -6.87, p < .00\). When accounting for group differences in acuity, the normality assumption, was violated as determined via the Shapiro-Wilk statistic. Violations included the 1.5-cpd condition for the AD group \((p < .01)\), the 1.5-cpd condition for the EC group \((p < .01)\), and the 3.0-cpd condition for the EC group \((p < .01)\). These findings were not of grave concern given that the ANCOVA is fairly robust with respect to violations of normality (Atiqullah, 1964). No other ANCOVA assumptions were violated.

Computations of additional statistics derived from the ANCOVA included effect size (for significant findings) using omega squared \((\omega^2)\) and power analyses (for nonsignificant findings). These statistics enable one to determine the amount of variability accounted for by the independent variable(s) (effect size) as well as the ability to detect a significant effect if indeed one exists (power analysis). For all analyses, power was computed for a medium effect size. For cpd, \(\omega^2 = .06\), for group, \(\omega^2 = .75\), and for the interaction between cpd and group, \(\omega^2 = .59\). The covariate of acuity accounted for a significant portion of the variability in the data (\(\omega^2 = .26\)). As evidenced by the findings, group differences in performance ceased to exist after adjusting for acuity differences. An illustration of this point can be observed in Figure 1, where the original and adjusted means are compared.

**Pelli-Robson Chart**

For the Pelli-Robson Chart, when ignoring group differences in acuity, an independent groups \(t\) test revealed a significant difference between AD patients and EC participants, \(t(28) = -6.87, p < .00\). When accounting for group differences in acuity, the normality assumption, was violated as determined via the Shapiro-Wilk statistic. Violations included the 1.5-cpd condition for the AD group \((p < .01)\), the 1.5-cpd condition for the EC group \((p < .01)\), and the 3.0-cpd condition for the EC group \((p < .01)\). These findings were not of grave concern given that the ANCOVA is fairly robust with respect to violations of normality (Atiqullah, 1964). No other ANCOVA assumptions were violated.

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**Vistech VCTS 6500 Chart**

Examination of the data revealed that 5 of the 15 AD patients and 1 of the 15 EC participants failed to complete the 18-cpd condition of the Vistech (i.e., they missed the correct grating orientation on all trials). For this reason data were analyzed only for the four lower cpd conditions. Additionally, 1 AD patient failed to complete the practice condition, whereas another failed to complete the 12-cpd condition (as well as the 18-cpd condition). Missing data for these 2 individuals were replaced with group means to keep sample sizes equal.

Initial analyses ignoring group differences in acuity were conducted. A split-plot factorial ANOVA with two levels of group (AD vs. EC) and four levels of spatial frequency (1.5, 3.0, 6.0, and 12.0 cpd) with subjects nested within group revealed a significant effect of cpd, \(F(3,84) = 24.51, MSE = .04, p < .00\), a significant effect of group, \(F(1,28) = 29.09, MSE = .22, p < .00\), and a significant interaction between cpd and group, \(F(3,84) = 5.24, MSE = .04, p < .00\). When accounting for group differences in acuity, a split-plot factorial ANCOVA revealed a significant effect of cpd, \(F(3,81) = 7.62, MSE = .034, p < .00\), no significant effect of group, \(F(1,27) = 6.17, MSE = .11, p = .02\), no significant interaction between cpd and group, \(F(3,81) = 0.35, MSE = .03, p = .79\), and a significant effect of the acuity covariate, \(F(1,27) = 26.75, MSE = .11, p < .00\). One ANCOVA as-
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**differences in acuity, a one-way ANCOVA revealed a significant main effect of group, \( F(1,27) = 16.25, \text{MSE} = .02, p < .00 \), and a significant effect of the acuity covariate, \( F(1,27) = 19.02, \text{MSE} = .02, p < .00 \). One assumption, the normality assumption, was violated as determined via the Shapiro-Wilk statistic. This violation occurred with the AD group (\( p < .01 \)). No other ANCOVA assumptions were violated. For the main effect of group, \( \omega^2 = .38 \); for the acuity covariate, \( \omega^2 = .41 \). As indicated by the findings, results of the Pelli-Robson remained robust (i.e., a significant difference was still observed) despite the acuity covariate. This is illustrated in Figure 2.**

**Freiburg Visual Acuity Test**

The Freiburg Visual Acuity Test when analyzed ignoring group differences in acuity also revealed a significant difference between groups as determined via an independent groups \( t \) test, \( t(28) = -5.62, p < .00 \). When accounting for group differences in acuity, a one-way ANCOVA revealed a significant main effect of group, \( F(1,27) = 9.4, \text{MSE} = .08, p < .01 \), and a significant effect of the acuity covariate, \( F(1,27) = 7.6, \text{MSE} = .08, p < .01 \). No assumptions of the ANCOVA were violated. One AD participant failed to complete the practice condition associated with this assessment; his data point was replaced with the group mean. For the main effect of group, \( \omega^2 = .11 \); for the acuity covariate, \( \omega^2 = .09 \). As demonstrated, including acuity as a covariate failed to significantly alter performance on this assessment. This point is illustrated in Figure 3.

**Regan Low Contrast Letter Acuity Charts**

Examination of the data revealed that 4/15 of the AD patients failed to successfully complete the 4% contrast condition (i.e., all responses were incorrect). For this reason, only data from the four remaining contrast levels were analyzed. Moreover, 1 AD participant failed to complete the 11% contrast condition (in addition to the 4% condition); his data point for this condition was replaced with the group mean.

Initial analyses ignoring group differences in acuity were conducted. A split-plot factorial ANOVA with two levels of group (AD vs. EC), and four levels of contrast (11%, 25%, 50%, and 96%) with subjects nested within group revealed a significant effect of contrast level, \( F(2.19,61.17) = 146.76, \text{MSE} = .41, p = .01, \) a significant effect of group, \( F(1.28) = 21.41, \text{MSE} = 128.23, p = .00, \) and no significant interaction between contrast and group, \( F(2.19,61.17) = 0.50, \text{MSE} = .41, p = .63 \). Note that the analyses revealed a violation of the sphericity assumption (\( p < .00 \)), thus the Huynh-Feldt correction (\( e = .73 \)) was applied to the data. This correction is advised when dealing with small sample sizes. When accounting for group differences in acuity, a split-plot factorial ANCOVA revealed no significant effect of contrast level, \( F(2.26,60.95) = 1.62, \text{MSE} = .40, p < .20 \), no significant effect of group, \( F(1.27) = 1.41, \text{MSE} = .73, p = .25 \), no significant interaction between contrast level and group, \( F(2.26,60.95) = 0.89, \text{MSE} = .40, p = .43, \) and a significant effect of the acuity covariate, \( F(1.27) = 201.35, \text{MSE} = .73, p < .00 \). Once again the sphericity assumption was violated (\( p < .00 \)), thus the Huynh-Feldt correction (\( e = .75 \)) was applied to the data.

As revealed in the ANCOVA, for the main effect of contrast level, power = .59, for the main effect of group, power = .75, and for the interaction between contrast level and group, power = .59. The covariate of acuity accounted for a significant portion of the variability in the data (\( \omega^2 = .75 \)). Group differences in performance at all contrast values ceased to exist after adjusting for acuity differences. This is illustrated in Figure 4.
Figure 4. Performance on the Regan Low Contrast Letter Acuity Charts. Performance for AD and EC participants for each contrast level is plotted as a function of Regan thresholds (the numbers closest to the y-axis) and Snellen equivalents. The bars represent mean performance prior to adjustments for group acuity differences. The small black bars represent the adjusted means derived from the ANCOVA. These bars indicate the location of the group means after variability associated with group acuity differences has been accounted for.

**Rank-Order Correlations**

Spearman’s rank-order correlations were conducted to examine the relation among the various assessments. Specifically, we were interested in the correlations between the Freiburg, the Pelli, the 3.0- and 6.0-cpd levels of the Vistech, and the four levels of the Regan (96%, 50%, 25%, and 11%). The two chosen levels of the Vistech most closely resemble the spatial frequency of the stimuli used in the Freiburg and Pelli assessments.

For the EC group, correlations ranged from 0 to .84 with an overall average correlation of .48. For the AD group, correlations ranged from .38 to .84 with an average correlation of .68. Although sample sizes were small, these patterns of correlations reveal that the relation between the measures of contrast sensitivity varies for the EC and AD groups, with the AD group yielding higher correlations among assessments. These higher correlations most likely result from the greater heterogeneity of scores exhibited by the AD group compared with the EC group across contrast measures.

**Test-Retest Reliability and Established Age Norms**

The Vistech is the only assessment for which age norms have been established for a wide variety of ages (from 10 to over 70 years). The age norms for the Regan depict performance for individuals aged 19 to 49 years, and to the best of our knowledge no normative data have been established for the Freiburg assessment. For the Pelli-Robson, normative data are not provided in the accompanying manual, but the Salisbury Eye Evaluation Project (SEE; Rubin et al., 1997) summarizes data collected from over 2,500 elderly individuals.

Test–retest reliability data for AD patients were available only for the Vistech. Reliability values for 13 AD patients determined via Spearman rank-order correlations were as follows: 1.5 cpd (.56), 3.0 cpd (.48), 6.0 cpd (.93), 12.0 cpd (.88), and 18.0 cpd (.78; Cronin-Golomb et al., 1995). Similar values have been reported in other clinical populations (Rubin, 1988). Despite the relatively low reliability at lower spatial frequencies, as reported in this single study of 13 patients, there are multiple reports of AD deficits at low spatial frequencies using this measure (Cronin-Golomb et al., 1991, 1995; Gilmore & Levy, 1991; Gilmore & Whitehouse, 1995; Lakshminarayanan et al., 1996). Although test–retest reliability data for AD patients were not available for the Pelli-Robson or the Regan, administration of these assessments to other clinical populations has yielded high test–retest reliability values (approximate values between .75 and .96; Elliott & Bullimore, 1993; Rubin, 1988). Reliability data for the Freiburg assessment for AD patients or other clinical populations are currently unreported.

**Other Factors**

**Time to administer and score.**—The Pelli-Robson was the fastest to administer and score. Administration time was approximately 5 min and scoring was immediate. The Vistech and the Freiburg each took about 10–15 min. The Vistech was shorter in administration (5–10 min) and Freiburg in scoring (immediate). The Regan took more time than the other tests for administration (15–20 min) and scoring (10–15 min) for a total of 25–35 min. There was little difference in administration time among participants, with AD patients as a group performing somewhat slower than EC participants.

**Training.**—The three chart tests required minimal training for administration or scoring. The Freiburg Test required sufficient technical ability to download the program and set the parameters (e.g., size of stimuli, number of trials). Once the program was set, minimal training was needed to administer the test and no training was needed for scoring.

**Cost.**—The Freiberg Test was available without cost and so was the least expensive of the tests for clinics or research groups with a computer available for testing. The three remaining tests were comparable in price, falling within the $350 to $600 range.

**DISCUSSION**

**Findings Across Assessments**

Results of this study demonstrate that acuity differentially impacts performance on several measures of contrast sensitivity. Performance on the Regan and the Vistech Tests was significantly affected by acuity differences between groups, whereas performance on the Pelli-Robson and Freiburg was not. In fact, for the former two assessments, noted contrast sensitivity deficits ceased to exist once acuity differences were factored out. These results suggest that variability due to acuity must be considered when examining contrast sensitivity performance in AD patients, and presumably in other populations.
Examination of previous literature indicates that very few investigators have accounted for acuity differences in their findings. The majority either never mention acuity at all (Nissen et al., 1985), report mean acuities but do not perform appropriate statistical comparisons (Gilmore & Levy, 1991; Mendola et al., 1995), report differences in group acuities but do not take measures to account for these differences (Bassi et al., 1993), or simply state that all participants had acuities of, for example, 20/40, 20/50, or better, without examining how individual acuities impact performance (Cronin-Golomb et al., 1995; Hutton, Morris, Elias, & Poston, 1993; Lakshminarayanan et al., 1996). In the present study, 29 of 30 participants exhibited acuities of 20/40 or better, suggesting that even minor impairments in acuity can dramatically influence performance on measures of contrast sensitivity. It is therefore crucial that researchers match groups closely on acuity or take other appropriate measures to control for potential acuity differences between groups, even when individual acuities deviate only slightly from normal. Failure to account for acuity differences between groups can alter the conclusions that are reached by investigators and may at least in part account for some of the discrepant findings noted in the literature.

Of equal significance, yet many times overlooked, is the importance of measuring acuity at the same distance that each contrast sensitivity assessment is administered. For example, because many standard clinical assessments of contrast sensitivity are administered from a distance of 10 feet, estimates of far acuity (at 10 feet), rather than near acuity, must be obtained. Failure to do so may lead to inaccurate conclusions regarding contrast sensitivity performance.

Besides finding an effect of acuity across assessments, results of this study also support the presence of a contrast sensitivity deficit across spatial frequencies in AD patients. Evidence supporting lower spatial frequency loss is provided by group differences on the Pelli-Robson and the Freiburg assessments, each utilizing letters with spatial frequencies below 6 cpd. This is in agreement with the trend toward group differences observed for the lower spatial frequency conditions on the Vistech assessment (i.e., 6.0-, 3.0-, and 1.5-cpd levels). Support for higher spatial frequency loss is evident in the acuity deficits observed on the 96% Regan Chart as well as the trend toward group differences for the higher spatial frequency condition (12 cpd) on the Vistech assessment. Together, these results support the view that AD patients exhibit deficits across a range of spatial frequencies (see e.g., Cronin-Golomb et al., 1991; Cronin-Golomb et al., 1995; Gilmore & Levy, 1991; Gilmore & Whitehouse, 1995; Lakshminarayanan et al., 1996).

### Individual Assessments

The contrast sensitivity assessments used in this study vary on a number of dimensions including the type and amount of information that can be obtained, the degree to which results are influenced by acuity, the availability of established norms and reliability data, and other factors such as the time, cost, and training needed to administer each assessment. The information provided on these points may

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<tr>
<th>Assessment</th>
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<th>Disadvantages</th>
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<td></td>
<td>Quick administration</td>
<td>The slight orientation differences between the gratings result in confusion for some AD patients</td>
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<td></td>
<td>Relatively easy scoring procedures</td>
<td>Possible truncation effects</td>
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<td></td>
<td>Established age norms for elderly individuals</td>
<td>Lower test–retest reliability data for lower than higher frequencies in AD patients</td>
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<td>Pelli-Robson</td>
<td>Letter-chart design facilitates completion by AD patients possessing various levels of dementia</td>
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<td>No test–retest reliability data for AD patients (values for other clinical populations are quite high)</td>
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<td>Freiburg</td>
<td>Can vary multiple parameters (e.g., target size, number of trials) allowing for measurement of thresholds under various conditions</td>
<td>Requires a computer; calibration issues</td>
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<td></td>
<td>Can measure both contrast and acuity thresholds</td>
<td>Displayed question mark is distracting (replaced with fixation cross in newer versions)</td>
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<td>Cost efficient (for assessment itself)</td>
<td>No established norms for elderly individuals</td>
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<td>Quick administration</td>
<td>No test–retest reliability data for AD patients or any other clinical population</td>
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<td>Easy scoring procedures</td>
<td>Testing session must be aborted if errors are made within first two trials</td>
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<td>Regan*</td>
<td>Thresholds based on multiple trials</td>
<td>Long administration time relative to other tests</td>
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<td></td>
<td>Measures both contrast thresholds and acuity</td>
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<td>Scoring procedures for both research and clinical settings</td>
<td>No test–retest reliability data for AD patients (values for other populations are reasonably high)</td>
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<td>Failed performance at 4% contrast level</td>
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* A new updated version of the Vistech is available through the Stereo Optical Company. This test, called the Sine Wave Contrast Test, is nearly identical to the Vistech except the stimuli are constructed via computer-generated images.

* The Regan Charts are not currently in production, although similar assessments testing low contrast acuity are available through VectorVision.

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<td></td>
<td>Relatively easy scoring procedures</td>
<td>Possible truncation effects</td>
</tr>
<tr>
<td></td>
<td>Established age norms for elderly individuals</td>
<td>Lower test–retest reliability data for lower than higher frequencies in AD patients</td>
</tr>
<tr>
<td>Pelli-Robson</td>
<td>Letter-chart design facilitates completion by AD patients possessing various levels of dementia</td>
<td>Threshold based on minimal number of trials</td>
</tr>
<tr>
<td></td>
<td>Quick administration</td>
<td>No established norms for elderly individuals</td>
</tr>
<tr>
<td></td>
<td>Easy scoring procedures</td>
<td>No test–retest reliability data for AD patients (values for other clinical populations are quite high)</td>
</tr>
<tr>
<td>Freiburg</td>
<td>Can vary multiple parameters (e.g., target size, number of trials) allowing for measurement of thresholds under various conditions</td>
<td>Requires a computer; calibration issues</td>
</tr>
<tr>
<td></td>
<td>Can measure both contrast and acuity thresholds</td>
<td>Displayed question mark is distracting (replaced with fixation cross in newer versions)</td>
</tr>
<tr>
<td></td>
<td>Cost efficient (for assessment itself)</td>
<td>No established norms for elderly individuals</td>
</tr>
<tr>
<td></td>
<td>Quick administration</td>
<td>No test–retest reliability data for AD patients or any other clinical population</td>
</tr>
<tr>
<td></td>
<td>Easy scoring procedures</td>
<td>Testing session must be aborted if errors are made within first two trials</td>
</tr>
<tr>
<td>Regan*</td>
<td>Thresholds based on multiple trials</td>
<td>Long administration time relative to other tests</td>
</tr>
<tr>
<td></td>
<td>Measures both contrast thresholds and acuity</td>
<td>Time-consuming scoring procedures</td>
</tr>
<tr>
<td></td>
<td>Letter-chart design facilitates completion by AD patients possessing various levels of dementia</td>
<td>No established norms for elderly individuals</td>
</tr>
<tr>
<td></td>
<td>Scoring procedures for both research and clinical settings</td>
<td>No test–retest reliability data for AD patients (values for other populations are reasonably high)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Failed performance at 4% contrast level</td>
</tr>
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prove useful for clinicians and researchers who are interested in examining contrast sensitivity performance in clinical populations such as AD. This information is provided below for each assessment and is summarized in Table 1.

**Vistech VCTS 6500 Chart.**—For the Vistech, a group effect failed to reach the level of significance once acuity was included as a covariate in the analysis. Even though a significant effect was not observed at the adjusted alpha level of .0127, inspection of Figure 1 demonstrates that a trend in performance is apparent, with AD patients exhibiting lower mean contrast sensitivity thresholds than EC participants at each level of spatial frequency. These group differences were not powerful enough to reach a level of significance with the current sample size, suggesting that this measure may require larger sample sizes in order to serve as a powerful assessment tool for detecting contrast sensitivity losses in AD patients.

Noteworthy is the large percentage of AD patients who failed to complete the 18-cpd condition. In the present study, this failure was not due to dementia severity but rather to the inability to process high spatial frequency information (as evidenced by the poor acuity levels exhibited by these individuals). Review of previous literature suggests this is a common occurrence when testing AD patients using this assessment (see e.g., Gilmore & Whitehouse, 1995), although this is not necessarily reported by all investigators. Some investigators may instead replace the missing data points in the 18-cpd condition or record them as 0s without noting the specific difficulties encountered by AD patients.

On the basis of a single report of 13 AD patients, the Vistech appears to have relatively poor test–retest reliability for testing AD patients at the lower spatial frequencies (1.5 and 3.0 cpd); reliability at higher frequencies is comparable with that obtained with the other assessments. Reliability may be better than indicated by that single study in that a number of studies using the Vistech have reported significant group differences at the low frequencies (Cronin-Golumb et al., 1991; Cronin-Golomb et al., 1995; Gilmore & Levy, 1991; Gilmore & Whitehouse, 1995; Lakshminarayanan et al., 1996). The combinations of failure to account for acuity differences, unreported failures at the 18-cpd condition, and suboptimal test–retest reliability at some spatial frequencies may account for some of the discrepant findings noted by investigators. A fourth difficulty with the Vistech Charts may be truncation effects. Truncation occurs when a grating is masked down such that only a few stripes are visible, as occurs for the lower spatial frequency patches (i.e., the 1.5- and 3-cpd conditions). Truncation reduces sensitivity to the target, resulting in increased contrast sensitivity thresholds (Corwin & Richman, 1986). A fifth factor pertains to sample differences between individual research studies. We re-examined the Vistech data from the Cronin-Golomb and colleagues (2000) study of 18 AD patients and 18 EC participants using acuity as a covariate. Results demonstrated significant group differences, $F(1,29) = 11.91, p < .00$, even when the variability due to acuity was extracted. These results suggest that other factors, such as sample differences, also contribute to discrepant findings noted in the literature.

Additional disadvantages of the Vistech include the fact that thresholds are based on a minimal number of trials, increasing the potential for erroneous thresholds, and the observation that some AD patients are occasionally confused by the slight orientation differences of the sinewave gratings on the chart. Some of these problems could potentially be eliminated through the use of the next-generation contrast sensitivity assessments.

The outstanding advantage of the Vistech is that it provides information regarding individual spatial frequencies and as such is often regarded as being more comprehensive than measures incorporating letter chart designs. Information obtained from the Vistech can be used to construct a contrast sensitivity curve, which is one of the most widely accepted tools for understanding and quantifying visual mechanisms (Figure 1). Additional advantages of the Vistech include a quick administration time and easy scoring procedures. Notably, it is one of the few assessments with established age norms for elderly individuals.

**Pelli-Robson Chart.**—Results from the Pelli-Robson were not significantly altered by adjustments for acuity differences between groups. Indeed, the main effect of group was quite powerful, suggesting that this assessment is sensitive to group differences in acuity. This finding is in agreement with previous literature wherein groups were matched on acuity (Rizzo et al., 2000).

There are two disadvantages associated with using this assessment. First, the contrast threshold is computed based on a minimal number of trials, increasing the potential for erroneous thresholds. Second, age norms are not provided with the manual, although they can be derived from data collected from the SEE Project (Rubin et al., 1997). Advantages include the Pelli-Robson’s quick administration time, easy scoring procedures, and high test–retest reliability (at least in other clinical populations; Elliot & Bullimore, 1993; Rubin, 1988), making it an attractive choice. Moreover, the easy letter-chart design facilitates completion by AD patients possessing various levels of dementia.

**Freiburg Visual Acuity Test.**—The Freiburg Test yielded results quite similar to those observed for the Pelli-Robson. Specifically, the main effect of group was not significantly affected by group differences in acuity.

One disadvantage of the Freiburg is that it requires the use of a computer. As such, one must deal with technical issues such as luminance calibration. The interaction between luminance levels of the monitor and manipulation of contrast could potentially confound obtained thresholds. Another disadvantage is that some AD patients in the present study had initial difficulty pulling their attention away from the question mark that appears on the screen throughout each trial. Newer versions of the Freiburg have replaced the question mark with a fixation cross, which could reduce or eliminate this potential distraction. A further potential problem with this assessment is that if the participant makes an error within the first two trials, the session must be aborted to avoid obtaining marred thresholds. Most importantly, as of yet, established norms and test–retest reliability data are not available. Without this information, especially the test–retest reliability data, the advisability of using this assessment in a clinical environment remains uncertain.
For advantages, the Freiburg, like the Pelli-Robson, has a quick administration time, easy scoring procedures, and is cost efficient (if a computer is available to run it). The contrast program allows the user to vary multiple parameters (e.g., target size and number of trials), allowing for the measurement of thresholds under a variety of different conditions. The program also has an added feature enabling the user to measure both contrast sensitivity and acuity using the same program. These features provide the user with a greater degree of flexibility than the other tests when attempting to measure contrast sensitivity thresholds. For example, if an individual exhibits poor acuity, the size of the stimuli can be altered to accommodate this deficiency. Of course, this flexibility can also be problematic if indeed test–retest reliability and established normative data have not been obtained using these variations in parameter settings.

Regan Low Contrast Letter Acuity Charts.—For the Regan Test, a group effect did not reach the level of significance once acuity was included as a covariate in the analysis. As mentioned previously, this test appears more sensitive to acuity differences than other standard measures of contrast sensitivity. The failure to detect group differences in performance on this assessment when groups were matched on acuity has been reported previously (Neargarder & Oross, 1999). Although it is not sensitive to contrast losses in AD patients, the Regan Test has demonstrated clinical utility for isolating contrast deficits in other clinical populations exhibiting normal visual acuities (Regan, 1988).

Disadvantages associated with the Regan measure using the research procedure include the long administration time, moderate cost, time-consuming scoring procedures, failed performance at the 4% contrast level (due to acuity deficits rather than dementia severity), and the lack of established age norms for elderly individuals. Advantages include the addition of scoring procedures specific for use in both research and clinical settings, associated high test–retest reliability (at least in other clinical populations), and the fact that one can examine both contrast acuity and Snellen acuity within the same assessment. In addition, thresholds are more reliable because they are determined by means of multiple trials, and the simple letter-chart design facilitates completion by patients possessing various levels of cognitive impairment. Interestingly, even though the Regan failed to elicit group differences, thereby suggesting the lack of a contrast deficit, other measures of contrast sensitivity (i.e., the Pelli-Robson and the Freiburg) demonstrate a deficit in AD patients. This inconsistency across measures suggests that perhaps these assessments, even though deemed comparable, are in fact measuring different abilities. Further research examining this possibility is warranted.

Conclusions

The first goal of this study was to examine the ability of four measures of contrast sensitivity to distinguish between AD patients and healthy elderly individuals. An important finding was that acuity differentially impacts upon performance on the measures we examined. Group differences from only two of the four measures, the Pelli-Robson and the Freiburg, remained robust when acuity was included as a covariate in the analyses. These results have important implications for both previous and future research involving the measurement of contrast sensitivity. Specifically, group acuity differences must be adjusted either through very careful sample matching or statistical procedures before results can be properly interpreted. It is equally important to measure acuity at the same distance at which the contrast sensitivity measures are administered. Without these two precautionary measures, results can be easily misinterpreted and lead to discrepancies in research findings, as evidenced by previously published reports.

A second goal of this study was to provide detailed information about each assessment as it pertains to the testing of AD patients. This information, which includes test–retest reliability, established norms, time, cost, and training needed to administer various measures, may aid clinicians and researchers in their search for an effective measure of contrast sensitivity.

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References


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