Article

Predicting Visual Disability in Glaucoma With Combinations of Vision Measures

Stephanie Lin[1], Aleksandra Mihailovic[1], Sheila K. West[1], Chris A. Johnson[2], David S. Friedman[1], Xiangrong Kong[1], and Pradeep Y. Ramulu[1]

[1] Ophthalmology, Johns Hopkins University/Wilmer Eye Institute, Baltimore, MD, USA
[2] Ophthalmology, University of Iowa, Iowa City, IA, USA

Correspondence: Pradeep Y. Ramulu, Johns Hopkins University, Wilmer Eye Institute, 600 N Wolfe St, Maumenee B110, Baltimore, MD 21287, USA. e-mail: pramulu@jhmi.edu

Purpose: We characterized vision in glaucoma using seven visual measures, with the goals of determining the dimensionality of vision, and how many and which visual measures best model activity limitation.

Methods: We analyzed cross-sectional data from 150 older adults with glaucoma, collecting seven visual measures: integrated visual field (VF) sensitivity, visual acuity, contrast sensitivity (CS), area under the log CS function, color vision, stereoacuity, and visual acuity with noise. Principal component analysis was used to examine the dimensionality of vision. Multivariable regression models using one, two, or three vision tests (and nonvisual predictors) were compared to determine which was best associated with Rasch-analyzed Glaucoma Quality of Life-15 (GQL-15) person measure scores.

Results: The participants had a mean age of 70.2 and IVF sensitivity of 26.6 dB, suggesting mild-to-moderate glaucoma. All seven vision measures loaded similarly onto the first principal component (eigenvectors, 0.220–0.442), which explained 56.9% of the variance in vision scores. In models for GQL scores, the maximum adjusted-R^2 values obtained were 0.263, 0.296, and 0.301 when using one, two, and three vision tests in the models, respectively, though several models in each category had similar adjusted-R^2 values. All three of the best-performing models contained CS.

Conclusions: Vision in glaucoma is a multidimensional construct that can be described by several variably-correlated vision measures. Measuring more than two vision tests does not substantially improve models for activity limitation.

Translational Relevance: A sufficient description of disability in glaucoma can be obtained using one to two vision tests, especially VF and CS.

Introduction

Patients with glaucoma experience disability in several functional domains, including driving,[1,2] mobility,[3–5] and reading,[6,7] and also report significant decreases in quality of life.[8–10] Multiple groups have shown that these disease consequences worsen with increasing visual field (VF) damage, the most commonly-used measure of glaucoma severity. Glaucomatous losses also can affect numerous other visual measures, including color vision,[11] visual acuity (VA),[9,10] and contrast sensitivity (CS) measured at fixation.[12] Each of these visual deficits also is associated with diminished functional ability and lower quality of life.[13]

Given the impact of glaucoma on multiple aspects of vision, and the demonstrated importance of each of these visual measures to activity limitation, it is unclear that assessment of VF damage alone is sufficient to gauge the impact of glaucoma on vision and function. Indeed, prior studies relating objective vision testing to self-reported disability measures have found that differences in vision test results, including VF damage, are at best moderately correlated with patient-reported disability.[13,14] However, this prior work primarily has assessed associations between single visual measures and self-reported outcomes;

efforts have not been made formally to determine whether combinations of visual measures may better help us understand the impact of glaucoma on activity limitation.

We performed a thorough visual assessment for patients with glaucoma, with two goals in mind. The first goal was to determine the extent to which relevant visual measures in glaucoma create a multidimensional space. A multidimensional visual space would suggest that using multiple measures may be helpful in assessing disability. Once this analysis suggested a multidimensional space, our second goal was to determine whether, and to what extent, we could improve models for self-reported activity limitation using multiple vision tests. We hoped the results from our research could improve how vision testing is used by clinicians and researchers to understand the impact of glaucoma on activity limitation.

Methods

The study was conducted using baseline patient data obtained from the ongoing Falls in Glaucoma Study (FIGS). The study protocol was approved by the Johns Hopkins University School of Medicine institutional review board and followed the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants.

Participant Recruitment

Participants were recruited between September 2013 and March 2015 at the Johns Hopkins Wilmer Eye Institute, with inclusion and exclusion criteria described previously in detail.[15] Briefly, patients had a glaucoma-related diagnosis (primary open angle glaucoma, primary angle closure glaucoma, pseudoexfoliation, pigmentary glaucoma, or were glaucoma suspects), had no other secondary glaucoma, were age 60 or older or turned 60 over the three-year study period, and had no concurrent eye disease resulting in VA worse than 20/40. Patients with a glaucoma diagnosis were included if they had either unilateral or bilateral VF damage. Patients were excluded if they had had any surgery (ocular or nonocular) in the past 2 months, any hospitalization in the past month, or were confined to a bed or wheelchair. To evaluate the representativeness of the recruited sample, we engaged 97% of study-eligible patients to complete a short questionnaire over a 1-week period. No significant differences were noted between our re- cruited patients and the target sample with regards to age, race, or glaucoma severity.

Vision Testing

Vision was tested binocularly except for VF testing and VA measurements. VFs were assessed using the Humphrey Field Analyzer II with the SITA standard 24-2 test (Carl Zeiss Meditec, Inc, Dublin, CA). Pointwise sensitivity values from right and left eyes then were used to calculate a mean sensitivity for the integrated VF (IVF).[16] VA was assessed using a backlit Early Treatment of Diabetic Retinopathy Study (ETDRS) chart at 4 m. Better-eye presenting VA was converted to the logarithm of the minimum angle of resolution (logMAR) for analysis. CS was tested using the MARS chart illuminated under standard fluorescent light (Mars Perceptrix, Chappaqua, NY). Participants were measured at 40 cm using their habitual correction, and letters correctly read were converted into log units of CS (logCS) for analysis. Area under the log contrast sensitivity function (AULCSF) was assessed using the quick contrast sensitivity function (qCSF) test, which assesses CS across a range of spatial frequencies using a Bayesian adaptive procedure, and models logCS as a function of stimulus size (Adaptive Sensory Technology, Boston, MA).[17] Color vision was evaluated using the Hardy-Rand-Rittler test with participants wearing their habitual corrective lenses under standard full spectrum lighting (OttLite Technology, Tampa, FL).[18] Stereoacuity was assessed at 3 m using the Distance Randot Stereotest, yielding values of no stereo acuity, or 400, 200, 100, or 60 seconds of arc.[19] VA in a background of noise was assessed with the Pelli-Levi Dual Acuity Chart. One-half of this chart is a standard Snellen VA chart, while the other half sets white noise (14.5 square checks per letter size) on the letters of a Snellen VA chart.[20] Participants were asked to read letters from the chart presented on a computer screen at 3 m distance with room lights turned off. The main outcome from this test was reported as the number of letters read from the background noise half of the chart.

Evaluation of Visual Disability

The Glaucoma Quality-of-Life 15 (GQL-15) scale[8] was used to quantify perceived visual disability, and was administered orally to subjects in an in-person interview. The scale includes questions about central and near vision, peripheral vision, lighting adaptation, personal care, and outdoor mobility. Partici-

pants were asked whether their vision gave them difficulty with 15 tasks, with choices of None (1), A little bit (2), Some (3), Quite a lot (4), Severe (5), and Not Applicable (do not perform for nonvisual reasons). Participants' responses were Rasch analyzed using the Winsteps Rasch statistical package version 3.91.2 (Winsteps, Chicago, IL) to estimate item measure and person measure scores. An item measure score denoting task difficulty was assigned to each task, with higher scores denoting more difficult tasks that would be performed more easily by individuals of greater ability (those with higher person measure scores). Individual person measure scores were derived from participants' reported difficulty with each task and the tasks' item scores. Higher person measure scores reflected difficulty only with more difficult tasks, indicating less visual disability, while lower scores reflected difficulty with easier tasks, indicating greater visual disability. Person and item measure scores were expressed along a log-odds (logits) scale.

Statistical Analysis

Pearson's correlation coefficients were used to assess correlations between each pair of vision tests. For correlations with stereoacuity, Spearman's rho was used, as stereoacuity was measured as an ordinal variable based on number of stereoplates read.

Because several of the visual parameters tested (stereoacuity, color vision, VA in noise) are not used typically to gauge glaucoma severity, regression models were constructed to test how these parameters related to the traditional measures of visual impairment (IVF sensitivity and VA). Models were generated in which each of the other vision measures were considered as the dependent variable, and either IVF or VA was considered as the independent variable. Deming regression models were used for associations with color vision and vision in noise, to account for measurement error in dependent and independent variables. Ordinal logistic regression models were used for associations with stereoacuity.

Because pairwise comparisons cannot adequately describe the complex matrix of correlations within the group of vision tests, we used principal component analysis to investigate the overall dimensionality of vision in glaucoma. The analysis generated a set of linearly uncorrelated principal components from the seven vision tests, and the percentage of overall visual variance explained by each component was calculated. The first principal component, defined by the linear combination of visual measures accounting for the largest possible variance in the data, then was used as an independent variable in a multivariable model for GQL-15 person measure scores, controlling for age, sex, race, number of comorbidities (the total number of health-related conditions from a standardized list[21] up to a total of five; those with more than five comorbidities [$n = 6$] were classified as having five comorbidities), and polypharmacy (more than five prescription medications used, excluding eye drops).

We next assessed how varying the number of visual predictors can contribute to understanding glaucoma-related activity limitation. To do so, we generated all possible regression models for GQL-15 scores using the seven vision tests. Each model contained a unique combination of one, two, or three vision tests, and controlled for age, sex, race, number of comorbidities, and polypharmacy. We compared the adjusted-R^2 values among models to assess how well combinations of tests accounted for variance in GQL-15 person-scores, and how addition of vision tests changed adjusted-R^2 values. The models with the highest adjusted-R^2 values within each set of models were isolated for a brief discussion, and plots of residuals versus fitted scores and independent variables were assessed for evidence of nonlinearity in these models.

Finally, we undertook a dominance analysis to characterize the relative contribution of each of the vision tests to models for GQL-15. Dominance analysis quantifies the average change in R^2 that results from adding each predictor to all possible subset models without the predictor. We performed a dominance analysis using the set of all seven vision tests, to see which contributed most to models' predictive capacities.

Data were analyzed using STATA v13 (Stata Statistical Software: Release 13; StataCorp LP, College Station, TX).

Results

A total of 150 patients completed the study procedures, and demographic and visual characteristics of the study sample are detailed in Tables 1 and 2, respectively. Patients in this study had a mean IVF sensitivity of 26.6 dB (normal value = 31 dB), better-eye mean deviation (MD) of −3.60 dB, worse-eye MD of −7.92, and mean better-eye VA of 0.09 (logMAR score). Of the 150 participants, 20 had severe (IVF <23 dB), 55 moderate (IVF ≥23 and ≤28), and 75 mild (IVF > 28 dB) glaucoma. Notably, only 35 participants (23.3%) demonstrated any measurable distance stereoacuity.

Table 1. Demographic and Health Characteristics in Studied Patients With Diagnosed or Suspect Glaucoma

Demographic Variable	N, Total n = 150	% of Patients, n = 150
Age (mean)	70.2[a]	
African-American	39	26.0
Male	71	47.3
Education		
Less than high school	5	3.3
High school	14	9.3
Some college	20	13.3
Bachelor's degree	37	24.7
More than Bachelor's degree	74	49.3
5+ medications	43	28.8
2+ comorbidities	90	60.0
Severe glaucoma	20	13.3
Moderate glaucoma	55	36.7
Mild glaucoma	75	50.0

[a] ±6.74 SD

From the Rasch analysis, the person and item measure separation reliabilities were 0.85 and 0.96, respectively, indicating that 85% and 96% of the variance in person and item measures were attributable to true differences between the person and items, instead of estimation error.

Relationships Between Individual Visual Measures

Correlations among all pairs of vision tests were statistically significant ($P < 0.05$; Table 3). AULCSF was highly correlated with CS ($r = 0.710$) and VA ($r = 0.747$), as expected. High levels of correlations also were observed between CS and IVF ($r = 0.748$), CS and VA ($r = 0.647$), AULCSF and IVF ($r = 0.639$), CS and color vision ($r = 0.624$), and number of noisy acuity letters read and AULCSF ($r = 0.611$). Lower levels of correlation were seen between stereoacuity and several measures, including CS ($r = 0.220$), color vision ($r = 0.226$), and VA ($r = 0.268$), though these correlations were expressed as rank correlations with Spearman's rho instead of Pearson's r.

Deming regression models were built to quantify the degree to which visual measures declined with IVF damage and poor VA. Each 5 dB decrement in IVF was associated with patients seeing 4.52 fewer color symbols ($P < 0.001$), reading 4.73 fewer noisy letters ($P < 0.001$), and having a 3.23-fold greater odds of

Table 2. Range of Vision Measures in Studied Patients With Diagnosed or Suspect Glaucoma

Vision Measures	Mean	Median	SD
IVF sensitivity, mean dB	26.6	27.9	5.6
Better-eye MD, dB	−3.60	−2.36	5.65
Worse-eye MD, dB	−7.92	−5	8.23
Better eye VA, logMAR	0.09	0.06	0.15
CS, logCS	1.66	1.72	0.21
CS function, AULCSF	1.13	1.16	0.32
Stereoacuity 400 arc and better (%)	23.3%	–	–
Noisy letters read	15.5	16	5.3
Number of color symbols seen (of 20)	17.7	20	5.1

poorer stereoacuity ($P < 0.01$; Table 4). When we restricted analysis to female participants (reducing the possibility of genetic color vision loss), participants saw 3.6 fewer color symbols for each 5 dB decrement in IVF ($P < 0.05$). Each 0.1 decrement in logMAR score for VA was associated with patients seeing 3.51 fewer color symbols ($P < 0.001$), reading 3.68 fewer noisy letters ($P < 0.001$), and having a 1.67 higher odds of poorer stereoacuity ($P < 0.001$). Similar results again were found when restricting color vision analysis to females only (2.81 fewer color symbols for each 0.1 decrement in logMAR score, $P < 0.04$).

Principal Component Analysis to Assess the Dimensionality of the Visual Function Tests

The first principal component explained 56.9% of the variance among all participants' aggregate vision scores (Fig. 1), the first two components together explained 71.7% of the variance, and the first three components together explained 81.9% of the variance. All components except for stereoacuity loaded similarly and positively onto the first component (eigenvectors, 0.327–0.442), while stereoacuity loaded less onto the first principal component (eigenvector, 0.220) and more strongly onto the second component (eigenvector, 0.734; Table 5).

The first principal component then was used in a multivariable analysis with the GQL-15 person measure scores as the dependent variable, controlling for age, sex, race, number of comorbidities, and polypharmacy. The adjusted-R^2 of the resulting model, or proportion of variance in GQL-15 scores explained by the model, was 0.282. A model with the first and second components had an adjusted-R^2 of 0.291. The adjusted-R^2 of a model containing only the

Table 3. Bivariate Correlations between All Pairs of Vision Tests in Sample of Patients With Glaucoma

	IVF	CS	AULCSF	VA	Noisy Letters Read	Stereoacuity
CS	0.748***					
AULCSF	0.639***	0.710***				
VA	0.540***	0.647***	0.747***			
Noisy letters read	0.471***	0.430***	0.611***	0.577***		
Stereoacuity	0.278**	0.220*	0.418***	0.268**	0.443***	
Color vision	0.534***	0.624***	0.421***	0.322***	0.375***	0.226*

Spearman's rho was used for comparisons with stereoacuity, while Pearson's r was used for all other comparisons. *$P <$ 0.05; **$P <$ 0.001; ***$P <$ 0.0001.

other covariates (age, sex, ethnicity, polypharmacy, and number of comorbidities) was 0.106.

Regressions Including One, Two, or Three Visual Function Tests

Because the results from our PCA suggested that vision in glaucoma may be multidimensional, we used an unbiased approach to determine how well different combinations of multiple vision measures predicted GQL-15 scores. To do so, we generated and compared all possible models with combinations of one, two, and three vision tests. Models using precisely one of the seven vision measures produced a maximum adjusted-R^2 value of 0.263 (using CS as the vision measure), the next highest adjusted-R^2 was 0.225 (using IVF as the vision measure), and the third highest was 0.221 (using VA as the vision measure; Fig. 2). Using two vision tests, the model incorporating CS and noisy letters read had the highest adjusted-R^2 of 0.296. The next highest adjusted-R^2 value was 0.274 (obtained with CS and VA as predictors), and the third highest adjusted-R^2 was 0.267 (obtained with IVF and CS as predictors). When using three vision tests, the model incorporating CS, noisy letters read, and stereoacuity had the highest adjusted-R^2 of 0.301.

The next best models contained IVF, CS, and noisy letters read (adjusted-R^2 = 0.294) and CS, VA, and noisy letters read (adjusted-R^2 = 0.293), respectively. Incorporating more than three visual predictors decreased the maximum adjusted-R^2 scores, to 0.299 in the four-visual measure models, and 0.287 in the seven-visual measure model (data not shown).

Dominance Analysis

In the dominance analysis, CS contributed most to the regression models using vision tests to describe GQL-15 scores (Table 6). Its dominance statistic of 0.067 suggested that on average, adding CS to a model for GQL-15 scores increased the amount of variance explained by the model (R^2) by 6.7%. Its standardized dominance statistic was 0.288, meaning that it accounted for 28.8% of the total variance in GQL-15 scores explained by all possible models using the vision tests as predictors. Noisy letters read (ViN) was the next-highest relative contributor to the models, with a dominance statistic of 0.042 (standardized value of 18.2%), though IVF and VA had similar contributions to the models (dominance statistics of 0.039 and 0.035, standardized values of 16.9% and 15.1%, respectively).

Table 4. Quantitative Relationship between IVF Sensitivity and VA and Other Measures of Vision, Including Color Vision, Noisy Letters Read, and Stereoacuity, as Determined by Deming Regression and Ordinal Logistic Regression

Variable	β or OR per 5dB IVF Decrement	95% CI	β or OR per 0.1 logMAR Decrement	95% CI
Color vision: fewer shapes seen	4.52	2.46–6.58	3.51	0.31–6.715
Noisy letters: fewer letters read	4.73	2.36–7.09	3.68	2.68–4.67
Stereoacuity: odds of lower stereoacuity	3.23	1.53–6.85	1.67	1.18–2.35

Results were derived from separate Deming regression models in which color vision, noisy letters read, and stereoacuity were the dependent variables, and IVF (IVF sensitivity) or VA was the independent variable. Deming regression was used for models of color vision and vision in noise, and ordinal logistic regression was used for stereoacuity models.
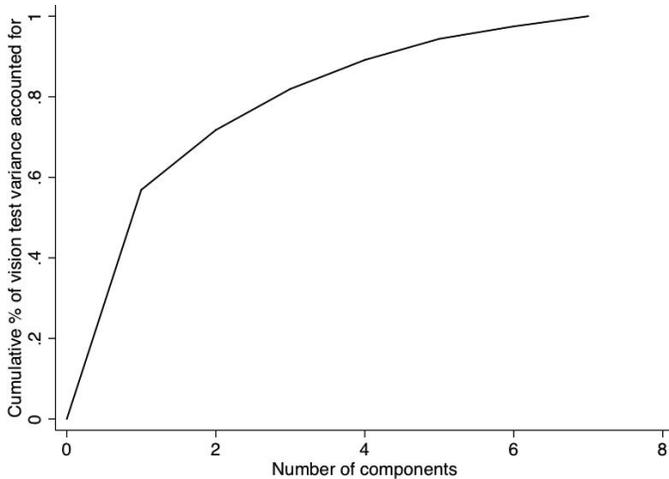
Figure 1. Cumulative percentage of the total variance in all vision test results explained by components generated though principal component analysis of the seven vision tests.

Discussion

We evaluated a group of patients with glaucoma using multiple measures of vision, with two purposes in mind: (1) to examine the dimensionality of vision in glaucoma, and (2) to determine which, and how many, visual factor(s) are needed to optimally account for variance in activity limitation. Our results suggested that, although vision in glaucoma is multidimensional, there is no benefit from incorporating more than two visual measures in models for activity limitation. Of note, the best models using one, two, and three visual parameters all included CS, and CS had the highest relative contribution to GQL-15 models in the dominance analysis. These results

Table 5. Eigenvectors Representing the Contribution of Vision Test Measures to the First Three Components Generated by Principal Component Analysis

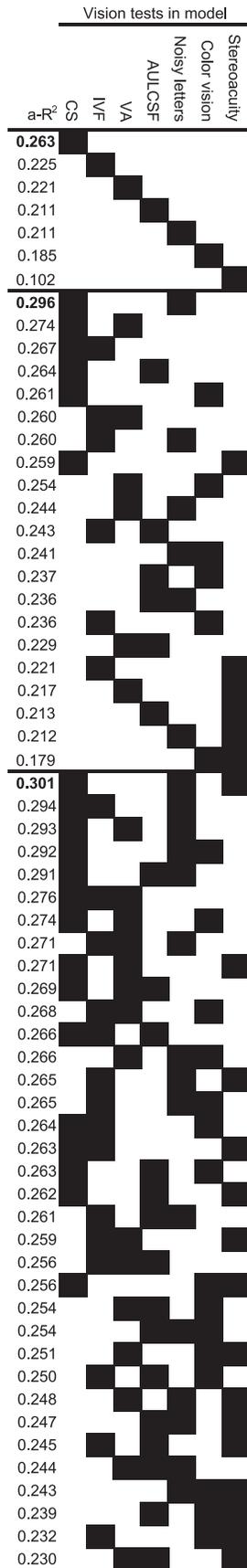| Variable	Component 1	Component 2	Component 3
AULCSF	0.4422	0.1252	−0.2292
CS	0.4302	−0.3275	−0.0056
IVF	0.4090	−0.2410	0.0767
VA	0.4030	0.0713	−0.5428
Noisy letters read	0.3666	0.3396	−0.656
Color vision	0.3268	−0.3998	0.6342
Stereoacuity	0.2201	0.7339	0.4904

Table 6. Dominance Analysis Representing Relative Contributions of Vision Tests to Models for GQL-15 Scores

Variable	Dominance Statistic	Standardized Dominance Statistic
CS	0.0670	0.2884
Noisy letters read	0.0422	0.1816
IVF	0.0394	0.1693
VA	0.0351	0.1510
AULCSF	0.0242	0.1041
Color vision	0.0187	0.0805
Stereoacuity	0.0058	0.0251

suggested that loss of CS may have a particularly significant role in patient disability.

Our correlation and principle component analyses support the concept that vision in glaucoma is a complex, multidimensional construct. All measures of vision examined here correlated with each other, with correlation coefficients ranging from 0.220 (between CS and stereoacuity) to 0.748 (for CS and IVF), and all measures of vision declined with increasing VF damage. These results aligned with those of previous studies that consistently have shown many types of vision worsening with glaucoma severity.[11,12] Individual correlation coefficients cannot, however, indicate the overlap of the correlations within vision space, and, thus, cannot describe the dimensionality of vision. With this in mind, we performed a principal component analysis that provided two pieces of evidence to suggest that vision in glaucoma is multidimensional. First, the principal component positively incorporated multiple visual measures, and was not dominated by any one element. Second, only 56.9% of the variance in the total visual space was explained by the principal component, and even the first three components together accounted for only 81.8% of the variability. These data suggested that no single visual measure is adequate to describe the full spectrum of vision loss resulting from glaucoma.

Based on these outcomes, we hypothesized that using multiple measures in combination may improve linear regression models for GQL-15 scores. However, our results suggested that this was not the case. The two-measure model most associated with GQL-15 scores yielded an adjusted-R^2 of 0.296, which was only slightly better than the best model incorporating only one visual parameter (adjusted-$R^2 = 0.263$). No

meaningful improvements in the adjusted-R^2 were noted with a third visual parameter (adjusted-$R^2 = 0.301$). The principal component generated from all vision variables did perform better than any single visual parameter, but accounted for slightly less GQL-15 score variance (28.2%) than the best two-test models. In a practical sense, our findings suggested that measuring multiple vision metrics may not be very helpful in improving our capacity to predict activity limitation in glaucoma patients, and that clinically, there is little need to incorporate more visual testing into the evaluation of patients to understand their level of disability.

We found that the measure most associated with GQL scores was not VF damage, the measure most often used clinically to diagnose and follow glaucoma. Rather, CS produced the best model for GQL scores, and outperformed IVF sensitivity in one-test models (adjusted-$R^2 = 0.263$ vs. 0.225). Furthermore, the top two two-predictor models (adjusted-$R^2 = 0.296$ and 0.274, respectively) included CS but not IVF as one of the visual parameters in the model, though the model with IVF and CS together was not substantially different (adjusted-$R^2 = 0.267$). Previous work by Nelson et al.[8] also found that measures of CS were on-par with measures of VF in associating with GQL scores. Vision in noise was a component, albeit a minor component, of the best two-variable and three-variable models modeling GQL, possibly resulting from the fact that this measure is relevant to activity limitation, and also sufficiently independent from CS ($r = 0.430$) to add additional information. Our dominance analysis also confirmed that CS and ViN had the highest relative contributions not only to the best-performing models for GQL-15, but on average, to all possible subset models. It is worth noting, however, that the best model in every category (one, two, or three variables) did not exceed the next by an adjusted-R^2 of more than 0.04.

The poor performance in distance stereoacuity in the cohort came as a surprise. In our older population with glaucoma, 76.7% demonstrated no measurable

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Figure 2. Performance of multivariable regression models in predicting Rasch-analyzed GQL-15 person measure scores using one, two, or three vision tests. The highest adjusted-R^2 value produced within each set is *bolded*. The variables used in each model are marked to the right of the R^2 values. Covariates for each model included age, sex, race, number of comorbidities, and polypharmacy.

stereoacuity (>400 arcsec) when tested at 3 m. In a previous group of normative subjects between ages 6 and 40, 96.8% demonstrated distance stereoacuity better than 100 arcsec.[22] When we used this distance randot test in a random sample of approximately 10 researchers age <45 without glaucoma, all had stereoacuity ≤60 arcsec, the maximum measured by the test (data not shown). Given the modest degree of glaucoma in the studied cohort, it is quite possible that our finding simply reflected age-related decay in distance stereoacuity, which would be consistent with decreases in close-range stereoacuity noted in previous studies.[23,24] The frequency of distance stereoblindness, however, appears much higher than rates of close-range stereoblindness noted previously: in the Salisbury Eye Evaluation Project, only 14.3% of an older population (ages 65–84) had no measurable stereoacuity when tested at 0.36 m.[25] The relationship of our results with age, distance, and glaucomatous change requires further follow-up.

Our VA in noise scores were not interpreted according to the suggestions of Levi et al.,[20] who used difference between noisy and nonnoisy letters read to determine how much noise contributed to vision deficits. Because patients with glaucoma have patchy loss of CS, it is reasonable to think that patients with more severe disease might have a greater decline in their VA in noise than in their high-contrast VA. However, we found that high-contrast VA and VA in noise declined similarly with VF loss (data not shown). These findings perhaps reflected the fact that only the most central portion of the VF is required for reading the chart letters, and glaucoma damage in this region is not patchy at the spatial frequency of the noise introduced. Although the difference between noisy and nonnoisy letters read did not significantly correlate with GQL-15 scores (data not shown), we did find the number of noisy letters read alone to be an important correlate of GQL-15 scores when combined with other vision measures.

Finally, we emphasized that the multiple social, demographic, health, and visual predictors included in our models accounted for only approximately 30% of the variance in GQL-15 scores. Models for activity limitation in previous studies have found similar results; the maximum adjusted-R^2 = noted in past studies was 0.543, found in a study that used over 10 covariates (including multiple measurements of VA and VF) in modeling non-Rasch–analyzed GQL-15 scores.[26] These data suggested that even with extensive vision testing clinicians may have limited ability to predict how patients experience their disability. This may be the case for several reasons. Vision-related activity limitation can be influenced independently by a person's general health and health-related quality of life, which is not entirely accounted for by the number of comorbidities.[27] The ability of vision to predict activity limitation also is likely lower in patients with earlier levels of disease,[28] and 62% of patients in this study had minimal VF loss (MD > −3) in the better-seeing eye, with 35% having minimal VF loss in both eyes.

There are several limitations of this study. Firstly, we verified that our study population was representative of the patient population followed at the Wilmer Eye Institute's glaucoma clinic in terms of age, other demographic characteristics, and glaucoma severity; it may not, however, be representative of the glaucoma population in the United States. Secondly, our models may have been improved by incorporating structural measures of glaucoma, as recent work by Medeiros et al.[29] have suggested that OCT measures can predict quality of life independently of VF. VF deficits in different hemifields also have been shown to associate with different functional outcomes.[30] Indicators of socioeconomic status also may have improved these models. The GQL-15 scale is largely mobility-focused, and may be less sensitive to other types of vision loss (e.g., color, VA in noise) that are less critical to mobility. The validity of these models also must be established by applying VF results from an independent population.

Conclusion

This study emphasizes the multidimensional nature of vision in glaucoma, and that visual deficits should not be thought of purely in terms of VF damage. CS in particular was the best predictor of glaucoma-related activity limitation, outperforming VF in modeling GQL-15 scores. However, variance in self-reported activity limitation is only moderately accounted for by vision testing, even when using multiple vision measures, and a maximum description of this limitation was obtained using one to two visual measures. Practically, these data suggested that incorporating more visual testing into patients' evaluations is not needed to understand their level of vision-related activity limitation.

Acknowledgments

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