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The Computerized Glaucoma Visual Function Test: A Pilot Study Evaluating Computer-Screen Based Tests of Visual Function in Glaucoma

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Purpose: We aimed to develop and evaluate the Computerized Glaucoma Visual Function Test (CoGVFT), among a cohort of glaucoma patients, and identify potential new items to optimize the test.

Method: A cross-sectional study involving 84 patients with open-angle glaucoma of varying severity and 18 controls without glaucoma were recruited. Better and worse eye visual field parameters, visual acuity, contrast sensitivity, 6-Part Cognitive Impairment Test (6CIT) and Glaucoma Activity Limitation-9 (GAL-9) questionnaire responses were recorded. The CoGVFT was administered to all participants. Rasch analysis was used to assess the psychometric properties of the CoGVFT, which was then evaluated with criterion, convergent, and divergent validity tests. Regression modeling determined factors predictive of CoGVFT performance.

Results: The 38-item CoGVFT demonstrated convergent validity with statistically significant differences in glaucoma severity groups ($P < 0.001$, analysis of variance). The correlation coefficient for CoGVFT person measures (logits) with GAL-9 person measures (logits) and better eye (BE) mean deviation was 0.528 ($P < 0.001$) and 0.762 ($P < 0.001$), respectively, demonstrating convergent validity. Divergent validity was suboptimal as the 6CIT score demonstrated moderate correlation ($r = 0.463$, $P < 0.001$) with CoGVFT person measures (logits). Multivariable analysis revealed that better BE contrast sensitivity, lower age, and better BE visual acuity were associated with better CoGVFT performance ($P < 0.001$).

Conclusions: The CoGVFT retains most of the features of its predecessor to estimate vision-based activity limitation related to glaucoma.

Translational Relevance: The CoGVFT is an easily accessible tool that can potentially be used in the community to help detect undiagnosed glaucoma in the population.

Introduction

Glaucoma is the leading cause of irreversible blindness worldwide[1] and its prevalence is rising.[2] Glaucoma affects 3.5% of those aged 40 to 80 years and will impact 112 million people by 2040.[2]

Progressive loss of vision caused by glaucoma leads to impairment of an individual's ability to perform activities such as reading, walking, driving, doing housework, and preparing meals.[3,4] It is important that tests exist that are not only capable of assessing the progression of glaucoma in a patient but are also capable of assessing how glaucoma affects their ability to perform their activities of daily living, so that such information can be integrated into the management of the patient.[3,5]

Currently, there are a variety of methods utilizable to assess the degree of activity limitation in a patient because of glaucoma. These methods include questionnaires or performance-based assessments. Questionnaires are widely accessible and easy to administer; however, the self-reported nature can lead to introduction of bias, personality, and other confounding factors

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that can impair its accuracy. Performance-based assessments are an objective method of assessing a patient but require a higher amount of resources that limit its ability to be widely adoptable.

The Cambridge Glaucoma Visual Function Test (CGVFT), on the other hand, is an easily accessible timed test involving a series of visually challenging tasks that reflect daily living but that can also objectively assess activity limitation. Although previously validated in a glaucoma cohort on a widescreen projector (subtending 120° of horizontal arc with binocular vision), it was not originally adapted to a computer screen, making it difficult for wide use.[6] Therefore we propose to validate the CGVFT on a computer screen, because the different viewing platform may affect the test performance. A computer-based simulation of visual challenges may have numerous applications, including improved understanding of the impact of glaucoma, a form of visual function monitoring in underresourced settings in which access to perimetry is limited or to allow a degree of self-diagnosis and monitoring by people using their home computers. We aimed to evaluate the CoGVFT and to identify potential new items to optimize the test.

Methods

Subjects

Patients were recruited from a multisite glaucoma subspecialty practice in Melbourne, 2019. Eligible subjects were invited to participate in the study after providing informed consent. The study adhered to the tenets of the Declaration of Helsinki. Ethical approval was provided by the Royal Australian and New Zealand College of Ophthalmology Human Research and Ethics Committee, with local site governance. Eligibility for the study included being able to speak, read and understand English fluently. Eligibility for the glaucoma group required participants to have a diagnosis of open-angle glaucoma in one or both eyes, based on gonioscopy findings, characteristic disc appearance and visual field changes defined on Anderson's criteria.[7] Eligibility for the control group required patients to not have glaucoma or another visually disabling eye illness and have valid visual field test results.

Patients with any nonglaucomatous condition that might influence visual function, such as visually-significant cataract (Lens Opacities Classification System III greater than Grade 2),[8] nonglaucomatous optic neuropathy or other neuro-ophthalmic condition, significant cognitive impairment, retinal or macular pathology, or ocular laser or surgery in the previous three months were excluded from the study, as were patients without reliable visual field test indexes.[9]

Assessment of Clinical Parameters

Recorded clinical parameters included visual acuity (VA), retinal nerve fiber layer (RNFL) thickness, cup/disc ratio, and visual field indexes using the Humphrey Field Analyzer (HFA) Swedish Interactive Threshold Algorithm standard 24-2 test. Contrast sensitivity was also recorded using the Pelli Robson chart monocularly at a distance of 1 m. Eyes were assigned into better eye (BE) and worse eye (WE) for each individual; the better eye was determined by the higher visual field index (VFI). When VFI was equivalent in both eyes, the less negative mean deviation (MD) determined the better eye. Better eye visual field test is a major determinant of binocular visual field and therefore an individual's ability to perform vision related tasks.[10]

Glaucoma patients were stratified by glaucoma severity using the binocular Nelson Glaucoma Staging System[6,11] into preperimetric (significant nerve fiber layer bundle loss but without visual field test results that met Anderson criteria), mild, moderate, and severe glaucoma groups. The Nelson Glaucoma Staging system was chosen because of its strong correlation with perimetric MD and pattern standard deviation (PSD).[11]

Subjective Assessment of Vision-Related Activity Limitation

Participants completed the GAL-9 questionnaire to serve as a subjective assessment of their activity limitation due to glaucoma.[12]

6-Part Cognitive Impairment Test (6CIT)

Participants were administered the 6CIT to assess level of cognitive impairment.[13] Participants are allocated points for incorrect answers to each question that classified them as normal, mildly cognitively impaired, or significantly cognitively impaired.

English Skills

Participants were requested to self-evaluate their ability to understand and speak the English language, providing a rating between 1 and 10, whereby 10 indicated proficient ability.

Rasch Analysis of the GAL-9

Rasch analysis was used to assess the psychometric properties of the GAL-9 using the Andrich rating scale model with Winsteps software, (Chicago, IL, USA).[12,14]

Computerized Glaucoma Visual Function Test

Participants completed the CoGVFT on a computer, sitting at a distance of 70 cm from the computer screen. Largely based on the preceding version, the CGVFT,[6] the new CoGVFT test comprises 13 types of tasks to be completed, with each type containing varying levels of difficulty (See Supplementary Material 1). In total, there were 58 tasks to be completed, each with written instructions displayed before the tasks began.

The CoGVFT was administered to participants by author CJ after conferring with SS about the study protocol to ensure consistency of testing conditions. The background lighting conditions were kept completely dark for five minutes, and the computer was turned on for at least 30 minutes before test administration to ensure consistency of adaptation and screen brightness. The images were displayed on a full HD screen with resolution 1920 × 1080 pixels. Participants were given a maximum of 30 seconds to complete each task. Each task involved viewing an image, in which a hidden object or a small item that was immediately previously shown to them must be found. The instructions for the task were provided in large font writing on the screen before the test image was shown. Clicking on the correct item within the allocated time results in successfully completing the task. Timing began when the participants had finished reading the instructions and stopped when the participants successfully completed the task. Participants were permitted to attempt the task again if they answered incorrectly for a maximum of three attempts. Participants were moved on to the next task after 30 seconds had been reached or if they had answered incorrectly three times. Each task had a central fixation point of a rotating gold star, and participants were asked to begin each task by looking at the fixation point but were subsequently permitted eye and/or head movements to complete the task.

Rasch Analysis of the Computerized Glaucoma Visual Function Test

Rasch analysis was used to assess the psychometric properties of the CoGVFT. Details regarding the methods of Rasch analysis can be found from previous studies and is similar to the prior validation study of the original CGVFT.[6,12,14,15]

Statistical Analysis

Statistical Package for Social Sciences (SPSS, IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0; IBM Corp., Armonk, NY, USA) was used for statistical analyses.

The desired sample size calculation was based on the modeled standard errors of the item calibration in the range: $2/[\sqrt{\text{sample size}}] < \text{standard error} < 3/[\sqrt{\text{sample size}}]$. This equates to a minimum acceptable sample size of 64.[16]

To account for subject dropout, we aimed to recruit slightly greater numbers, with the ratio of controls to glaucoma patients 1:4 to 5 in keeping with previous studies.[17–19]

Receiver Operating Characteristic (ROC) Curve, Sensitivity, and Specificity

A ROC curve was generated using CoGVFT person measure scores and the Youden index determined the maximum possible combination of sensitivity and specificity.

Validity Evaluation of the Computerized Glaucoma Visual Function Test

The following tests were used to validate the CoGVFT:

Criterion Validity

Criterion validity was assessed by evaluating the ability of the CoGVFT person measure scores (logits) to distinguish between glaucoma severity levels.

Convergent Validity

Convergent validity (investigation of whether constructs that are expected to be related, are in fact related) was assessed by exploring the correlation of the CoGVFT with the GAL-9 and better eye MD. We hypothesized there would be moderate correlation (r = 0.4–0.7) between the measurements as both the GAL-9 and better eye MD measure related constructs.[20]

Divergent Validity

Divergent validity of the CoGVFT was assessed by evaluating correlation between CoGVFT and factors (gender, 6CIT cognitive function score, subjective

Table 1. Clinical Variable Among Different Glaucoma Severity Groups

		Patients With Glaucoma				
Variable	Control (n = 18)	Preperimetric (n = 20)	Mild (n = 19)	Moderate (n = 28)	Severe (n = 17)	*P* Value
Age	58.1 (17.83)	53.150 (14.680)	67.105 (11.614)	66.500 (14.533)	76.177 (8.225)	<0.001
Gender						0.934
Male	6	9	9	12	7	
Female	12	11	10	16	10	
BE RNFL	96 (8.01)	86.100 (10.508)	80.579 (10.495)	74.786 (14.968)	62.941 (10.065)	<0.001
BE VA	−0.039 (0.069)	−0.035 (0.067)	0.021 (0.085)	0.032 (0.086)	0.347 (0.314)	<0.001
BE MD	0.248 (0.973)	−0.020 (0.995)	−0.562 (1.646)	−2.722 (2.740)	−17.556 (8.340)	<0.001
BE PSD	1.433 (0.203)	1.504 (0.259)	1.799 (0.901)	4.092 (2.614)	9.029 (2.536)	<0.001
BE VFI	0.998 (0.006)	0.994 (0.008)	0.985 (0.013)	0.932 (0.071)	0.561 (0.241)	<0.001
BE cup/disc ratio	0.565 (0.123)	0.547 (0.196)	0.615 (0.105)	0.656 (0.157)	0.803 (0.131)	<0.001
BE contrast sensitivity	1.933 (0.229)	1.905 (0.176)	1.721 (0.214)	1.671 (0.318)	1.076 (0.531)	<0.001
WE RNFL	94.500 (8.219)	83.450 (12.754)	71.052 (11.217)	64.444 (13.839)	58.786 (8.719)	<0.001
WE VA	−0.028 (0.089)	0.060 (0.312)	0.053 (0.112)	0.243 (0.693)	0.641 (0.969)	0.004
WE MD	−0.386 (1.244)	−0.983 (1.273)	−4.292 (5.937)	−8.549 (4.807)	−18.867 (6.329)	<0.001
WE PSD	1.631 (0.529)	1.563 (0.345)	3.966 (2.643)	8.477 (4.235)	10.200 (3.290)	<0.001
WE VFI	0.991 (0.011)	0.988 (0.016)	0.901 (0.185)	0.779 (0.141)	0.434 (0.199)	<0.001
WE cup/disc ratio	0.562 (0.126)	0.563 (0.208)	0.658 (0.139)	0.731 (0.162)	0.856 (0.099)	<0.001
WE contrast sensitivity	1.933 (0.246)	1.718 (0.478)	1.689 (0.228)	1.500 (0.512)	0.847 (0.687)	<0.001
GAL-9	−3.423 (1.817)	−3.576 (1.527)	−2.934 (1.821)	−2.675 (2.105)	−0.682 (2.420)	<0.001
CoGVFT	−2.6117 (1.32283)	−2.509 (0.897211)	−3.3447 (1.203303)	−3.6425 (1.523171)	−6.2594 (2.259487)	<0.001

Age: age mean y (SD). RNFL: RNFL mean µm (SD). VA: logMAR mean (SD). MD: MD mean dB (SD). PSD: PSD mean dB (SD). VFI: VFI mean % dB (SD). Cup/disc ratio: cup disc/ratio mean (SD). Contrast sensitivity: contrast sensitivity log, mean (SD). GAL-9: GAL-9 logit, mean (SD). CoGVFT: CoGVFT logit, mean (SD). SD, standard deviation; dB, decibels; PSD, pattern standard deviation.

English skills score) hypothesized to have no/mild correlation with CoGVFT performance.

Regression Analysis

Univariate regression analysis was performed to investigate the relationship between CoGVFT scores and clinical parameters. Significant predictors of CoGVFT scores were subsequently included in a stepwise linear multivariate analysis.

Results

The cohort consisted of 84 glaucoma patients (20 preperimetric, 19 mild, 28 moderate, and 17 severe glaucoma) and 18 controls. Two patients were excluded from this study because of insufficient visual field data; three were excluded due to significant cognitive impairment. There were statistically significant ($P < 0.05$) intergroup differences for most clinical variables (Table 1). The average time taken for individuals to complete the test (not including time taken to read instructions) was 8 minutes and 34 seconds, with a standard deviation of 3 minutes and 31 seconds.

Gal-9 Rasch Analysis

The GAL-9 scores displayed good fit to the Rasch model, with no evidence of multidimensionality, ordered thresholds, no differential item functioning or item misfit. Person separation and person reliability indexes were acceptable on initial analysis (2.04, 0.81 respectively), however, targeting was suboptimal (−2.6).

CoGVFT Rasch Analysis

With the initial 116 items included, a PCA of the residuals was performed and the unexplained variance explained by the first contrast was 25.9 eigenvalue units, with 52 items loading (>0.4) onto the first contrast. The unexplained variance explained by the second contrast was 8.7 eigenvalue units, with 16 items loading (>0.4) onto the second contrast. The unexplained variance explained by the third contrast was 4.9 eigenvalue units, with 4 items loading (>0.4) onto the third contrast. The unexplained variance explained by the fourth contrast was 3.9 eigenvalue units, with two items loading (>0.4) onto the fourth contrast. The unexplained variance explained by the fifth contrast was 3.6 eigenvalue units, with two items loading (>0.4) onto the fifth contrast.

The items within each of the five contrasts formed five distinct domains for further psychometric testing.

Table 2. Steps Involved in Reducing the Computerized Glaucoma Visual Function Test From 116 Items to 38 Items

Step 1	Principal component analysis (PCA) of all 116 items
Step 2	Unexplained variance explained by the first contrast was 25.9 eigenvalue units, with 52 items loading (>0.4) onto the first contrast
Step 3	11 items were found to misfit (outside the range 0.40–1.70) and were removed:
Step 4	3 items displayed differential item functioning (DIF) for gender—these were removed
Step 5	Assessment of person separation: 2.98 and reliability: 0.9(acceptable)
Step 6	Assessment of targeting: difference of −2.6 between the mean patient and item values (suboptimal).
Step 7	Rasch analysis of each of the second to fifth possible domains (from PCA) indicated that none provided valid measurement. Items were grossly misfitting and the person separation was inadequate.

Rasch analysis was performed for the first domain containing 52 items, and the item fit statistics indicated that four items misfitted. These were removed and on a second iteration five items were found to misfit. These were removed and on a third iteration two further items were found to misfit. On the fourth iteration no misfitting items were detected however differential item functioning was detected for 3 items for gender, which was removed. No further DIF was identified. Person separation and reliability were acceptable with values of 2.98 and 0.9, respectively. Targeting was suboptimal with a difference of 2.6 between the mean patient and item values. Rasch analysis of each of the second to fifth domains indicated that none provided valid measurement. Items were grossly misfitting and the person separation was inadequate (Table 2).

A CoGVFT person measure (logit) score was created for each of the 102 subjects based on the 38 items that fit the Rasch model (Table 3). All 38 items involved the binary Correct/Incorrect test information; details of timing per item did not pass Rasch analysis for any item.

Table 3. The Computerized Glaucoma Visual Function Test Items

1. Street scene
This is a street scene. Find these objects:
 ~~a. (bus)~~
 ~~b. (Virgin shop sign)~~
 ~~c. (Brazilian flag)~~
 d. (graffiti)
2. Face in the crowd
Find the person shown in each artwork
 a. (Mustacho man)
 b. (Seurat girl)
 c. (Renoir man)
 d. (Rembrandt man)
 e. (Raphael man)
3. Hidden objects
Find the odd one out
 a. (raspberry)
 b. (old coin)
4. Camouflaged animals
In each image is an animal—Find the hidden animal
 a. (Left—gecko)
 b. (Right—turtle)
 c. (Left—lobster)
 d. (Right—fish)
 ~~e. (Left—grasshopper)~~
 f. (Right—bird)
5. Cutlery
 a. Find the spoon among the forks
 b. Find the plastic spoon
6. The crowded room
Find the following objects in the crowded room:
 a. clock
 ~~b. kettle~~
 ~~c. scissors~~
 d. apple
 e. metal spoon
7. Shadowy furniture
How many chairs are in the room?
(Answer options 1–7)
8. The newspaper
Please look at this news page and find the following answers:
 ~~a. What is the name of the newspaper?~~
 b. What is the temperature today?
 c. Who won the Masters?
 d. How long is the writing course?

Table 3. Continued

9. Find the x among the +s
~~a. (bottom right) Easy~~
b. (top left) Moderate
c. (left) Hard
10. Find the pair—match the sock:
~~a. (correct: top far left) Easy~~
~~b. (correct: middle right) Moderate~~
c. (correct: top far right) Hard
11. Moving balls
From where do you see the ball?
~~a1. (top right) Easy~~
~~a2. (bottom left) Easy~~
~~a3. (bottom) Easy~~
~~a4. (top left) Easy~~
~~b1. (right) Easy~~
~~b2. (top) Easy~~
b3. (bottom) Easy
~~b4. (top left) Easy~~
c1. (bottom left) Moderate
c2. (top) Moderate
c3. (bottom right) Moderate
c4. (top right) Moderate
d1. (top right) Hard
d2. (bottom left) Hard
d3. (bottom) Hard
d4. (top left) Hard
12. Reading
Read the text. Follow the hidden instruction in the text regarding the numbered buttons
a. *The Great Gatsby*, by F Scott Fitzgerald
b. *David Copperfield*, by Charles Dickens
c. Newspaper text
13. Find the cheese
Find the cheese in the following images
~~a. (correct: middle left)~~
~~b. (correct: middle right)~~
c. (correct: bottom far right)
d. (correct: middle top right)

Those items marked with a strikethrough are those from the pilot test that were not included in the final Rasch model.

Receiver Operating Characteristic (ROC) Curve, Sensitivity and Specificity

The generated ROC curve displayed a statistically significant area under the ROC curve of 0.688 ($P = 0.0045$) (Fig. 1). The Youden Index J was 0.2976 at an associated criterion (CoGVFT person measures) ≤ -2.83. The sensitivity and specificity at that associated criterion was 63.1 and 66.67, respectively.

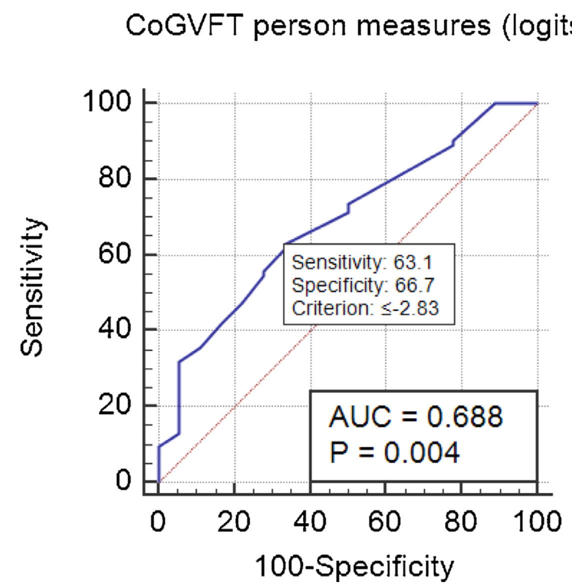

Figure 1. CoGVFT receiver operating characteristic curve.

CoGVFT Validation in a Glaucoma Cohort

Criterion Validity

Statistically significant differences for CoGVFT scores were detected among glaucoma severity groups ($P < 0.001$, analysis of variance), indicating worsening CoGVFT ability with worsening glaucoma, demonstrating criterion validity (Fig. 2).

Convergent Validity

The Pearson correlation coefficient for CoGVFT with GAL-9 and BE MD was 0.528 ($P < 0.001$) and 0.762 ($P < 0.001$), respectively, indicating convergent validity (Fig. 3).

Divergent Validity

CoGVFT score did not correlate with gender and correlated weakly with subjective English ability (Pearson coefficient 0.219, $P = 0.027$), indicating that gender had no effect and subjective English ability had a small effect on CoGVFT performance. However moderate correlation (Pearson coefficient 0.463 ($P < 0.001$)) between CoGVFT and 6CIT score was detected indicating suboptimal divergent vaalidity.

Factors Predictive of CoGVFT (logit) Score: Univariable and Multivariable Analysis

Univariate regression analysis demonstrated that GAL-9 (logit) score, Age, WE MD, WE VA, BE

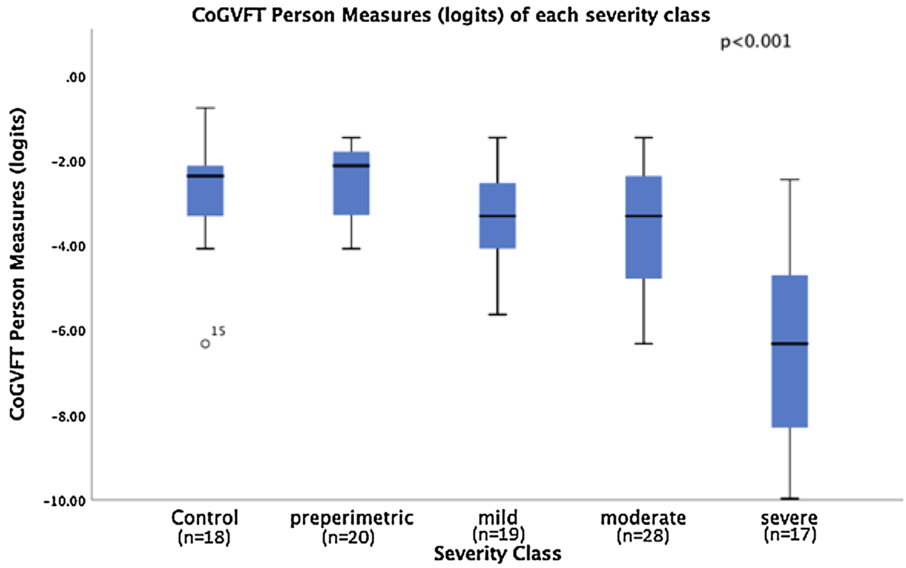

Figure 2. CoGVFT person measures (logits) versus glaucoma severity class.

RNFL, WE RNFL, BE PSD, WE PSD, WE VFI, BE cup/disc ratio, and WE cup/disc ratio had a statistically significant correlation with CoGVFT scores (Table 4). BE contrast sensitivity had the highest correlation coefficient with CoGVFT Person Measure score (logits), $r = 0.831$ (Fig. 4).

Variables that were significant on multivariable analysis were BE contrast sensitivity, age, and BE VA, together producing a correlation coefficient of 0.852.

Discussion

This study demonstrates that the CoGVFT is a potentially useful test for simulating activity limitation related to glaucoma but will likely benefit from some modifications.

The strength of the CoGVFT is that it is an objective computer based test, which can therefore be

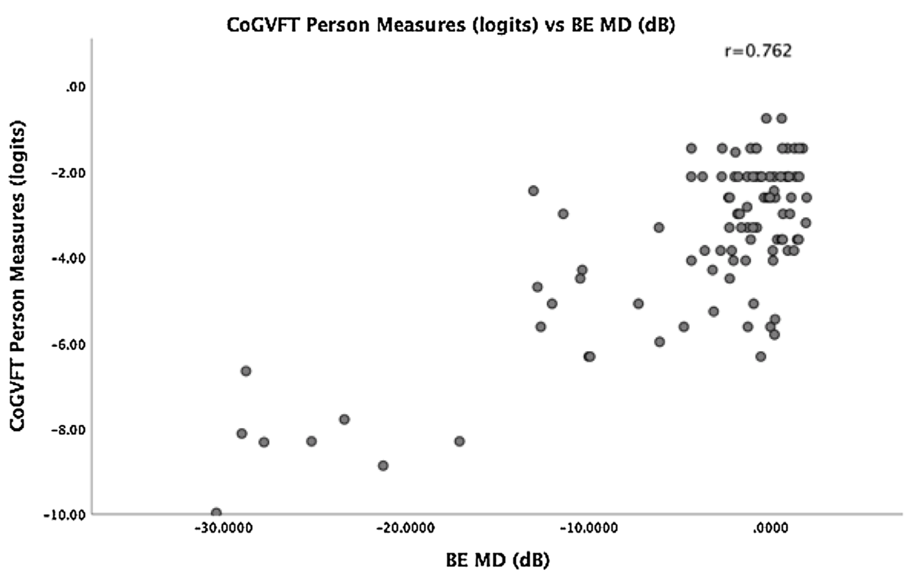

Figure 3. CoGVFT person measures (logits) versus BE MD (dB).

Table 4. Univariate and Multivariate Analysis of Factors Predictive of Computerized Glaucoma Visual Function Test (Logit) Score

Variable	β	β 95% CI	R Statistic	F Statistic	P Value
Univariate analysis					
Gal-9 logits	−0.587	−0.775 to −0.4000	0.528	38.614	<0.001
Age, y	−5.057	−6.302 to −3.812	0.628	64.962	<0.001
BE MD dB	2.905	2.409–3.400	0.762	135.398	<0.001
WE MD dB	2.665	1.936–3.394	0.603	52.698	<0.001
BE logMAR VA	−0.073	−0.087 to −0.059	0.718	106.672	<0.001
WE logMAR VA	−0.167	−0.217 to −0.116	0.545	42.332	<0.001
BE RNFL µm	3.514	2.099–4.928	0.442	24.28	<0.001
WE RNFL µm	4.375	2.593–6.157	0.445	23.756	<0.001
BE PSD dB	−0.875	−1.161 to −0.590	0.524	37.007	<0.001
WE PSD dB	−0.926	−1.429 to −0.424	0.357	13.408	<0.001
BE VFI % dB	0.073	0.059–0.087	0.727	107.453	<0.001
WE VFI % dB	0.080	0.056–0.103	0.581	45.951	<0.001
BE cup/disc ratio	−0.039	−0.054 to −0.023	0.446	24.791	<0.001
WE cup/disc ratio	−0.043	−0.060 to −0.026	0.447	25.034	<0.001
BE contrast sensitivity, log	0.181	0.157–0.205	0.831	223.116	<0.001
WE contrast sensitivity, log	0.221	0.182–0.260	0.749	127.867	<0.001
Subjective English Ability	−7.548	−11.043 to −4.053	0.219	5.031	0.027
6CIT score	−2.897	−3.332 to −2.461	0.463	27.323	<0.001
Multivariable analysis					
BE contrast sensitivity, log	1.911	1.043–2.779	0.852	77.783	<0.001
Age, y	−0.030	−0.044 to −0.015			
BE logMAR VA	−2.251	−3.766 to −0.736			

widely accessible and utilizable. It is a useful bridge between daily patient function and peripheral visual testing, allowing clinicians, patients, and policy makers to better understand the impact of glaucoma on daily life. It is also safer to administer compared to performance-based assessments that requires individuals to physically perform tasks such as ambulation.[21] The CoGVFT also does not preclude individuals with neurological or musculoskeletal disease affecting mobility or speech from undertaking the test.[21]

The CoGVFT may have many potential applications once further refined. It may allow a form of glaucoma detection and monitoring by individuals in their own home. Currently up to 50% of glaucoma remains undiagnosed in developed countries,[22] largely because undetected cases have not attended an optometrist for glaucoma screening. Tests that can be performed without attending the optometrist (i.e., on a personal computer) may have a role in increasing detection rates. In addition, computer-based tests like the CoGVFT may be a suitable alternative for use as a visual function assessment in low resource areas that lack accessibility to Ganzfield-bowl perimetry. Given that the test can be quickly completed on an average of 8 minutes and 34 seconds, it can also be widely used in busy clinical environments to assess individuals and identify any visual deficits while they wait for their appointments.

On Rasch analysis the CoGVFT displayed good person separation and reliability, and no DIF. However, targeting was suboptimal, indicating the cohort overall were too able for the test. This is similar to the GAL-9 and other glaucoma-specific tools with good Rasch metrics and reflects that glaucoma tends to not greatly impact activity limitation until more advanced stages.[23] Such a finding could be due to the test being too easy. Alternatively, it may be because of binocular administration of the test, allowing the better eye to compensate for the worse eye until later stages of disease. We feel the test could benefit from monocular administration, as well as the inclusion of more challenging tasks to improve interperson discrimination.

Multivariate analysis revealed that BE contrast sensitivity, lower age, and BE VA were the best combination of predictors of CoGVFT ability. This finding is logical, because many of the tasks require VA and contrast sensitivity. It is possible that older age may

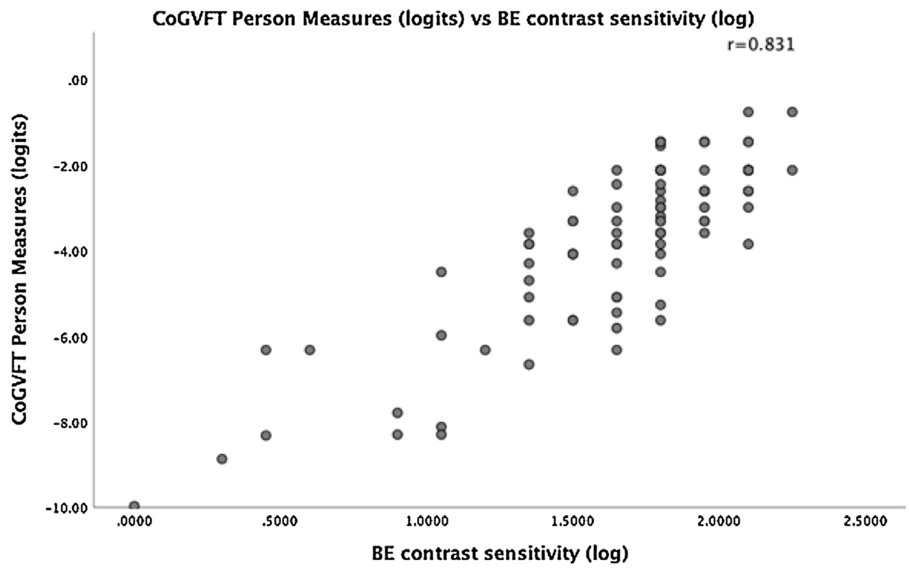

Figure 4. CoGVFT person measures versus BE contrast sensitivity (log).

correlate with poorer performance because those with more advanced glaucoma were older in our cohort. This is generally unavoidable because glaucomatous damage tends to accumulate with age. Another possible explanation for this observation is unfamiliarity with the technology being used to conduct the CoGVFT among older individuals. During administration of the test, it was observed that the older participants had more difficulty with using the mouse, and it was this inexperience that in some cases resulted in failing to complete a task. Simplifying the tasks, using a touch screen instead of a mouse, and perhaps a trial learning (nonscored) task at the beginning of the test might help improve usability and consistency of measurement.

Although the CoGVFT was assessed successfully using criterion and convergent validity testing, divergent validity was suboptimal as 6CIT score demonstrated moderate correlation ($r = 0.463$, $P < 0.001$) with CoGVFT score; there was a weaker correlation between 6CIT and BE MD of 0.221 ($P = 0.004$). This finding suggests that increasing cognitive impairment is associated with poorer performance on the CoGVFT. This is consistent with findings that cognitive impairment influences visual field test performance[24]; however, the CoGVFT may have higher cognitive requirements than HFA, because participants are asked to read, understand, and follow different instructions listed for each task.[25] Future versions of the CoGVFT might benefit from reducing the cognitive requirements of the tasks, so that it can test visual ability more and cognition less. The test also requires participants to be competent with the English language, as the tasks are accompanied with English instructions. Future versions may have potential to translate the tasks into other languages or onto different platforms such as touch-screen tablets or mobile phones to help increase accessibility.

The test displayed suboptimal diagnostic ability as seen in Figure 1, with sensitivity and specificity levels that did not satisfy the Prevent Blindness America's criteria for minimum performance of a screening test.[26] The test was best at differentiating severe versus moderate cases of glaucoma and not as good at moderate versus mild, as seen in Figure 2. However, there are many potential avenues available for improving the test discrimination. The test was administered binocularly, but monocular occlusion (testing one eye at a time) will likely result in increased ability to distinguish a wider range of glaucoma severity levels. Furthermore, it may be of benefit to test individual loci on the computer screen methodically; doing so will help distinguish smaller, focal scotoma.

This study itself has potential drawbacks. The sample population was recruited from glaucoma subspecialty clinics at a multisite private clinic and therefore may not be representative of the general population. The study can benefit from having larger sample sizes, especially in the control group (which ideally would be age-matched). However, the current study was powered a priori and was required as a pilot study to help refine the computerized test before larger studies could be undertaken.

Additionally, the study validates the CoGVFT for use on a specific monitor. When the test is disseminated and administered on different monitors, the differing resolution, brightness, and contrast settings of the monitor will impact on the difficulty of the test. It is therefore vital to be conscious of this potential impact and attempt to control for these influencing factors. In addition, it is unknown whether the tasks included in the CoGVFT are a true representation of the real-life tasks that patients experience on a day to day basis. It is at best an estimation of the potential visual difficulties that patients encounter.

In conclusion the CoGVFT retains many of the functions of the original validated CGVFT despite being administered on a smaller computer screen. There are many potential avenues to improve the test's ability to evaluate visual function related to glaucoma.

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