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A novel Bayesian approach to testing and analyzing visual acuity

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Abstract

Purpose : To develop a computational framework for improving the precision for testing visual acuity (VA), and the detection of its changes

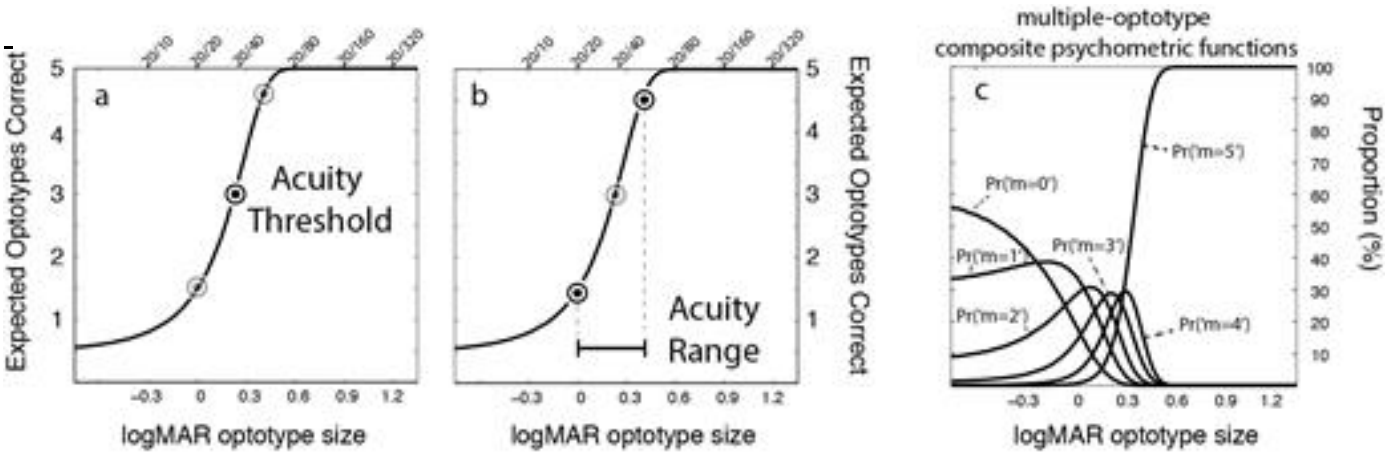
Methods : We developed a novel Bayesian method (Fig 1) for testing and analyzing VA that: (1) uses high-density sampling of optotype size (.02 logMAR resolution); (2) describes the full acuity function (threshold and range;Fig 1a,b); (3) considers acuity behavior via composite multiple-optotype psychometric functions, Fig1c; (4) applies a Bayesian adaptive strategy to gain information about acuity threshold and range, and (5) calculates an acuity change index based on ROC analyses of Bayesian posteriors. In this proof-of-concept study, simulations compare the stimulus sampling, precision/repeatability, and sensitivity to change for Bayesian VA and e-ETDRS testing. Although VA testing is designed to estimate threshold-size for correctly reporting 3/5 optotypes- Carkeet et al (2001;2017) have demonstrated that blur/contrast conditions can affect acuity range, and thereby increase VA test variability. Simulated observers were drawn from a sample population with mean VA=.30 logMAR, (s.d., .30) and different parameters of acuity range (from .10 to .80).

Results : For e-ETDRS, varing from low to high acuity range doubled the test-retest variability from .05 to >.10, and test-retest precision decreased from 92% to 82%. The Bayesian VA algorithm continues to converge with increased test duration. For testing 10-30 rows of five optotypes (50-150 letters), test-retest variability exhibited for low and high ranges varied from .015-.033 logMAR to .07-.11 logMAR, respectively. Corresponding values of test-retest precision varied from 97% to 84%. The amount of Bayesian VA testing needed to match the precision of e-ETDRS is 5-7 rows. This precision advantage is likely provided by precise stimulus sampling that matches the full acuity function. In a simulation of a 5-letter change

in VA, e-ETDRS exhibited a 85% accuracy for detecting acuity change, whereas Bayesian VA testing provided detection accuracy of 86%, 94%, and 97% with testing of 10, 20, and 30 rows.

Conclusions : This study provides a proof-of-concept for Bayesian testing of visual acuity. Estimation of the full acuity function with high-density sampling of optotype size exhibits the potential for sensitive and precise detection of changes in VA.

This is an abstract that was submitted for the 2018 ARVO Annual Meeting, held in Honolulu, Hawaii, April 29 - May 3, 2018.



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Accuracy in detecting vision changes with visual acuity and contrast sensitivity tests

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Abstract

Purpose : Accurate detection of vision change is important in diagnosing and monitoring visual disease progression and treatment effects. In this study, we evaluated the accuracy of three tests in detecting vision changes: the e-ETDRS (Beck et al., 2003), a new Bayesian visual acuity test (Lesmes, 2017), and qCSF assessment of the contrast sensitivity function (Lesmes, et al, 2010; Hou, et al, 2015).

Methods : Monocular visual acuities and contrast sensitivities were measured with the three tests in both eyes of six subjects with normal or corrected-to-normal vision in four simulated vision conditions (no foil and three different levels of Bangerter foil that degraded vision). Each session tested one foil condition. Subjects were tested monocularly with both the new Bayesian visual acuity and e-ETDRS methods 4 times, with random test order of the two methods and two eyes in different blocks. At the end of each session, the contrast sensitivity function of each eye was measured with the qCSF method. An ROC analysis (Hou et al., 2016) was conducted to evaluate the accuracy of the methods in detecting changes in visual acuity and area under the log CSF (AULCSF) associated with different foil conditions. The analysis consisted of computing (1) the average acuity from repeated e-ETDRS measures in each eye and foil condition for each subject; (2) posterior distributions of the estimated VA from the new visual acuity and e-ETDRS tests and AULCSF from the qCSF, (3) the accuracy of detecting acuity changes (averaged across all 16 possible combinations of the four repeats in each condition) and AULCSF changes between each pair of foil conditions; (4) the average accuracy in three ranges of mean acuity changes: 0.02-0.05, 0.05-0.10, and 0.10-0.20 logMAR.

Results : For detection of visual function change, the qCSF with 50 trials had the highest accuracy (0.996 ± 0.008, 0.996 ± 0.007, and 0.987 ± 0.020 in the three ranges), followed by the new Bayesian visual acuity test with 45 trials or 135 letters (0.874 ± 0.038, 0.910 ± 0.047,

and 0.971 ± 0.036), and lastly by the e-ETDRS test with 30.8 ± 5.4 letters (0.826 ± 0.036, 0.808 ± 0.029, and 0.0.905 ± 0.042).

Conclusions : Bangerter foils produce deficits in visual function beyond visual acuity. The qCSF was the most accurate test for these deficits, and the new Bayesian VA test is more accurate than e-ETDRS in detecting associated visual acuity changes.

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A Novel Contrast Sensitivity Test as a New Measure of Visual Function in Central Serous Chorioretinopathy

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Abstract

Purpose : To evaluate the efficacy of computerized testing of contrast function in central serous chorioretinopathy (CSCR).

Methods : A multicenter, prospective, cohort study of 36 eyes of 18 patients with a history of CSCR. Patients were enrolled from September 2016 to November 2017 and met the following criteria: age 18 years or older, history of current or prior CSCR, non-visually significant cataracts, and no other ocular pathology. All patients underwent spectral domain optical coherence tomography (SD-OCT) and testing of the contrast sensitivity function (CSF) using the quick CSF (qCSF) algorithm implemented on the novel AST platform (Adaptive Sensory Technology, San Diego, CA). The contrast sensitivity function was broadly summarized by the area under the log contrast sensitivity function (AULCSF). Results were compared to an already acquired age-matched control group of 81 eyes via z-score: zAULCSF = (AULCSF-meanControl)/stdControl.

Results : Of the 36 included eyes, 22 had evidence of current or prior CSCR. Affected eyes had a statistically significant reduction in the AULCSF compared to controls (.94 vs 1.28, p=.005). Mean best-corrected visual acuity was logMAR 0.09 (~20/25) in unaffected eyes versus 0.25 (~20/35) in affected eyes. Unaffected eyes had a statistically significant reduction in the AULCSF compared to controls (1.08 vs 1.28, p=.005), but not relative to affected eyes (p=.13). Comparing our results to the age-matched controls, the median z-score for AULCSF was -1.07 ± 1.34 in affected eyes, compared with -.15 ± 1.6 in unaffected eyes (p=0.005).

Conclusions : Contrast sensitivity is significantly reduced in eyes affected by CSCR. The qCSF test provides a sensitive and efficient way to provide additional functional vision measures that may otherwise not be well quantified with current clinical measures.

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A Novel Contrast Sensitivity Test as a Measure of Functional Vision in Macular Telangiectasia and Central Retinal Vein Occlusion

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Abstract

Purpose : Traditional letter visual acuity does not always adequately describe a patient's visual limitations or pathologic changes in a variety of maculopathies. Herein, we evaluate the utility of a computerized contrast testing device in patients with macular telangiectasia (mac tel) and central retinal vein occlusion (CRVO).

Methods : Prospective, observational, IRB-approved study. All patients had a history of mac tel or CRVO in one or both eyes. Exclusion criteria was cataract status >2+ nuclear sclerosis, or visual acuity (VA) <20/200. All patients underwent quick contrast sensitivity function (qCSF) testing in each eye using the Sentio Platform (Adaptive Sensory Technologies, San Diego, CA) and SD-OCT at their regularly scheduled visit. The qCSF method uses computerized, Bayesian, adaptive testing to track changes in a patient's contrast sensitivity with varying spatial frequencies to calculate an area under the curve (AUC). Contrast sensitivity was compared to previously collected data for 81 age-matched healthy controls, represented by calculating a Z-score (AUC-AgeMean)/AgeStdDev.

Results : 6 patients with mac tel (11 eyes) and 7 patients with CRVO (8 eyes) were tested with a mean age of 64.5 years ± 15.0. In mac tel, the mean BCVA was logMAR 0.197±0.18 (20/33) with a mean area under the CSF curve (AULCSF) of 0.609±0.20. In CRVO, the mean BCVA was logMAR 0.207±0.16 (20/32) with a mean AULCSF of 0.716±0.31. Compared to the healthy controls, we found a statistically significant reduction in mean AULCSF for both mac tel ($p=9.63x10^{-9}$) and CRVO (p=0.00004). This reduction in contrast function can be further illustrated by Z-scores, demonstrating a nearly 2 standard deviation difference; Z=-1.97±0.6

in mac tel and Z=-1.91±0.9 in CRVO. Even when looking at all patients with greater than 20/30 letter acuity, the difference in AULCSF reached statistical significance (AULCSF=0.857±0.18, p=0.002).

Conclusions : We present a novel contrast test that demonstrated a statistically significant difference in contrast sensitivity function in patients with CRVO and mac tel. Further analysis of high letter acuity patients still revealed a statistically significant reduction in contrast function. CSF assessment may provide another useful clinical endpoint in disease monitoring of patients with CRVO with macular edema and macular telangiectasia.

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A novel Bayesian adaptive method for mapping the visual field

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Investigative Ophthalmology & Visual Science July 2018, Vol.59, 1266. doi:

Abstract

Purpose : Measuring visual functions - light and contrast sensitivity, visual acuity, reading speed, crowding - across retinal locations provides visual field maps (VFMs) that are valuable for detecting and managing eye disease. Mapping light sensitivity is standard for glaucoma, but its assessment is noisy (Keltner et al, 2000). Mapping other visual functions is difficult. To improve the precision of light sensitivity mapping, and enable other VFM testing, we develop a novel hybrid Bayesian adaptive test framework. This study validates the quick VFM (qVFM) method to measure light sensitivity across the visual field.

Methods : The qVFM combines a parametric approach for preliminary assessment of the VFM's shape, and a non-parametric approach for assessing individual VF locations. In both simulation and psychophysics studies,we sampled 100 VF locations (60 x 60 deg) and compared the performance of qVFM with a qYN procedure that tested each location independently (Lesmes, et al, 2015). Subjects were cued to report a target dot's presence or absence, with its luminance adaptively-adjusted on each trial. Simulated runs of 300trials (for both qVFM and qYN) were used to compare the accuracy and precision of the methods. In addition, data were collected from six eyes (3 OS, 3 OD) of 4 normal subjects.

Results : Simulations showed that the bias and standard deviation (SD) of the estimated thresholds (in dB: -10*log10(luminance (in asb)/10000)) were 0.049 and 0.63 dB by the qVFM, and 0.21 and 0.85 dB by the qYN. Estimates of within-run variability (68.2% HWCIs) were comparable to cross-run variability (SD). For the subjects, the average HWCI of the qVFM estimates decreased from 7.65 dB on the first trial to 0.51 dB after 150 trials, and to

0.41 dB after 300 trials. The root mean squared error (RMSE) of light sensitivity estimates from the qVFM and qYN methods started at 1.95 dB on the first trial and decreased to 1.51 dB after 150 qVFM trials and to 1.08 dB after 300 trials.

Conclusions : The qVFM provides accurate, precise, and efficient mapping of light sensitivity. The method can be extended to map other visual functions, with potential clinical signals for monitoring vision loss, evaluating therapeutic interventions, and developing effective rehabilitation for low vision.

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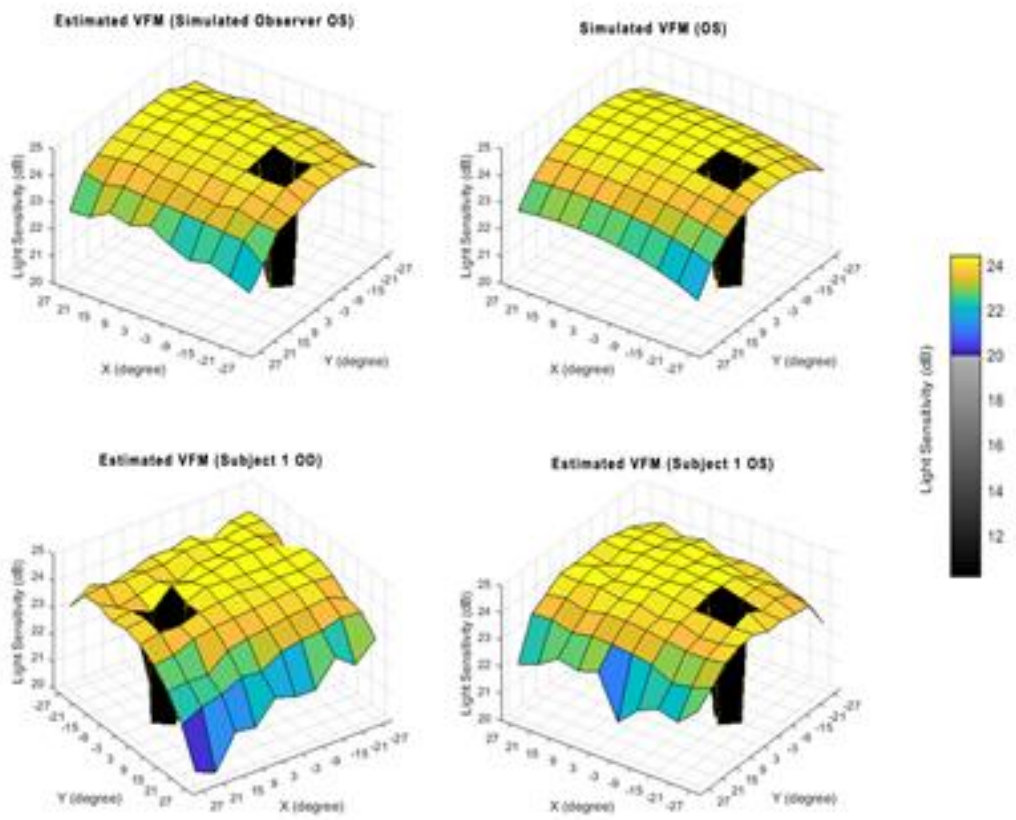

Estimated VFM from Simulated and Human Observers

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Visual Quality and Contrast Sensitivity Function after Corneal Transplant

Jin Yuan; Jing Zhong; Zhong-Lin Lu; Fang Hou; Michael Dorr; Zhipeng Chen; Siyuan Deng; Jinrong Li

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Investigative Ophthalmology & Visual Science July 2018, Vol.59, 5753. doi:

Abstract

Purpose : To assessed the contrast sensitivity function (CSF) of post-keratoplasty patients following keratoplasty with the quick CSF method and evaluated the relationship between CSF and visual quality of the patients.

Methods : 27 patients (12 cases of keratoconus, 7 corneal stromal dystrophy, 5 limbal dermoid, 2 herpes simplex keratitis and 1 mooren's ulcer; mean age: 24.6 ± 14.1 yrs; mean spherical and cylindrical correction: -2.66 ± 3.05 D and 2.56 ± 0.84 D) were included in this study. All patients underwent a routine ophthalmic examination and monocular visual acuity and quick CSF tests under full optical correction in the post-surgery eye. In addition, 13 patients performed a binocular quick CSF test and filled out the 9-SF visual quality questionnaire. The normal group consisted of 15 normal subjects (mean age: 25.83 ± 1.67 yrs; mean spherical and cylindrical correction: -5.35 ± 3.01 D and 0.17 ± 0.24D) whose visual acuities were reduced to the corresponding degree to match the patients by using the positive spherical lens of 1.0D to 6.0D. Subjects in the normal group participated in a monocular quick CSF test. Two summary metrics, the cutoff spatial frequency (cutoff SF) and the area under log CSF (AULCSF) in CSF were derived from the quick CSF tests.

Results : The cutoff SF of the keratoplasty group (7.09 ± 2.65 cpd) was significantly lower than that of the normal group (mean ± SD, 8.64 ± 4.12cpd) ($P < 0.001$). The AULCSF of the keratoplasty group (0.56 ± 0.18) was significantly lower than that of the normal group (0.69 ± 0.34) ($P < 0.001$). For the keratoplasty patients, the monocular AULCSF and cutoff SF both correlated negatively with the degree of astigmatism of the surgical eye ($r = -0.591$, $P = 0.020$; $r = -0.618$, $P = 0.014$); the AULCSF but not the cutoff SF correlated negatively with the LogMAR BCVA ($r = -0.407$, $P = 0.048$; $r = -0.150$, $P = 0.485$). The results suggest that post-

keratoplasty astigmatism significantly contributed to CSF deficits. For the 13 patients who performed the binocular quick CSF test, both AULCSF and cutoff SF correlated positively with the 9-SF scores (r = 0.831, P < 0.0001; r = 0.856, P < 0.0001).

Conclusions : Patients following keratoplasty exhibited CSF deficits above and beyond their visual acuity deficits. As CSF is highly correlated with visual quality, it is an important clinical management tool for assessing visual quality of patients with keratoplasty.

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Psychophysical validation of a novel Bayesian method for measuring visual acuity

Yukai Zhao; Luis A Lesmes; Michael Dorr; Peter J. Bex; Zhong-Lin Lu

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Abstract

Purpose : The ETDRS chart (Ferris III, et al., 1982) and its computerized version, e-ETDRS (Beck et al., 2003), remain the standard for testing visual acuity in clinical trials, but testing acuity with precision remains a challenge. Lesmes (2018) introduced a novel Bayesian visual acuity test (Bayesian VA) that provides the advantages of high-density sampling of optotype size (.02 logMAR), adaptive stimulus optimization (Lesmes, et al, 2006), and the post-hoc analyses of Bayesian credible intervals (68.2% half-width credible interval - HWCI). Here, a proof-of-concept psychophysical study evaluates the accuracy and precision of the Bayesian VA method.

Methods : For six subjects with normal or corrected-to-normal vision, monocular visual acuities were measured for both eyes in four acuity conditions (three with different levels of Bangerter foil to degrade vision and one with no foil). In each session, subjects were tested monocularly with Bayesian VA and e-ETDRS methods 4 times in each eye in one of four foil conditions, with random ordering of the two methods and two eyes in different blocks. For each trial of Bayesian VA testing, three optotypes were presented, with their size selected by an adaptive maximization of information gained about the threshold and range of the full acuity function.

Results : There was excellent agreement between the estimated thresholds from the novel VA approach and the e-ETDRS standard, with a correlation coefficient of .99 ($p<0.001$) across all subjects and foil conditions. Across conditions with average acuities ranging from -0.02 to 0.50 logMAR, the average HWCI of the estimated acuity from e-ETDRS was 0.096 ± 0.019 decimal log units. In comparison, the precision of Bayesian VA increased with the number of trials. The average HWCI of estimated acuities after 10, 15, and 45 trials were 0.091 ± 0.028, 0.070 ± 0.022, and 0.037 ± 0.011, respectively. Because of different stimulus sampling

resolutions (.02 vs .10 logMAR), we compared the test-retest precision of the two methods using Fractional Rank Precision (FRP, where higher values indicate higher precision; Dorr, et al., 2017): for Bayesian VA, FRP=0.852 ± 0.025; for e-ETDRS: FRP=0.826 ± 0.027.

Conclusions : After 10 trials (30 letters~40 sec), the precision of Bayesian acuity estimates matched that of the e-ETDRS in 30.8 ± 5.4 letters. With more trials, the precision of Bayesian VA continued to improve over that of e-ETDRS.

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Validation of the quick CSF method with digit stimuli

Haiyan Zheng; Fang Hou; Luis A Lesmes; Zhong-Lin Lu

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Abstract

Purpose : The contrast sensitivity function (CSF), typically measured with sinewave gratings, provides a comprehensive assessment of functional vision. Recently, we implemented the quick CSF method (Lesmes, et al, 2010) with a 10 alternative forced-choice (10AFC) paradigm using filtered Sloan letters and greatly improved the efficiency of the test (Hou, et al, 2015). However, people in non-English speaking countries who are unfamiliar with English letters can't benefit from the more efficient quick CSF test. To address this problem, we implemented the quick CSF method using a new set of digit stimuli and conducted two psychophysics experiments to validate the new procedure.

Methods : We created a set of Sloan digits (0 ~ 9) based on the principles used to design Sloan letters. The digits were then filtered with a raised cosine filter (Chung, Legge et al. 2002), rescaled to different sizes to cover a range of spatial frequencies (0.5 ~ 16 cpd), and used as stimuli in a 10AFC digit identification task. We measured (1) the CSFs of five normal participants using both the 10AFC digit identification and 2AFC grating orientation (± 45°) identification tasks with the Psi method (Kontsevich and Tyler 1999), and (2) the CSFs of five normal participants using both the quick CSF and Psi methods with the 10AFC digit identification task.

Results : We found that the digit CSF almost perfectly matched the grating CSF after controlling for stimulus and task differences. The root mean square error (RMSE) between the digit and grating CSFs was 0.049 ± 0.027 log units. With 150 trials, the 68.2% half width credible interval (HWCI) of digit CSF with the Psi method was 0.057 ± 0.005 log units, smaller than that of the grating CSF (0.127 ± 0.022 log units). We also found that, with the digit identification task, the CSFs obtained with the quick CSF method matched very well with those obtained with the Psi method (RMSE = 0.053 ± 0.019 log units). With 150 trials, the

average 68.2% HWCI of the CSFs obtained with the quick CSF procedure was 0.037 ± 0.009 log units, which is significantly lower than that from the Psi method (0.052 ± 0.004 log units, $p < 0.001$).

Conclusions : The digit CSF provides essentially the same measure as the grating CSF. The quick CSF method combined with the digit stimuli could serve as a precise and efficient test instrument for CSF, especially for people who are unfamiliar with English letters.

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