Article

A New Contrast Sensitivity Test for Pediatric Patients: Feasibility and Inter-Examiner Reliability in Ocular Disorders and Cerebral Visual Impairment

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Purpose: Assess feasibility and interexaminer reliability of a new test of contrast sensitivity (CS) for pediatric populations.

Methods: The Double Happy (DH) measures CS using a method similar to the Teller Acuity Cards. The schematic DH face is 16 degrees in diameter with features of 0.3 c/d and a channel frequency of 0.8 c/d. DH $\log_{10}$ CS is in 0.15 log unit steps, 0.05 to 2.1. Participants were 43 unselected patients, ages 2 to 18 years: 23 were diagnosed with ocular disorders only; 20 were diagnosed with cerebral visual impairment (CVI). Two examiners measured DH $\log_{10}$ CS. Visual acuity (VA) was also measured.

Results: All 43 participants were tested for binocular DH $\log_{10}$CS. Cohen's kappa values for interexaminer reliability were fair. The between examiner ICC was $+0.92$ ($P < 0.001$). The mean difference between examiners was near zero, and the 95% CI was -0.44 to 0.45 $\log_{10}$CS. DH $\log_{10}$CS was near normal in the ocular disorder group and reduced in the CVI group. VA was reduced in both groups. DH $\log_{10}$ CS and VA were correlated ($r = -0.65$). DH $\log_{10}$ CS was a marginally better predictor of diagnosis than VA.

Conclusions: DH $\log_{10}$CS test was successful in a diverse pediatric population diagnosed with ocular disorders or CVI. Interexaminer reliability was comparable to that of adults tested previously using the same stimuli and methods. Both CS and VA are reduced in CVI.

Translational Relevance: CS and VA both should be tested in pediatric clinical populations, especially in those at risk of CVI.

Introduction

Contrast sensitivity (CS) loss is associated with impaired daily living skills in adults, including difficulties in mobility, driving, face recognition, using tools, and finding objects.[1–3] CS may be a better predictor of performance in activities such as discriminating between objects, recognizing faces, and judging distance than visual acuity (VA).[4,5] Thus, there is good reason to measure both CS and VA in individuals with visual impairments; both need to be considered when managing habilitation and rehabilitation.

Recent studies report that functional visual abilities and vision-related quality of life (QoL) are reduced in children with congenital ocular disorders.[6,7] An extensive study of diverse pediatric vision disorders found impaired functional vision and eye-related QoL in children with moderate-severe visual impairment defined by their visual acuity deficit.[8] A study of adolescents with low vision tested with the Ohio Contrast Cards (OCC) found that CS correlated with vision-related QoL, whereas visual acuity did not.[9] This study provides some evidence that CS may be more sensitive than VA to aspects of vision-related QoL.

Efficient and reliable tests of letter CS are in widespread clinical use.[10–14] Often, clinical tests of the contrast sensitivity function (CSF) use sine wave gratings.[15,16] To measure CS, patients can identify letters or indicate the orientation of a grating for sine-wave grating CSF tests. However, letter identification and grating orientation skills tend not to be reliable even in normal children younger than age four to five years.[17,18] Visual evoked potentials (VEP) can measure the contrast sensitivity of children with ocular[19,20] and neurologic disorders, including cortical vision impairment (CVI).[21,22] However, VEPs do not measure behavior, rather the physiological response of the visual pathway. Clinical use of VEP tends to be restricted to specialized practices because complex equipment, specialized procedures, and experienced personnel are required.

Behavioral tests developed to assess CS in infants and children are more straightforward to administer in the clinic because the examiner directly assesses the child's "looking" response. Pediatric CS test stimuli include sine-wave gratings (contrast sensitivity card test [CSCT]),[23–26] a large low frequency square wave grating (OCC),[9] schematic face stimuli (Hiding Heidi[27,28] [HH], www.good-lite.com; Mr. Happy[29]), and picture outlines (Cardiff Contrast Test[30,31] [CCT], www.eyesfirst.eu). There are limitations to these tests and their clinical applications. For example, measuring a CSF with sine-wave gratings (CSCT) is time consuming and requires two people. Other tests have a relatively low maximum CS (e.g., HH, Mr. Happy, CCT), and their test-retest reliability has not been reported. Nor have most tests been validated against a standard CS test. Finally, clinical feasibility has not been determined for young patients with visual and multiple impairments.

We developed a stimulus and test procedures to address the limitations of previously developed pediatric tests of CS. Feasibility, test-retest reliability, and interexaminer reliability of this new CS test were assessed in a clinical population of children diagnosed with ocular disorders or cortical/cerebral visual impairment (CVI). CS results were analyzed by age, visual acuity, and diagnosis.

Methods

Stimulus, Test Cards, and Procedures

We designed a schematic smiling face stimulus that would appeal to young children, similar to the HH[27,28] face. Multiple spatial frequencies comprise the HH face,[27] whereas the features in the DH face are

Figure 1. The Double Happy Contrast Test shown at three contrast levels: high contrast in the center, mid-level contrast on the left, and low contrast on the right. The Double Happy face is identical when rotated 180 degrees. The dot in the center of the card is the viewing peephole for the examiner to observe the child's visual responses.

constrained to a narrow band of spatial frequencies enabling the testing of a restricted range of spatial frequencies. The DH stimulus is offset from the center of 40 cm wide by 25 cm high cards, whereas the HH faces fill the entire test card. The DH face stimulus is identical when rotated by 180 degrees (deg) (Fig. 1). This characteristic led to the name double happy contrast sensitivity test (DH CS) test.

The visual angle of the DH face and features are calculated at the horizontally displaced location of the face and shown to the child at a distance of 40 cm. The diameter of the face is 12 cm, subtending 16.1 deg. The features of the face and the spaces are approximately 1.25 cm in width. The average visual angle of the features is 1.67 deg (100.2 min arc or 2 logMAR) equivalent to 0.3 c/d in spatial frequency.

The channel spatial frequency of the DH face stimulus is 0.8 c/d when calculated with the formula from Majaj et al.[32] That is, the five strokes in the 16 deg DH face result in 0.8 c/d. Both the feature frequency of 0.3 c/d and the channel frequency of 0.8 c/d are below the peak (maximum) spatial frequency of the CSF for square wave gratings in normal adults.[33] CS for stimuli created with square wave edges is relatively constant for spatial frequencies lower than peak contrast sensitivity. Square wave CS is unlike CS for sine wave gratings. Sine wave CS is reduced for spatial frequencies below the peak CS (see Fig. 6A in reference 9).[33] The DH stimulus contains square wave–like edges, and the DH face features are near the peak contrast sensitivity for individuals with a range of visual acuity reduction. However, individuals with a visual acuity lower than the DH spatial frequency and channel frequency, i.e., 1.55 to 2.0 logMAR, may not have a measurable CS.

The DH test set is 16 cards, 15 printed with a face varying in contrast relative to the white card background and one card without a face stimulus. The DH stimuli and test cards were produced by Precision

Vision (Woodstock, IL, USA). The Weber contrast of the stimuli ranges from 89% to 0.8% (0.05 to 2.1 $\log_{10}$ CS). Weber contrast was measured by Precision Vision, in collaboration with John Robson (Ed Kopidlansky, personal communication, 2019), with a proprietary method. The difference in CS between the DH stimulus cards is 0.15 $\log_{10}$. Labels placed on two diagonally opposite corners of the rear of the card indicate the Weber contrast, CS, and $\log_{10}$ CS. Thus there are no cues on the rear of the cards that give the location of the face stimulus on the card to the tester. The luminance of the white background of the DH cards was measured with a Konica Minolta LS-100 luminance meter as 2.1 $\log_{10}$ cd/m^2. (Konica Minolta, Tokyo, Japan). A fluorescent lamp placed above and behind the child and parent holder illuminated the test cards. The test cards were held by the examiner when s/he presented them to the child.

The test distance of 40 cm equals the horizontal length of the test card, which aids in the administration of the test. The examiner measured the test distance with the card length before the test and as needed during the test.

The test procedure is similar to that recommended for clinical testing of grating visual acuity with TAC.[34] The DH cards are tested in sequence from highest to lowest contrast. But, unlike testing with the clinical TAC method, all DH cards are tested. The tester assesses the participant's responses for cards at suprathreshold contrast, usually presenting each only once or twice. The DH cards around contrast threshold are tested several times. Children's responses are defined as a fixation shift to one side of the card, searching the card and then fixating one side, or pointing to one side.

As in the recommended TAC test procedure,[34] the examiner is unaware of the location of the face and the study would not influence the child's examination, remains unaware until s/he determines whether the child detected the face. Only then the examiner checks the location of the face on the card. If s/he is uncertain whether the participant detected the face on a specific card, the card is set aside and retested after higher contrast faces are detected successfully. The lowest contrast DH face that the child detected is then defined as their contrast threshold.

Two examiners (authors DLM and BK) tested all participants in this study. Both the order of the test and tester identity were block-randomized before each appointment. For example, for participant 1, BK was the first tester and DLM the second tester; for participant 2, DLM was the first tester and BK the second tester. The tests were completed in a single session in separate examination rooms. Participants were tested binocularly. The second examiner was unaware of the first examiner's test results.

Visual acuity was tested as part of the participant's clinical examination. Binocular acuity was measured to make VA measures comparable with DH CS thresholds. The participants wore their glasses for visual acuity and DH testing. The type of visual acuity test depended upon the participant's ability to respond, and the most advanced method was used for each patient. Line letter acuities were tested in 17 participants. Single optotypes (letters or symbols such as Lea [Goodlite, Elgin, IL, USA] or Patti Pics [Precision Vision, Woodstock, IL, USA] were tested with 10 participants who either named or matched the optotypes. Grating acuity was tested with the clinical TAC procedure[34] in 16 participants.

Participants and Diagnoses

Participants were recruited from those patients scheduled for an examination at the New England College of Optometry's clinic, New England Eye Low Vision Clinic at the Perkins School for the Blind. Inclusion criteria were age between birth and age 18 years and visual acuity better than 2 log MAR, if known. Recruited patients included both previously examined and new patients. Patients were not included or excluded based on their diagnosis. Patients with developmental disabilities were not excluded.

The protocol of the DH study was approved by the New England College of Optometry Institutional Review Board. The study complied with the Helsinki Declaration regarding research with human subjects. A recruitment letter with information about the study was sent to the patients' families before their appointment. If the parent and child agreed to participate in the study, then informed consent and assent were obtained. The parent was assured that participation in the study would not influence the child's examination.

Parents of 66 consecutive, unselected patients were invited to participate; five parents declined; 14 were unable to be tested due to examiner illness; three canceled and could not be rescheduled; and one patient did not show. Thus 43 patients completed the study. The mean/median age of the participants was 6.9/6 years (standard deviation [SD] 4.52, range 2–18 years). Mean binocular acuity was 0.68 log MAR (SD 0.43).

The participant's primary cause of visual impairment was divided into two categories, ocular disorder, or cerebral/cortical visual impairment (CVI). Supplementary Material S1 provides details on the determination of ocular disorders and CVI diagnoses. Supplementary Table S2 provides ocular diagnostic information for each participant as well as

neurological, genetic, syndromic, and systemic abnormalities, DH log contrast sensitivity (DH $\log_{10}$ CS), and visual acuity (logMAR) with an indication of visual acuity test type.

Of the 43 participants, 23 had an ocular disorder with no evidence of CVI. Twenty (20) participants were diagnosed with CVI. Five of the participants with CVI also had a significant ocular disorder: optic atrophy (patient 25), optic atrophy and history of retinal hemorrhages (patient 30); optic nerve and chiasmal hypoplasia (patient 32); optic nerve hypoplasia (patient 34); retinopathy of prematurity (patient 41). However, visual function deficits (visual acuity, visual fields) associated with these ocular disorders did not explain their CVI (see Supplementary Material S1). Many participants had significant neurologic or systemic disorders. Of the 43 study participants, 25% (11) had cerebral palsy, and 21% (9) had a seizure disorder. Cerebral palsy and seizure disorders were more frequent in participants with CVI (cerebral palsy in 10, seizures in 8) than in those with ocular/ocular motor disorder.

Results

Feasibility of DH CS Test

All 43 participants were successfully tested for binocular DH $\log_{10}$ CS by two examiners. The total test time was approximately two to three minutes. A few participants required more time, especially if a break was needed.

We predicted that participants with acuity below the DH spatial frequency or the channel spatial frequency (>1.55 to 2.0 logMAR) would not have measurable CS. Nevertheless, all participants had measurable CS. Three participants with reduced visual acuity at about the DH feature and channel spatial frequency (Supplementary Table S1: patient 18, patient 27, and patient 30: logMAR 1.51, 1.55, 1.55, respectively) had measurable CS (mean $\log_{10}$ CS 1.13, 0.98, 0.38, respectively). Testing DH CS in clinical practice also reveals some patients with poor acuity who have surprisingly good DH CS. See the discussion for a likely explanation for this (page no. 6).

Test-Retest Reliability of DH $\log_{10}$ CS

There was no difference between DH $\log_{10}$ CS on test 1 versus test 2 ($t = -0.51$, *df* = 42, *P* = 0.61). The mean difference between tests was −0.017, and the 95% confidence interval (CI), defined as the mean ± 1.96 times the SD, was −0.58 to 0.54 $\log_{10}$.
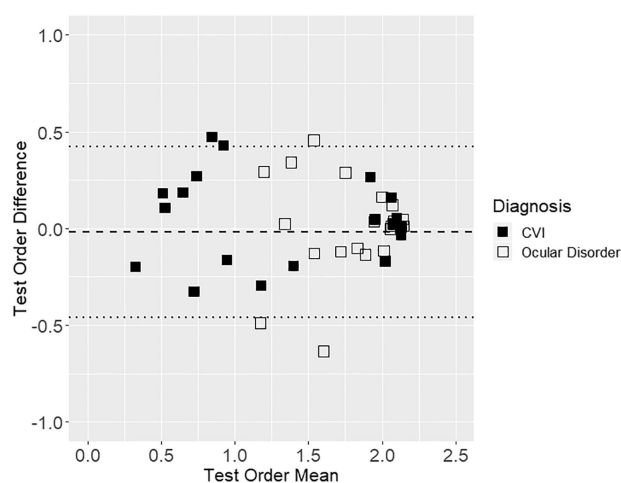
Figure 2. The *filled squares* represent DH $\log_{10}$ CS scores for the CVI patients and the *open squares* for those with ocular disorder. The abscissa is the mean of the scores from the first and second test and the ordinate the difference between test 1 and test 2. The *dashed line* is the median difference between the first and second test, and the *dotted lines* the limits of the 95% CI on the difference. Note that DH $\log_{10}$ CS scores were lower for those with CVI.

Interexaminer Reliability of DH $\log_{10}$ CS

Cohen's kappa for two raters (unweighted) was 0.238 ($z = 4.16$, *P* < 0.001). Kappa for the ocular group (n = 23) was 0.274 ($z = 3.05$, *P* < 0.01) and for the CVI group (n = 20) 0.176 ($z = 2.19$, *P* < 0.05). The difference between the mean DH $\log_{10}$ CS measured by the two examiners in all participants was not statistically significant (paired *t*-test, Examiner 1 mean 1.611, Examiner 2 mean 1.615, difference −0.003, SD 0.226; $t = -0.101$, *df* = 42, *P* = 0.46). The 95% CI was −0.44 to 0.45 $\log_{10}$ CS. The ICC of DH $\log_{10}$ CS between the two examiners was 0.921 (*P* < 0.001). The high level of agreement between testers led us to use DH $\log_{10}$ CS for subsequent data analyses.

Bland-Altman Analyses of Test Order and Tester Identity

Figures 2 and 3 show the Bland-Altman graphical analysis of test order and tester identity. The median difference shown in Figure 2 is consistent with the previously stated observation of no significant difference between DH $\log_{10}$ CS on test 1 versus test 2. The Bland-Altman analysis depicted in Figure 3 also agrees with the inferential test of interexaminer reliability.

Age at Test

The mean DH $\log_{10}$ CS for all participants did not correlate significantly with age at test (Pearson
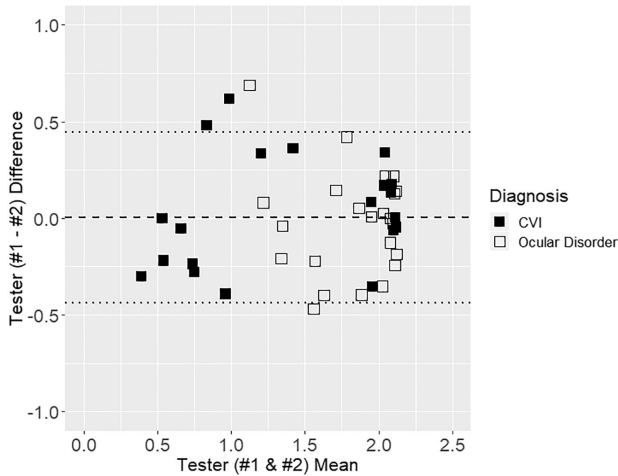
Figure 3. The *filled squares* represent DH $\log_{10}$ CS scores for the CVI patients, and the *open squares* for those with ocular disorder. The abscissa is the mean of the scores from the two testers and the ordinate the difference. The *dashed line* is the median difference between the two testers, and the *dotted lines* the limits of the 95% CI on the difference. Note that DH $\log_{10}$ CS scores were lower for those with CVI.

Figure 4. Visual acuity versus DH contrast sensitivity for all participants. The filled squares represent results from CVI patients and the open squares results from those with ocular disorders. The *solid black* line shows the line of best fit and the shaded region the 95% CI. Note that DH $\log_{10}$ CS and VA were reduced in participants with CVI compared with those with ocular disorders.

$r = 0.243$, $P = 0.12$). Visual acuity (logMAR) did not correlate significantly with age at test (Pearson $r = -0.025$, $P = 0.87$).
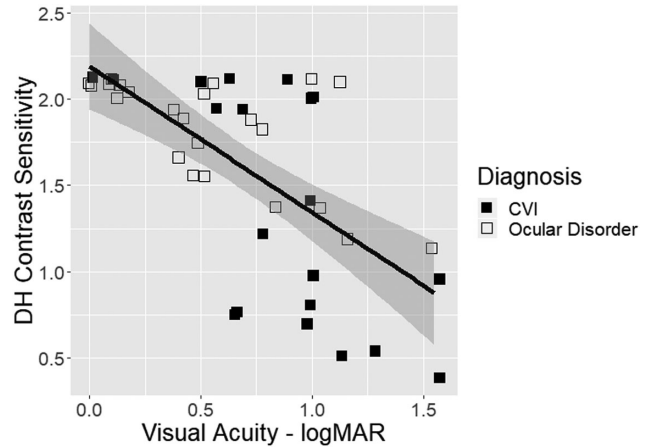
DH $\log_{10}$ CS and Diagnosis

Using a Welch two-sample *t*-test, the means of DH $\log_{10}$ CS for the CVI versus ocular disorder groups were different ($t = -2.75$, $df = 26.38$, $P = 0.011$). The 95%CI of the difference ranged from -0.79 to -0.11. The mean DH $\log_{10}$ CS was 1.37 for the CVI group and 1.82 for the ocular disorder group.

Correlation Between DH $\log_{10}$ CS and Visual Acuity

Figure 4 shows the mean CS from the two DH tests with an individual participant versus the individual's visual acuity; Pearson's *r* was -0.65 ($P < 0.01$). To evaluate the robustness of the correlation and protect against high-leverage points,[35] we used the bootstrap[36,37] to calculate a 95% confidence interval on *r*. The range of the confidence interval for *r* was -0.80 to -0.44.

Linear Mixed-Model of DH $\log_{10}$ CS

To evaluate the ability of the independent variables to predict mean DH $\log_{10}$ CS, we used a linear mixed-effect model. The model was calculated with the R software environment and the *nlme* package.[38,39]

There are at least two benefits of linear mixed-effect models over repeated measures analysis of variance (ANOVA). First, mixed-effect models have the benefit of assuming the variance of the residuals are normally distributed and not the data itself. Second, unlike repeated-measures ANOVA designs, mixed-models do not assume homoscedasticity of variance (i.e., that the variance within groups or independent variances is equal).

The full model used DH $\log_{10}$ CS as a dependent variable with VA, diagnosis, age, and VA test type as fixed effects and tester and subject as random effects. In the full mixed-model VA ($t = -2.91$, $P < 0.01$) and test type ($t = -5.03$, $P < 0.001$) were significant. However, including both age and test type in the model has the disadvantage that the VA test type correlates with both age (0.53) and VA (-0.48). The selection of VA test type was based on the participant's ability to perform the test, which correlated with age. Excluding the VA test type from the model, VA ($t = -4.70$, $P < 0.01$) is significant, whereas both age ($t = 2.06$, $P = 0.046$) and diagnosis ($t = -1.79$, $P = 0.081$) are marginal.

One concern when modeling is overfitting, which arises from including too many model parameters. To address the possibility of overfitting, we used a backward stepwise procedure[40] using the Akaike Information Criterion (AIC). Using AIC penalizes models that have more model parameters, and if a simpler model has a higher AIC, it is preferred over a more highly parameterized model. The full model had an AIC $= 32.4$, whereas a simple model that includes only VA and diagnosis had an AIC $= 53.7$.

The increased AIC value shows the model with VA and diagnosis is the most parsimonious model for the data. Under this reduced model VA ($t = -4.67$, $P < 0.001$) is significant, whereas diagnosis remains marginal ($t = -1.59$, $P = 0.11$).

Logistic Regression to Predict Diagnosis from VA Versus DH $\log_{10}$ CS

Logistic regression analysis uses a binary outcome variable and a continuous dependent variable to generate a model that can be used for prediction. We used logistic regression analysis as an exploratory tool to evaluate the predictive power of DH $\log_{10}$ CS or VA for diagnosis. Under an analysis of deviance,[41] both logistic regression models were better than the null model (DH $\log_{10}$ CS: deviance $= -7.61$, $P = 0.0058$, VA: deviance $= -5.9879$, $P = 0.014$). Nagelkerke's[42] R^2 was used to compare the two models and mean DH $\log_{10}$ CS and explained 21.7% of the variance, whereas VA explained 17.4% of the variance.

Discussion

The new Double Happy Contrast Sensitivity Test was successful in assessing CS with a diverse pediatric population diagnosed with ocular disorders or CVI. Two examiners successfully tested all 43 patients scheduled for an examination in a low vision clinic. Test time was rapid for most participants. Many participants had significant neurologic or systemic disorders. Our success in testing this diverse pediatric clinical population may be because we did not recruit participants with very poor visual acuity (>2.0 logMAR). Also, we tested participants binocularly because clinical experience shows monocular testing is more difficult. DH testing was successful across the age range, two to 18 years. In our clinical experience, infants younger than two years also can be tested successfully with the DH test.

This study is the first to examine the interexaminer reliability of a test of CS in children with visual deficits. The Cohen kappa reliability statistics indicated only fair agreement between examiners. However, the intraclass correlation coefficient (ICC) was significant. The average difference in DH $\log_{10}$ CS between the two examiners was near zero, with the CI of the difference at -0.44 to 0.45 $\log_{10}$.

A previous study of adults by our group[43] found high DH $\log_{10}$ CS test-retest differences. Visually normal adults (39) were tested in two sessions in two conditions, with their habitual correction and with their visual acuity reduced optically. The 95% CI for DH $\log_{10}$ CS was -0.61 to 0.39 in the habitual correction condition and -0.44 to 0.43 in the optically reduced vision condition. Along with the results from our child participants, these results from adults suggest that DH CS has relatively high test-retest variability. That is, high variability may be a more general property of the DH CS test and not necessarily the result of the young age of participants or their visual impairments or other disabilities.

We predicted that participants with acuity below the DH spatial frequency or the channel spatial frequency (>1.55 to 2.0 logMAR) would not have measurable CS. Nevertheless, all participants, including three with very reduced visual acuity, had measurable CS. Lower spatial frequencies than the nominal and channel spatial frequency are present in the DH stimulus and could provide a cue to its detection in participants with poor visual acuity. Adults tested in the study by Gerger et al.[43] reported using a part of the face, such as a portion of the circumference or the mouth, to detect its right or left location rather than the whole face at threshold. In half the conditions, the adults' acuity was not reduced. Thus even subjects with good visual acuity may use very low spatial frequencies to detect the DH face at threshold.

In this study, DH $\log_{10}$ CS was close to normal on average for the group with ocular disorders, whereas the average was reduced in the group with CVI. VEP studies found reduced CS in children with CVI who had no coexisting ocular disorder.[21,22] Thus children with CVI may be vulnerable for low CS regardless of their ocular status. VA was reduced both in those with CVI and in those with ocular disorders only. These results suggest CVI in young patients may show both low CS and low VA.

The correlation between DH CS and VA ($r = -0.65$) in our study suggests the two measures of visual function are not independent. The strength of the correlation is consistent with about 42% of shared variance. Notably, in an extensive study by Kiser et al.[44] in adults with advanced ocular disorders, the correlation between VA and CS was $r = -0.80$ with a shared variance of 64%; the higher correlation in the Kiser study may be due to the larger range of VA and CS.

A study of DH CS in a sample where age and visual acuity are more homogenous may help sort out important factors contributing to CS and VA variability. Alternatively, a larger study of child participants with various ocular disorders and CVI and a wide range of acuity could be designed to stratify for relevant factors.

Modeling of the results of our study found that the best predictor of the DH $\log_{10}$ CS was visual acuity. Consistent with the analyses of interexaminer

reliability, tester identity was not a significant predictor. In the experimental design, the type of visual acuity test covaried with age, which favors using a simpler model for predicting DH $\log_{10}$ CS that does not include age or visual acuity test type. The regression analyses demonstrate that the most parsimonious model is one that includes VA and diagnosis. Figure 4 shows the negative correlation between VA and DH $\log_{10}$ CS and clustering of the data for CVI versus ocular disorder patients (filled and open symbols). The modeling and the correlation shown in Figure 4 together show that the DH CS test provides additional information to the clinician beyond VA to guide diagnosis of CVI. The exploratory logistic regression modeling of diagnosis with DH CS and VA provides some modest support for this claim. However, neither test is a particularly powerful predictor, as shown by the relatively low percentage of the variance explained by the two logistic regression models.

VA test type in this study was a confounder. We chose to follow clinical practice by testing with the highest level VA test possible. This resulted in different stimuli and test formats. TAC acuity was the only possible test for 16 of our participants, and as might be expected they were among the youngest. TAC acuity could have been tested in all participants. In retrospect, this would have simplified data modeling. To resolve this issue, future studies could increase the age range of the subjects and evaluate CS with VA based only on TAC grating acuity. Alternatively, age and developmental status may be constrained such that symbol or letter acuity is measurable in all subjects.

The DH test has advantages over previous tests of CS developed for young children. It uses a two-alternative procedure and clinical method based on the TAC grating acuity test.[34] The DH test is objective and relatively unbiased because the examiner is unaware of DH stimulus location until s/he can judge if the participant detected the stimulus. This is in contrast to Hiding Heidi (HH)[27,28] and Mr. Happy CS test[29] where the examiner may have knowledge of the right or left position of the stimulus during testing. The DH test has a wide range of $\log_{10}$ CS values, greater than 2 log units, 0.05 to 2.1. The interval between $\log_{10}$ CS for each stimulus is smaller than other pediatric tests of CS (0.15 in DH test versus 0.30 in HH test and CCT,[27,28] 0.19 for Mr. Happy[29]). Smaller intervals between stimulus levels can result in more accurate outcomes.[45]

A face stimulus such as Double Happy may have greater interest for young children than a large grating as in the OCC.[9] Nevertheless, the testing protocol of the OCC has similar advantages to the DH test. The TAC testing method[34] can be used with OCC because the large grating is printed on one side of the test cards.

The OCC grating stimulus has square wave edges, chosen because CS for square-wave stimuli is high and relatively constant over a wide range of low spatial frequencies. The OCC uses a large range of CS and intervals of 0.15 $\log_{10}$ CS as in the DH set. The developers of the OCC test measured CS and a vision-related quality of life (QoL) measure in low vision students.[9] OCC CS was correlated with the QoL measure whereas Pelli-Robson CS was not, nor were two measures of visual acuity. A study of test-retest reliability of the OCC is in progress (AM Brown, personal communication, 2019).

Few published studies report test-retest reliability of CS in children, and those that do show low reliability. CSF test-retest reliability for sine-wave gratings in chart format using a detection task (CSV-1000) was low, both with visually normal children age five to 12 years and adults.[46] In a study of test-retest reliability with sine-wave CSF in visually normal three- month-old infants, Drover and colleagues found an average coefficient of reliability (COR) of ± 0.49 $\log_{10}$ CS across four spatial frequencies.[26] (COR is equivalent to CI.) Test-retest reliability studies with other tests of behavioral CS in visually normal children and clinical populations are needed to judge whether behavioral tests of CS are more variable generally in children.

There are some limitations of our study. The small size of our study population, in combination with the diversity of the clinical conditions, may have reduced the reliability of our findings. The youngest participants were age two. We recruited participants from the consecutive patients scheduled for an eye examination. Inadvertently no patients under age two years were scheduled or recruited. Therefore we cannot determine DH test-retest reliability with infants. We did not investigate intraexaminer test-retest reliability, and thus we cannot provide a guideline for interpreting differences in DH CS between tests done by a single examiner. Intraexaminer reliability would be expected to be better than interexaminer reliability, but the difference appears to be small (see monocular acuity card study by Mayer et al.[47])

There are no age norms for the DH test. Studies of normative CS in young children using pediatric behavioral tests show maximal CS at the upper CS limits of the test by age two to three years (HH,[27,28] Mr. Happy,[29] CCT[30,31]). Maximal CS is higher in the DH test than in two previous pediatric CS tests ($\log_{10}$ DH CS 2.1 vs. 1.9 for HH and 1.8 for Mr. Happy). This suggests that if our population included sufficient young children, we might have found a relationship between DH $\log_{10}$ CS and age; 11 of the 43 participants were age two to three years; however, none was younger than age two years. Their DH_{10} log CS values were not

at the ceiling, only three of the 11 had normal or near-normal CS. A caveat is that significant DH versus age effects in a diverse population of children with ocular disorders or CVI might not be expected.

Leat and colleagues[48] reviewed studies of CS development in normal children. Most studies discussed found that adult CS levels are not reached by eight years. One exception is a study using two-alternative forced choice procedure that found adult level CSF at age nine years.[24] Leat et al.[49] suggest that methodologic differences between behavioral studies of CS make it difficult to determine when in normal development CS is mature.

In summary, the population assessed in our study had diverse visual disorders due to ocular and CVI causes, and ranged widely in age. Those with CVI had complex neurologic and developmental disabilities. The study showed that binocular DH CS testing is successful in such a diverse pediatric population. The interexaminer reliability results suggest that 95% of DH CS tests by two examiners should agree to within about 0.45 $\log_{10}$. The present DH set has 0.15 $\log_{10}$ interval between stimuli; therefore two examiners' results should agree within three cards in most cases. This is relevant in assessing progressive ocular disease, monitoring effects of treatment for ocular disease, and evaluating the effects of rehabilitation, for example for CVI. High test-retest variability of DH appears to be a general consideration, not confined to pediatric population with ocular disorders or CVI, but also in visually normal adults tested with their habitual glasses and when their vision was reduced optically (Gerger et al.).[43]

In our study, DH CS was more reduced in CVI than in ocular disorders, although both groups had below normal VA. This indicates that DH CS could be a sensitive indicator of CVI and that children suspected of CVI should be tested for DH CS. There is also the suggestion that CS may be more sensitive than VA to vision-related QoL as shown in the study by Hopkins et al.[9]

VA and CS both should be measured in young patients because each spatial vision measure may be independently associated with different functional daily life activities and skills as shown for adults.[2,50] Studies of VA and CS in relation to functional vision abilities in diverse vision disorders are needed to delineate these relationships.

Acknowledgments

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