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ORIGINAL ARTICLE

Evaluation of the SpotChecks contrast sensitivity test in children

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Abstract

Purpose: The purpose of this study was to determine intrasession repeatability of a worksheet style contrast sensitivity test (SpotChecks) in children and agreement with an established contrast sensitivity test (Pelli–Robson).

Methods: Forty-three children aged 4 to 12 years participated in this single visit study that included two administrations of the SpotChecks binocularly, a single administration of the Pelli–Robson test and other measures of visual performance such as high-contrast visual acuity. Test order was randomised, and participants wore their habitual correction (39 unaided, 4 wearing glasses) for testing. Bland–Altman plots were used to assess the test–retest repeatability of SpotChecks and its agreement with the Pelli–Robson test. Multiple linear regressions were performed to evaluate whether contrast sensitivity was related to participant characteristics such as age, sex and near binocular visual acuity.

Results: The mean difference in log contrast sensitivity (logCS) between two administrations of the SpotChecks was 0.01, with a coefficient of repeatability (1.96*SD of differences) of 0.14 logCS. The mean difference between SpotChecks and Pelli–Robson was 0.00 logCS with 95% limits of agreement of −0.19 to +0.20. For both tests, a statistically significant increase in logCS was associated with age (slopes were 0.02 logCS/year, $p < 0.001$ and 0.01 logCS/year, $p = 0.02$ for the SpotChecks and Pelli–Robson tests, respectively).

Conclusions: The SpotChecks test shows good intrasession repeatability and excellent agreement with the Pelli–Robson test in children. Contrast sensitivity showed an increase in logCS with age in children for both tests.

KEYWORDS
contrast sensitivity, paediatrics, repeatability, test agreement, visual acuity

INTRODUCTION

Contrast sensitivity is an important aspect of visual function, defined as the inverse of the minimum difference in luminance required to distinguish an object against its background.[1] Practically, reduced contrast sensitivity can negatively impact activities such as mobility[2,3] and facial recognition,[4] and has also been shown to have an association with slower reading speed.[4–6] Contrast sensitivity is not always correlated with high-contrast visual acuity,[7,8] and may reveal deficits due to an underlying condition even in patients with normal visual acuity.[8] Therefore, although it is not often used routinely or diagnostically in typical clinical examinations, implementing contrast sensitivity testing in vision screenings and comprehensive eye examinations can be beneficial as a more complete assessment of overall visual function.

Measuring contrast sensitivity is equally important in children as it is in adults, particularly for individuals with underlying health conditions and disabilities who have a higher risk of reduced vision, including a reduction in contrast sensitivity.[8,9] Assessing contrast sensitivity in children with amblyopia has also gained more clinical relevance given the adoption of therapies that utilise dichoptic images to stimulate the amblyopic eye by boosting the contrast of the image presented to the affected eye and reducing contrast to the image presented to the nonamblyopic eye.[10–12] Monitoring not only high-contrast visual acuity but also contrast sensitivity in children undergoing these treatments may give important insight into the effectiveness of these treatments, or the need to modify the contrast levels being utilised.

For clinical measurement of contrast sensitivity, the Pelli–Robson contrast sensitivity test[13] has become widely accepted given its good reliability and repeatability,[14,15] although additional tests that do not require literacy have emerged recently that also show promise for clinical use.[16–18] Some of the currently available symbol-based contrast sensitivity tests designed for children, such as the LEA low-contrast symbols and the Hiding Heidi contrast sensitivity test are more easily administered to children, but have limitations resulting from a lack of sufficient lower contrast levels to measure an accurate threshold.[9] Therefore, in order to measure contrast sensitivity accurately in children, a test with simple administration that is not subject to floor effects could be valuable.

The SpotChecks contrast sensitivity test is one such potential test that has evolved from a previous iteration named CamBlobs2.[19] The SpotChecks test was designed as a worksheet style contrast sensitivity test in which the patient identifies spots of progressively decreasing contrast located in rows on a page. The test was originally designed for use in home monitoring of visual function by adults with ocular disease,[19] and thus needed to perform in a similar manner across a range of lighting conditions and working distances, as would be the case in home testing environments. Previous work has shown a circular test stimulus to function equally well across a wide range of luminance and sizes when determining the log contrast sensitivity (logCS) of observers.[20] Similar findings were observed with different versions of the CamBlobs2 produced with various spot sizes.[21] In a study of adult observers, the mean difference in logCS between CamBlobs2 tests composed of 6 mm and 13 mm circles was only 0.02 logCS.[21] The commercially available SpotChecks test is printed with 9 mm spots and thus should have similar accuracy across a reasonable range of working distances. The absence of a strict working distance requirement simplifies test administration. In addition, given that the SpotChecks test does not require literacy, it may be easier for younger patients to complete. The primary aim of this study was to evaluate the use of the SpotChecks contrast sensitivity test in children by: (1) determining intrasession repeatability and (2) determining agreement with the Pelli–Robson contrast sensitivity test.

Key points

- The SpotChecks test demonstrated good agreement with the Pelli–Robson test in children.
- The SpotChecks test had good repeatability across test administrations in children.
- The time to administer the SpotChecks ranged from 3 to 15 min in children.

METHODS

This research was reviewed by the University of Houston Committee for the Protection of Human Subjects and conforms with the principles and applicable guidelines for the protection of human subjects in biomedical research. Eligibility criteria included being between 3 and 12 years of age and an ability to perform the study tasks. Individuals recruited for the study were not prescreened for refractive status, visual acuity, binocular vision status, ocular disease history or developmental disorder. Participants were recruited from the family or friends of the University of Houston College of Optometry faculty, staff, students and clinic patrons. Forty-three subjects aged 4–12 years old were enrolled in the study following parental permission and written assent from children aged 7–12 years. A written assent waiver was approved by the Institutional Review Board for children aged 4–6 years.

To characterise participants in the study, estimates of refractive error were collected by performing lensometry on the spectacles of any participant wearing a spectacle correction. Distance Grand Seiko autorefraction (Luneau Technology, luneautechusa.com) was also performed for all participants, either unaided or over the presenting correction if one was worn. Binocular vision status was assessed using distance and near cover tests with prism neutralisation, as well as stereoacuity thresholds determined with the Randot Preschool Stereoacuity Test (Stereo Optical Company, stereooptical.com). Visual acuity and contrast sensitivity were measured as described below by randomising test order for five tests: distance visual acuity, near visual acuity, Pelli–Robson contrast sensitivity, SpotChecks contrast sensitivity and a repeat test of SpotChecks contrast sensitivity.

Distance visual acuity: Distance visual acuity at 3 m was measured monocularly and binocularly using the Electronic Visual Acuity Tester[22] with the Sloan letter set. Participants named letters if they were able, or alternatively matched using a laminated matching card of the 10-letter set. Letter presentation followed a four-step process to include a screening phase, first threshold determination, reinforcement phase and second threshold determination as described by Moke et al.[22] Both letter by letter scoring and the Snellen equivalent visual acuity were recorded.

Near visual acuity: Near visual acuity was measured monocularly and binocularly using the ATS4 logMAR HOTV near acuity test (Precision Vision, precision-vision.com).[23] Testing was performed at 40 cm, and the acuity was determined as the lowest line where three out of four letters were identified correctly.

Pelli–Robson Contrast Sensitivity: Testing with the Pelli–Robson contrast sensitivity chart (Precision Vision, precision-vision.com) was conducted binocularly at a 1 m viewing distance with chart luminance in the manufacturer's recommended range of 60–120 cd/m^2. Chart luminance was verified for each participant using the Konica Minolta LS-110 Luminance Meter (Konica Minolta, konicaminolta.com). Participants read or matched the letters in each triplet in order of decreasing contrast from 0.00 to 2.25 logCS. Testing was terminated when two out of three letters in a triplet were missed. LogCS was calculated as: (the number of all correctly identified letters – 3) × 0.05.

SpotChecks Contrast Sensitivity Test: SpotChecks (Precision Vision, precision-vision.com) is a worksheet consisting of five columns and 24 rows of spots that decrease in Weber contrast from top to bottom (Figure 1). Each spot is 9 mm in diameter and subtends approximately 1.3° at the eye when viewed at a 40 cm distance. Within each row, each spot decreases in contrast by 0.01 logCS from left to right. The label on each row indicates the logCS of the spot in the first box of the corresponding row. The test rows are labelled beginning with 0.90 logCS and increasing by 0.05 to a last row of 2.05 logCS, with the faintest spot at the end of that row having 2.09 logCS. The test was performed in the same room with the same ceiling light as the Pelli–Robson test. Specific testing distances were not implemented in order to assess the test using the simplified testing administration manner that was both intended and desired.

Participants identified the location of each spot beginning from the top left with either a pen or by pointing for an examiner to mark the location. The majority of participants voluntarily completed the entire worksheet. Some participants reported they could no longer see the spots before the end of the worksheet was reached. These participants were told to guess and continue row by row until two or more spots in a single row were incorrectly marked. Per the manufacturer's instructions, the contrast sensitivity of the highest line where two or more spots were incorrectly marked was recorded. During testing, an examiner measured the participant's self-selected working distance three times throughout the test to obtain an average working distance. Test time was documented with a stopwatch. Participants completed the SpotChecks test binocularly twice (not always sequentially but depending upon the randomised order). For testing, two different worksheets were randomly selected from the 12 available versions so that participants would not remember the location of the spots from the previous test.

Following completion of the study visits, a modification was approved to contact the parent of each participant to ask three questions regarding ocular and overall health, namely: (1) Has your child ever had an eye exam by an eye doctor? (2) If yes, has your child ever been diagnosed with any conditions or received any treatment? (3) Are you aware of an eye or health problems that may affect your child's vision?

Data analysis

The distribution of the differences (d) in between the SpotChecks test and retest were plotted to assess the normality of the data, following which a paired t-test was used to determine whether the difference in the group mean performance between the test and retest of the SpotChecks was significant. Difference versus mean analysis was used for assessing the repeatability of the two administrations of the SpotChecks, as well as the agreement between the SpotChecks and the Pelli–Robson Test.[24] Specifically, after ensuring that there was no significant linear relationship between the difference and the mean, the bias between tests (mean difference) and the 95% limits of agreement (upper limit = mean difference + (1.96 * SD of differences); lower limit = mean difference – (1.96 * SD of differences)) were calculated.[24] For the two repeated measurements of SpotChecks, if the mean difference is zero, then the 95% limit of agreement (1.96*SD of differences = $1.96\sqrt{\frac{\sum d_i^2}{n-1}}$) is mathematically equivalent to the Coefficient of Repeatability (COR = $1.96 * \sqrt{2} * Sw$; where $Sw = \sqrt{\frac{\sum d_i^2}{2n}}$).[24]

Lastly, multiple linear regressions were performed to evaluate whether contrast sensitivity was related to participant characteristics such as age, sex and near binocular visual acuity.

RESULTS

Participant characteristics

Forty-three participants (25 male, 18 female) aged 4–12 years (mean (SD) age = 8.3 (2.6) years) were enrolled in the study. Four participants presented wearing glasses (two with hyperopia, one with astigmatism and one with myopia) and 39 presented unaided. The average (SD) letters read for binocular distance visual acuity was 88

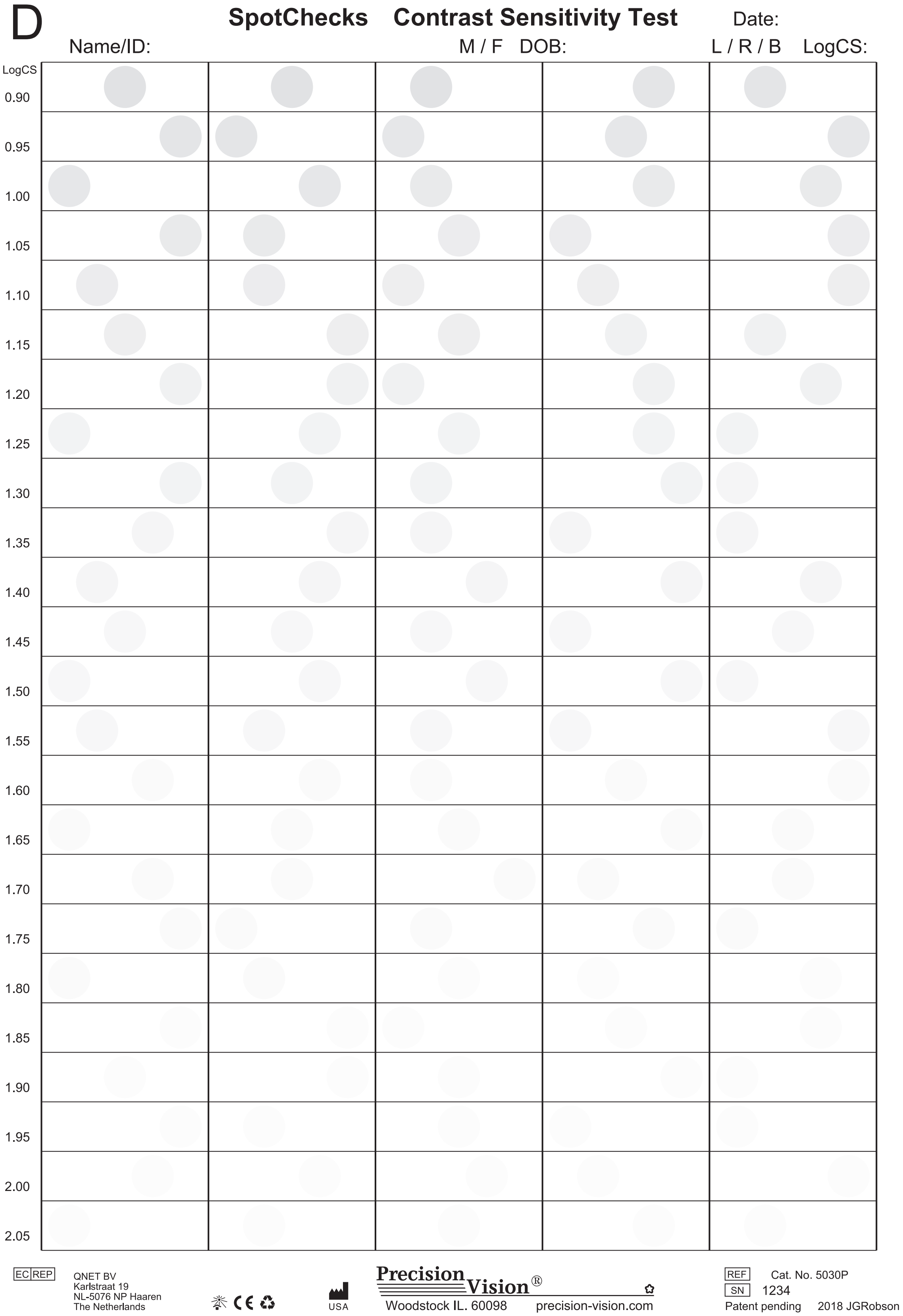

FIGURE 1 SpotChecks contrast sensitivity test sample sheet. Copyright J.G. Robson.

(7) with a range of 56–97, which corresponds to an average Snellen equivalent of 6/5.3 and a range from 6/3.5 to 6/22.8. The average (SD) binocular near visual acuity for the study sample was 0.06 (0.13) logMAR (range = 0.00–0.50). Spherical equivalent distance autorefraction (either unaided or residual refractive error for those wearing spectacles) ranged from −2.12D to +2.00D for both eyes combined with a mean (SD) of +0.27 (0.69) D. One participant had a constant alternating exotropia at distance but was orthophoric at near. Stereoacuity was nil for that participant and also for one participant wearing a low hyperopic correction with near acuity of 0.2 logMAR. The remaining participants had the following distribution of stereoacuity: 40″ (n = 28), 60″ (n = 7), 100″ (n = 5), 200″ (n = 1).

Repeatability of SpotChecks

The average (SD) time for the first administration of the SpotChecks was 7.2 (3.2) minutes (range = 3–15 min). Overall test time decreased by an average of 1.8 min for the second administration to 5.4 (1.9) minutes (range = 2–10 min). The average (SD) test distance was similar between the two administrations at 24.8 (5.9) cm (range = 12.3–35.7 cm) for the first and 24.2 (5.6) cm (range = 14.0–38.3 cm) for the second administration. Over the extremes of the test range used by the participants, the 9 mm circles subtended approximately 4.2° at the closest test distance and 1.3° at the farthest. Despite the range in test distance across participants, there was no significant relationship between performance on the SpotChecks and test distance ($R^2 = 0.08$, $p = 0.06$) as shown in Figure 2. There was no significant difference between mean logCS on the first and second administration of the SpotChecks (first = 1.93 logCS, second = 1.92 logCS; $t_{1,42} = 0.65$, $p = 0.52$). The mean difference in log contrast sensitivity between the two administrations of the SpotChecks was 0.01, with 95% limits of agreement from −0.13 to +0.14 logCS (Figure 3). The COR was 0.14, or approximately 3 lines.

Agreement between tests

For comparisons between test types, the first administration of the SpotChecks test was used for each participant. The mean difference in logCS between the SpotChecks and Pelli–Robson was zero, with 95% limits of agreement of −0.19 to +0.20 (Figure 4).

Contrast sensitivity with age

Of the 43 children who participated in this study, 31 had a parental report of normal ocular health previously verified with a complete eye examination. Parents of seven participants reported their child had no prior eye examination. One participant was reported to have a diagnosis of autism by their parent and was also found to have alternating exotropia at the study visit. Parents of four participants were unable to be contacted for the postvisit survey. While the sample is too small to conduct formal analysis to determine whether the repeatability of the SpotChecks is impacted by these health and ocular conditions, an individual inspection found that test scores

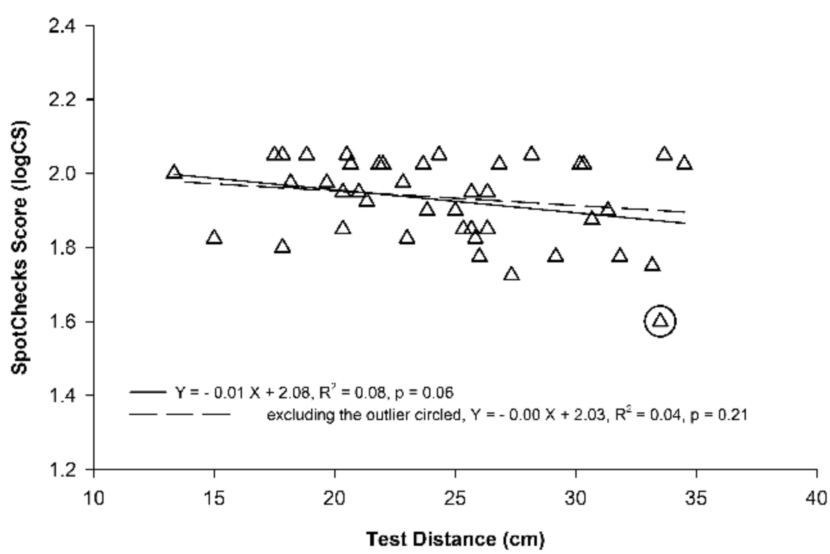

FIGURE 2 There was no significant relationship between test distance and log contrast sensitivity. Each data point represents an individual participant's average test distance and log contrast sensitivity from two administrations of the SpotChecks. One outlier was identified by visual inspection and the linear regressions are shown with and without the inclusion of this participant. logCS, log contrast sensitivity.

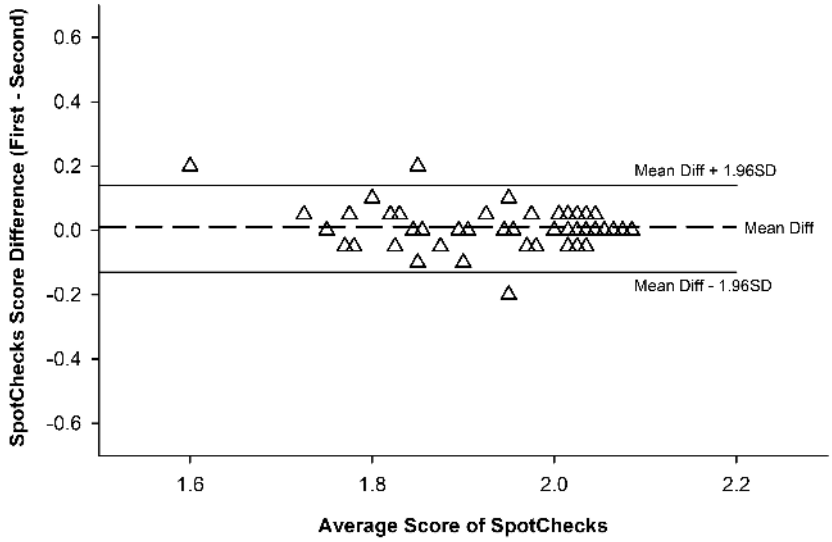

FIGURE 3 Repeatability of the SpotChecks contrast sensitivity test. The dashed line represents the mean difference between the two repeated measurements (0.01 logCS), and the lower and upper limits of agreement (i.e., limits of repeatability) are represented by the solid lines (−0.13 to 0.14 logCS). Linear regression showed no significant relationship between the score difference and the mean scores ($R^2 = 0.06$, $p = 0.11$). Overlapping data points are displayed with slight shifts along the horizontal axis. SD, standard deviation, logCS, log contrast sensitivity.

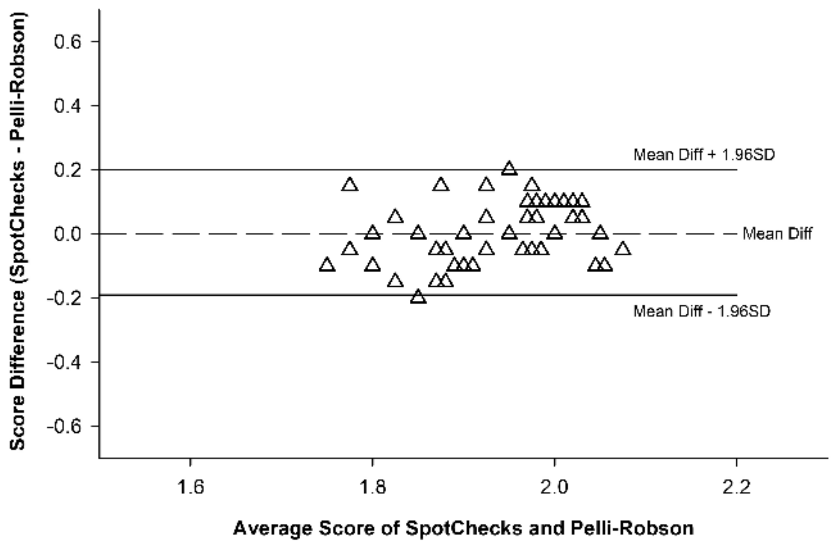

FIGURE 4 Agreement between the SpotChecks and Pelli–Robson contrast sensitivity test. The dashed line represents the mean difference (0.00 logCS) between tests and the lower and upper limits of agreement are represented by the solid lines (−0.19 to 0.20 logCS). Linear regression showed no significant relationship between the score difference and the average scores ($R^2 = 0.08$, $p = 0.07$). Overlapping data points are displayed with slight shifts along the horizontal axis. SD, standard deviation, logCS, log contrast sensitivity.

were identical on the first and second administration of the SpotChecks for the participant with autism who also had distance exotropia and no measurable near stereopsis and for the participant with the greatest reduction in near visual acuity. All study participants were included in the analysis of age trends in contrast sensitivity with these categories of ocular health verification noted in the figures.

For comparisons of logCS as a function of age, the average of the two administrations of the SpotChecks was used for each participant. Simple linear regression plots are shown for both the SpotChecks and Pelli–Robson contrast tests in Figure 5. Data for all participants are plotted, but regression plots reflect the removal of one outlier with low logCS for SpotChecks identified by visual inspection (1.70 first trial, 1.50 second trial, the same outlier as in Figure 2) (Figure 5a). There was a significant linear increase in contrast sensitivity with age for both test types with a stronger correlation occurring for the SpotChecks test ($R^2 = 0.51$, $p < 0.001$ when the outlier

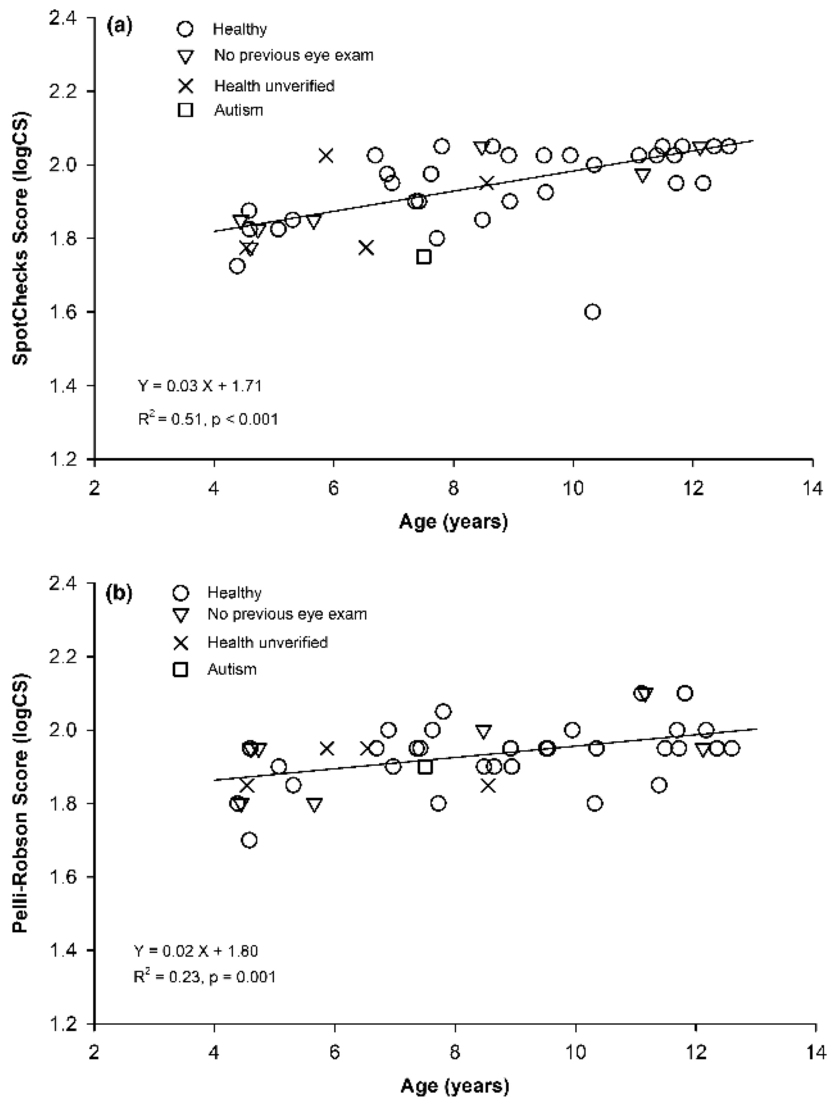

FIGURE 5 Log contrast sensitivity as a function of age for the SpotChecks (Figure 5a) and Pelli–Robson (Figure 5b) contrast sensitivity tests. logCS, log contrast sensitivity.

was excluded; R^2 =0.33, p <0.001 when the outlier was included). Multiple linear regression between logCS with dependent variables age, sex, near visual acuity (Spotchecks) and distance visual acuity (Pelli–Robson) only showed a significant relationship with age for both SpotChecks (slope = 0.02/year, p <0.001) and Pelli–Robson (slope = 0.01/year, p = 0.02).

Table 1 shows the mean logCS in age bins for the participants in this study. The data include all participants with the exception of the outlier from the SpotChecks test as identified in Figure 5a.

TABLE 1 Mean (SD) log contrast sensitivity per age group

Age (years)	SpotChecks	Pelli–Robson
4–5	1.84 (0.08) (n = 11)	1.86 (0.08) (n = 11)
6–7	1.91 (0.10) (n = 10)	1.95 (0.07) (n = 10)
8–10	1.98 (0.07) (n = 10)	1.92 (0.06) (n = 11)
11–12	2.02 (0.04) (n = 11)	1.99 (0.08) (n = 11)

DISCUSSION

This study found the repeatability of the SpotChecks to be 0.14 logCS, or approximately three lines on the worksheet, when administered twice in one study session. While repeatability of three lines may initially appear to be a large range, it is important to recognise that the SpotChecks test has fine granularity with step sizes of 0.01 logCS between adjacent spots. By comparison, repeatability of 0.14 logCS is less than the step size of adjacent triplets on the Pelli–Robson chart, which differ by 0.15 logCS. The repeatability of 0.14 on the SpotChecks is also in good agreement with previous studies demonstrating 0.15 logCS repeatability in adults for the Pelli–Robson[14,25] and within 0.20 logCS repeatability for adults with the CamBlobs2 test.[19]

In the present study, we applied the scoring criterion listed by the manufacturer using the labelled contrast sensitivity level of the highest row for which two or more mistakes were made. However, given that the test is organised with spots of decreasing contrast throughout each row (unlike its predecessor CamBlobs2, which had rows where all spots were of the same contrast[19]), we decided to explore other scoring criteria, such as spot-by-spot strategies, to determine whether it had an impact on the repeatability of testing. We calculated the COR (see values in parentheses) for SpotChecks using logCS determined from six alternative scoring methods: (1) adjust the score by adding 0.01 logCS for each additional spot correct on the threshold line (0.14); (2) adjust the score of method #1 by subtracting 0.01 logCS for spots missed before the threshold line (0.13); (3) score the logCS of the first spot missed (0.35); (4) score the logCS of the second spot missed (0.23); (5) score the logCS of the second spot when two consecutive errors are made (0.25); (6) adjust the score for two consecutive errors by subtracting 0.01 for any errors made prior to the two consecutive errors (0.22). Of the six alternative scoring methods we explored, none resulted in more than a 0.01 logCS improvement in coefficient of repeatability. Thus, we concluded that there was no compelling evidence to deviate from the manufacturer's recommended scoring method.

Previous studies have reported that contrast sensitivity improves through early childhood with adult-like performance reached around 9[26] or 12 years of age.[27] These studies reported that improvements from 4 years of age and upwards are small and primarily occur in the peak of the contrast sensitivity function or below (≤4 cycles per degree), with essentially stable performance at spatial frequencies above the peak from 4 to 18 years of age.[27] We observed a linear improvement with age in contrast sensitivity performance in both the SpotChecks and Pelli–Robson tests for our participants between 4–12 years of age. This is in agreement with the age-related improvements in contrast sensitivity previously reported for mid to lower spatial frequencies.

While we did observe a linear improvement in logCS with age for both the Pelli–Robson and SpotChecks contrast sensitivity tests, the overall group performance on Pelli–Robson reached that previously reported for the dominant eye of healthy, young adults,[14] with all but one 4-year-old participant achieving 1.80 logCS or greater. Performance on the SpotChecks test also agreed well with the previously reported performance on the CamBlobs2 test in young, healthy adults, with a group average of 1.93 logCS in our paediatric cohort versus means ranging from 1.86–1.91 logCS for monocular testing in an adult cohort[19] and means of 1.98–2.00 logCS for binocular testing in a different adult cohort.[21] One limitation of our study, however, is the smaller sample size and relatively homogenous socioeconomic recruitment group, making it difficult to discern whether values are generalisable to the population at large.

The SpotChecks test is unique in that it is designed to be self-administered without a standardised test distance. The spot target was specifically selected by the designer based on evidence that detection of a spot target is not related to spot size for targets ≥1 degree,[20] thus making it an excellent target for at-home testing. In this study, we evaluated the SpotChecks as it was intended without fixing the test distance, but compared it with the Pelli–Robson test that is typically performed at a fixed distance. This raises the question of whether or not the results of the two tests can be compared since a variable test distance was used for one and not the other. First, no difference was found between the two tests (Figure 4). Second, no significant relationship was found between the test distances adopted and contrast sensitivity measured with the SpotChecks (Figure 2). Even for the analysis that included the outlier ($p = 0.06$), the slope of the linear regression was shallow and the range of differences in contrast sensitivity across the extremes of the testing distances spanned 0.15 logCS, which is the same as the repeatability of testing. Lastly, previous work has shown that in typically sighted elderly patients, contrast sensitivity measured with the Pelli–Robson chart does not differ for test administrations at 1 m versus 3 m (visual angle of 2.85 vs. 0.95°),[28] indicating that adopting a variable testing distance for the Pelli–Robson chart would not likely impact the results. Thus, the adoption of a variable test distance for the SpotChecks versus a fixed test distance for the Pelli–Robson test in the present study should not have impacted the ability to compare the tests.

Benefits of the SpotChecks test include its ease of administration in children due to the simple instructions, the ability to use a variety of testing distances and lighting conditions and the engaging worksheet style nature of the test. That said, our protocol of having children begin with the top row of the chart took as long as 15 min for a single administration in children aged 4–12 years. This may exceed the desirable testing time in a clinical setting, particularly if the clinician wishes to test each eye individually. Additional investigation is needed to determine whether a more expedited administration of the test could be used, such as beginning with rows that are more challenging rather than starting from the top of the chart. Another limitation of our study was that only intrasession repeatability was evaluated, and thus the repeatability of testing across sessions remains unknown.

CONCLUSIONS

In summary, the SpotChecks shows good test–retest repeatability and excellent agreement with the Pelli–Robson contrast sensitivity test in children. It may be a useful tool for children or patients with limited communication since it does not require literacy or fixed viewing distances.

AUTHOR CONTRIBUTIONS

Heather A Anderson: Conceptualization (lead); data curation (equal); formal analysis (supporting); funding acquisition (lead); investigation (equal); methodology (lead); project administration (supporting); resources (lead); software (equal); supervision (equal); validation (equal); visualization (equal); writing – original draft (lead); writing – review and editing (equal). **Anusha Rachel Mathew:** Conceptualization (supporting); data curation (supporting); formal analysis (supporting); investigation (equal); methodology (supporting); project administration (equal); writing – original draft (supporting); writing – review and editing (supporting). **Han Cheng:** Conceptualization (supporting); data curation (supporting); formal analysis (lead); funding acquisition (supporting); investigation (supporting); methodology (supporting); project administration (supporting); resources (supporting); software (equal); supervision (equal); validation (equal); visualization (equal); writing – original draft (supporting); writing – review and editing (supporting).

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