Mobile App Aston Contrast Sensitivity Test

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Running Title: Aston Contrast Sensitivity Test

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Background: Contrast detection is an important aspect of the assessment of visual function. However clinical tests evaluate limited spatial frequencies and contrasts. This study validates the accuracy and inter-test repeatability of a swept-frequency near and distance mobile App Aston contrast sensitivity test which overcomes this limitation compared to traditional charts.

Method: Twenty subjects wearing their full refractive correction underwent contrast sensitivity testing on the new near app, distance app, CSV1000 and Pelli-Robson charts with full correction and with vision degraded by 0.8 and 0.2 Bangerter degradation foils. In addition repeated measures using the 0.8 occluding foil were taken.

Results: The mobile apps (near more than distance, p=0.005) recorded a higher contrast sensitivity than printed tests (p<0.001). However, all charts showed a reduction in measured contrast sensitivity with degradation (p<0.001) and a similar decrease with increasing spatial frequency (interaction > 0.05). Although the coefficients of repeatability was lowest for the Pelli-Robson charts (0.14 log Units), the mobile app charts measured more spatial frequencies, took less time and were more repeatable (near: 0.26-0.37 log Units; distance: 0.34-0.39 log Units) than the CSV1000 (0.30-0.93 log Units). The duration to complete the CSV-1000 was 124±37s, Pelli-Robson 78±27s, Near App 53±15s and Distance App 107±36s.

Conclusions: While there were differences between charts in contrast levels measured, the new Aston near and distance app are valid, repeatable and time efficient method of assessing contrast sensitivity at multiple spatial frequencies.

Measurements of the contrast sensitivity function (CSF) better characterise functional vision than high contrast visual acuity alone. CSF testing has been used effectively as a tool to identify aspects of visual function in conditions such as diabetes, glaucoma and macular degeneration.[1-3] Despite its usefulness, CSF testing is rarely used due to the time and specialist equipment required.

Contrast sensitivity testing methods such as the method of limits, adjustment and two-alternative forced choice procedures (2-AFC) require custom stimuli to be presented in response to patient feedback. Paper based charts are often limited in the number of stimuli they can present and require the examiner to manually implement and respond to feedback from the patient.[4] Hence, clinical measurements of psychophysical contrast thresholds can only be assessed in broad discrete steps of spatial frequency and contrast. Meanwhile computerized CSF testing equipment can render a multitude of grating stimuli of various frequencies and contrast and adopt complicated testing methods that render stimuli in response to patient feedback, such as the staircase or adaptive 2-AFC procedure.[5]

Paper based charts have been the most popular form of testing, but their reliability has been under question.[6, 7] Cathode ray tube (CRT) computerized testing has remained a research tool owing to the large size, expense, and testing time required to perform CSF assessment. To combat these problems contrast sensitivity tests based on tablet computers with liquid crystal displays (LCD's) have emerged.[8, 9] Despite a reduction in the contrast resolution available to the screen, innovative pixel dithering techniques[10] have enabled gratings based testing on mobile tablets to be indistinguishable from CRT lab setups.[9]

Whereas accuracy is essential for a clinical test, clinical utility requires not only portability but also time efficiency to be taken into account. It is well known that forced choice procedures are the most reliable way of testing physchopysical thresholds,[11] however, they often require a large testing duration to implement which can make them unsuitable for clinical contrast testing. The classical method of adustment provided enough validity for the studies that defined the CSF and spatial frequency theory [12, 13] and so may afford adequate performance in a contrast screening test. Additionally, by eschewing multiple discrete stimuli presentations, testing duration may be lowered in comparison to 2-AFC methods. Hence a method of measuring patient's CSF that is more time efficient and mobile than current computerised testing systems, with greater control over illumination, contrast, and frequency levels than paper based charts, may have substantial clinical utility.

Both the near and distance Aston contrast sensitivity apps were inspired by a chart designed by Campbell and Robson.[13] Unlike other contrast stimuli, the app displays all contrasts and spatial frequencies in one presentation using a swept frequency design rendered onto a device monitor (Figure 1). Whilst the idea of a swept frequency style contrast chart is not new, the authors could not find any published quantitative studies that have used such a chart on patients. A bit stealing routine [14] that dithers each pixel to increase the greyscale resolution from 8 bits up to 11 bits from the LCD screens was employed. This technique changes the value of the individual sub-pixels to achieve greater luminance resolution at the detriment of a constant chromaticity within the contrast stimuli. A luminance meter (Konica Minolta LS-110) confirmed that the bit stealing technique had been successful in increasing the grayscale resolution. The bit stealing technique has been validated previously in a contrast sensitivity app using an iPad and produced results indistinguishable from a laboratory grade CRT setup.[9]

The aim of this study was to compare these novel near and far Aston contrast sensitivity mobile apps to existing clinical methods of determining contrast sensitivity.

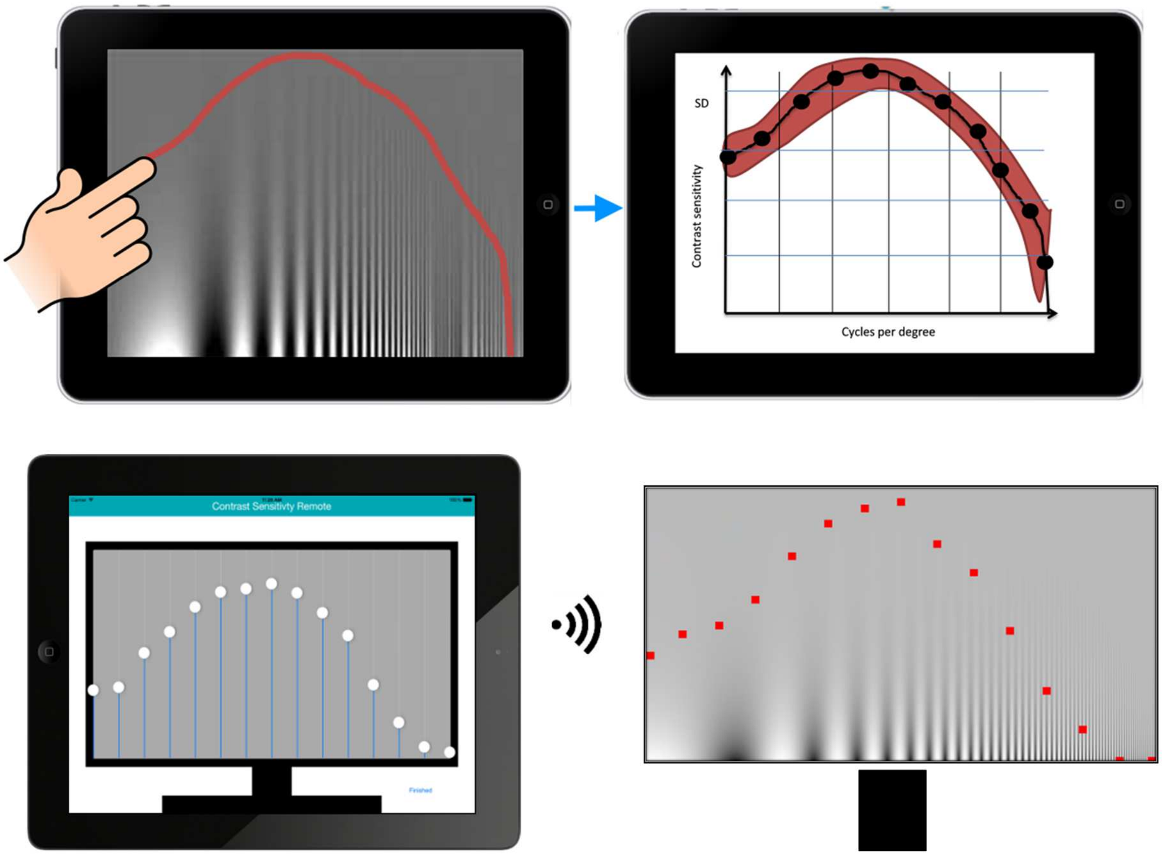

Figure 1: The Aston Contrast Sensitivity Near app (top) in which patients use the iPad’s touch screen to trace the boundary where the grating can be detected allowing the full contrast sensitivity function to be determined rapidly. For the Aston contrast sensitivity distance chart (bottom), the swept frequency target is displayed on a separate monitor controlled by the iPad with patients required to use sliders on the iPad that in turn move red targets on the distant monitor to indicate where the boundary between the visible and invisible regions of the chart are located.

METHOD

Selection of the traditional contrast tests reflected the two main types of contrast stimuli that can be used in a clinical setting, the letter and gratings based charts. All subjects had a best corrected VA of 0.0 logMAR or better and had no history of ocular disease. Informed consent was obtained from all participants and the study was conducted in accordance with the declarations of Helsinki. Ethical approval for the study was granted by the Aston University Ethics Committee. Four different contrast sensitivity charts (Table 1) were evaluated with the 20 subjects (aged 19-28 years, average 23.4 ± 2.1 years) wearing their full best distance refractive correction in randomised order: the near and distance Aston contrast sensitivity apps, the CSV-1000 back illuminated chart, and the Pelli-Robson letter chart. A tape measure was used to place subjects at the correct working distance for each test. For each test, contrast sensitivity was measured monocularly with three levels of vision in random order, degraded by 0.8 and 0.2 Bangerter degradation foils (Western Ophthalmics, Lynnwood, Wahington, USA) mounted in a trial frame and a no foil condition. These three conditions were chosen to simulate different levels of contrast deficiency within patients, with the 0.2 foil previously shown to be the most severe.[15] In addition to testing each of the conditions, a repeated measure using the 0.8 occluding foil was taken so an assessment of the contrast charts inter-test repeatability could be undertaken. The time taken to complete each contrast sensitivity test under the no foil condition, was recorded using a manual timer.

The apps were created for the iPad (Apple Inc. Cupertino, California, USA) using the X-Code software development kit in objective-C, while the swept frequency contrast targets were created using the MATLAB (MathWorks, Natick, Massachusetts, USA) programming environment. For the near app, patients use the iPad’s touch screen to trace the boundary where the grating can be detected. This allows the full CSF to be determined rapidly. For the distance chart, the swept frequency target is displayed on a separate monitor controlled by the iPad. Patients are required to use several sliders on the iPad that in turn move red targets on the distant monitor to indicate where the boundary between the visible and invisible regions of the chart are located. This is analogous to using the method of adjustment in psychophysical threshold experiments.

Due to the various chart designs, the testing procedure for each chart was different. The CSV-1000, distance and near app specified contrast in terms of Michaelson contrast (Eq.1), while the letter chart used the Weber equivalent (Eq.2), where H and L are the high and low luminance values respectively. Using these definitions a conversion formula was derived to convert weber contrast to Michaelson contrast for comparisons, see Eq 3. For the near app subjects were asked to trace a line with their finger on the screen where they believe they could no longer see the height of the various bars, this was taken as the contrast threshold. Discrete frequency results were extracted to allow comparison with the other charts. With the distance app, subjects were required to move sliders on the iPad that shifted red markers on the monitor displayed contrast stimuli to indicate where the gratings first became visible to the subject at discrete frequencies selected to match the comparison charts. A modified 2-AFC procedure was used with the CSV-1000 chart; patients were presented with two patches and asked to identify which one contained a sine wave grating.[16] The contrast level of the last correct response was taken as the contrast threshold. The Pelli-Robson chart, whose groups of three letters decrease in contrast across the design, required that two out of the three letters be identified incorrectly before the group's contrast was taken as the threshold measurement.[17] The chart was used at 1.7m rather than the 1.0m standard distance to achieve an approximate spatial frequency of 1.5cpd to be comparable to the other tests. The time to complete each test was manually timed by stopwatch.

$$W = \frac{H-L}{H} \qquad \text{Eq. 1}$$

$$M = \frac{H-L}{H+L} \qquad \text{Eq. 2}$$

$$M = \frac{W}{2-W} \qquad \text{Eq. 3}$$

Chart	**Stimuli Type**	**Luminance,** $\boldsymbol{cd/m^2}$	**Working Distance,** ***m***	**Frequencies,** ***cpd***
Aston Near App	Swept-Frequency	127	0.4	1.0 to >20
Aston Distance App	Swept-Frequency	119	2.4	1.5,3,6,12,18
CSV-1000	Gratings	71	2.4	3,6,12,18
Pelli-Robson	Letter	78	1.7	1.5 (Equivalent)

Table 1: Each contrast sensitivity chart's luminance (tested with a Konica Minolta LS-110 luminance meter) and characteristics including required working distance and frequencies tested.

As the data was normally distributed (distance app Kolmogorov-Smirnov test Z = 1.191, p = 0.117; near app Z = 1.379, p = 0.055), repeated measures ANOVA's with chart type, spatial frequency and occluding foil were applied, with t-tests used to determine between conditions when significance (taken as $p<0.05$) was indicated. Inter-test repeatability was assessed using Bland-Altman analysis and Pearson's correlation coefficients and coefficient of repeatability (95% confidence interval of the difference between the compared tests).

RESULTS

Agreement

Distance versus Near Aston Contrast Sensitivity Profile

Distance contrast sensitivity was significantly lower than near (F=9.807, p=0.005), decreased with the level of degradation (F=212.355, p<0.001) and increasing spatial frequency (F=449.620, p<0.001) with a significant interaction between degradation and spatial frequency (F=15.135, p<0.001), but not between distance and degradation (F=3.088, p=0.057), distance and spatial frequency (F=0.821, p=0.538) or between all three factors (F=1.848, p=0.055; Figure 2).

CSV1000 versus mobile Apps

CSV1000 contrast sensitivity (between and 3 and 18cpd) was significantly lower than the distance mobile app (F=49.418, p<0.001), decreased with the level of degradation (F=321.024, p<0.001) and increasing spatial frequency (F=432.045, p<0.001) with a significant interaction between degradation and spatial frequency (F=10.092, p<0.001), test and spatial frequency (F=37.624, p<0.0014), between all three factors (F=4.390, p<0.001), but not between the tests and degradation (F=1.024, p=0.369; Figure 2).

CSV1000 contrast sensitivity was significantly lower than the near mobile app (F=25.207, p<0.001), decreased with the level of degradation (F=237.932, p<0.001) and increasing spatial frequency (F=396.7402, p<0.001) with a significant interaction between degradation and spatial frequency (F=17.644, p<0.001), test and spatial frequency (F=47.242, p<0.001), between all three factors (F=2.2646, p=0.042), but not between the tests and degradation (F=0.212, p=0.810; Figure 2).

Pelli-Robson versus Mobile Apps

At 1.5cpd, both the distance (F=31.733, p<0.001) and near (F=168.749, p<0.001) mobile app measured a higher contrast sensitivity than the Pelli-Robson chart and decreased with increasing degradation (F=134.053, p<0.001; F=179.907; p<0.001, respectively; Figure 2).

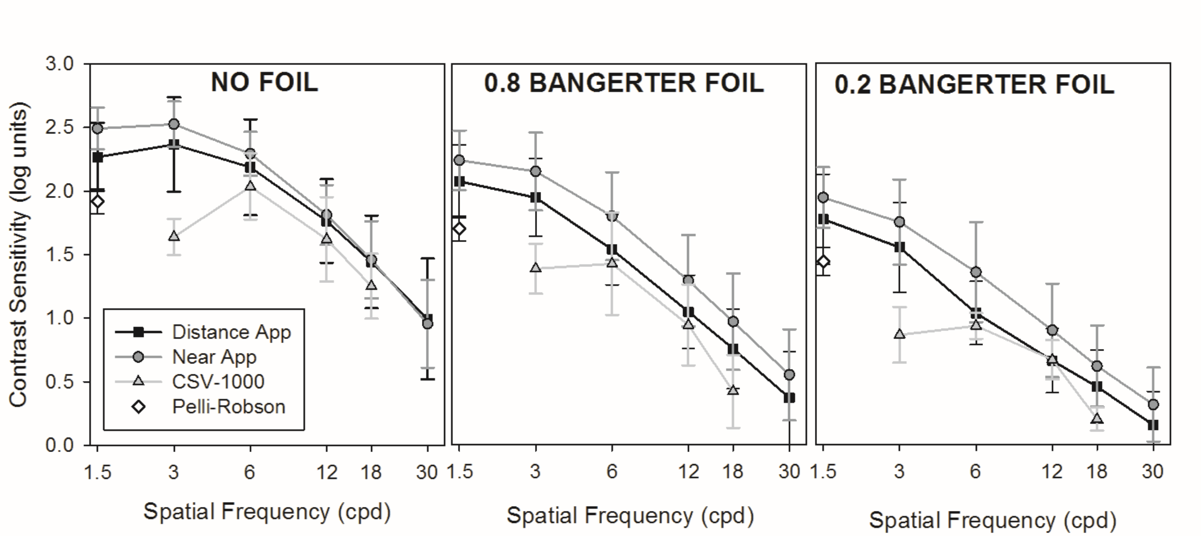

Figure 2: Contrast sensitivity at the range of spatial frequencies covered by the Aston distance and near app, CSV-1000 and Pelli-Robson test. Cpd = cycles per degree. Error bars = 1 S.D.

Repeatability

Bland-Altman coefficient of repeatability (COR) and Pearson's correlation coefficients data for the Pelli-Robson, Aston near app, Aston distance app, and CSV-1000 using the repeated measures on the 0.8 Bangerter foil are presented in table 2. The COR is 1.96x the standard deviation of the difference between two within subject contrast sensitivity measures. As the acuity limit was approximately 30cpd, repeatability was not calculated at this spatial frequency. The Pelli-Robson chart had the greatest agreement (COR 0.14logCS) between repeated measures at 1.5cpd followed by the

Aston near app whose COR values averaged 0.32±0.04logCS. The distance app had a slightly higher average COR values across all frequencies (0.39±0.04 logCS), meanwhile the CSV-1000 demonstrated a robust COR of 0.30 logCS at 3cpd but poor agreement at the higher spatial frequencies. Strong, statistically significant correlations ($p<0.001$) were found with near app, distance app and Pelli Robson chart at all frequencies studied, however the CSV-1000 only showed strong correlation at 3.0cpd.

Time to Complete Tests

The mean time duration to complete contrast sensitivity testing on the CSV-1000 was 124±37s, Pelli-Robson 78±27s (one spatial frequency only), Near App 53±15s and the Distance App 107±36s.

		Spatial Frequency, cpd				
		1.5	**3**	**6**	**12**	**18**
Near App	COR log (contrast sensitivity)	0.26	0.28	0.34	0.37	0.30
	Pearson’s r	0.83	0.89	0.87	0.86	0.92
Distance App	COR log (contrast sensitivity)	0.34	0.41	0.44	0.39	0.39
	Pearson’s r	0.80	0.76	0.77	0.79	0.81
CSV-1000	COR log (contrast sensitivity)	--	0.30	0.87	0.93	0.86
	Pearson’s r	--	0.79	0.29	-0.01	0.07
Pelli-Robson	COR log (contrast sensitivity)	0.14	--	--	--	--
	Pearson’s r	0.76	--	--	--	--
		0.76				

Table 2: Bland-Altman coefficient of repeatability (COR) and Pearson's correlation coefficients data for the Pelli-Robson, Aston near app, Aston distance app and CSV-1000 using the repeated measures on the 0.8 Bangerter foil condition.

DISCUSSION

This study aimed to create a novel contrast sensitivity test on a tablet computer that is as reliable as current paper based charts, assesses contrast across all spatial frequencies, has reduced testing time in comparison to existing computerised setups and is portable enough to be used on the examination chair. The chart was developed for the iPad due to their built in battery and light weight, making them portable, the standardization of their monitors and the resolution possible with the newer versions. Despite the limited greyscales (256 levels) from the 8 bit system, the application of a bit stealing technique allowed the perception of a far greater range of contrasts to improve the sensitivity of the test. The test took an old concept of displaying a sinusoidal grading changing from low to high spatial frequency in the X axis and from low to high contrast in the Y axis,[13] but the near chart enabled tracing of the users contrast detection, ensuring rapid assessment at all (rather than selected) contrasts and spatial frequencies. Furthermore, to the best of the authors knowledge, this was the first study to quantitatively examine the repeatability of a swept frequency based contrast sensitivity test. Selective spatial frequency loss (or ‘notches’ in the contrast sensitivity function) can be overlooked by test than assess only limited points across this function. This is not only due to optical aberrations such as astigmatism,[18,19] but has also been described in patients with retinal disease, optic nerve disease and cerebral lesions including disseminated sclerosis, attributed to damage of spatial frequency selective neural elements of the central visual pathways.[20-22] The test employs vertical gratings and therefore could be effected by high astigmatism or meridional amblyopia, but the patient should be fully corrected and the test could be repeated with the stimulus rotated if this was suspected to be an issue.

Studying the mean contrast results for all patients with each chart in Figure 2, it is clear that all charts were impacted by the increased visual degradation from the Bangerter foils in a similar way (interaction between test and degradation was not significant) supporting the validity of the new app based charts. Significant interactions between spatial frequency and Bangerter foil induced degradation condition were noted with the three charts that measured contrast sensitivity at multiple spatial frequencies, fitting with the previous characterization of the foils by Pérez et al.,[15] who found that they reduced contrast more heavily at the higher spatial frequencies.

Both the near and distance app charts showed higher mean contrast thresholds at all frequencies in comparison to that of the CSV-1000 and the Pelli-Robson charts. In addition mean thresholds were higher than those found by Dorr et al.[9] who used a 2-AFC procedure to assess up to 19 spatial frequencies on an iPad based contrast sensitivity test, which at 3-5 minutes a test took significantly longer. These higher threshold values seen with the app charts may be a result of using the method of adjustment (patients were asked to find the height of the vertical bars). This is analogous with an adjustment based descending trial which has been shown to increase threshold measures in psychophysical experiments[23] compared to 2AFC methods. While the CSV-1000 paper chart displays a definitive peak threshold at 6 cpd with no foil in place, the app Aston contrast sensitivity charts shows similar sensitivity at 1.5 and 3.0cpd before thresholds reduce at higher spatial frequencies. Dorr et al.[9] found a similar shape to these app results for the contrast sensitivity function determined using a 2-AFC procedure on both the iPad and a traditional CRT laboratory setup, with no “peaks” seen, but with a maximum contrast sensitivity around 1cpd. Also previous studies using research laboratory grade CRT setups found maximum contrast sensitivities to occur between 2-5cpd.[24-26] Artefacts or visual cues present within the CSV-1000 printed chart may bias patient responses and explain why peak contrast sensitivity appears to be shifted towards the higher frequencies. The difference in sensitivity between the Apps and the Pelli-Robson chart is unsurprising as the Apps are specified in terms of Michelson contrast while the Pelli-Robson uses the Weber contrast.

Few studies have measured distance and near contrast sensitivity in the same patients [27, 28] and none of these used a chart of similar design allowing comparison of the thresholds across the range of spatial frequencies. Distance contrast sensitivity was significantly lower than near contrast sensitivity, with no interactions between the distance and near versions of the test and these factors indicating they have a similar shape profile. The scores may be higher for the near version of the app because of the increased stimulus area. For sinewave gratings the larger the area the higher the sensitivity.[29] However, further work to determine whether the difference between distance and near contrast sensitivity at multiple spatial frequencies could be diagnostic or influence optimized patient management is needed to identify whether both are necessary, or the simpler to perform near test is sufficient. For example lighting affects distance vision more than near vision in glaucoma patients than demographically matched people with normal vision,[2] perhaps due to neural processing of blur or physiological changes to the refractive components of the eye.

Within-session repeatability was poor for the CSV-1000 test at 6, 12 and 18cpd, as the 95% confidence intervals were large (range: 0.76-0.93 logCS) and the correlation coefficients low (r=-0.01-0.29). These results are in agreement with Reeves et al.[7] who tested the within session repeatability of a similar gratings chart (VCTS 6500) and found 95% confidence intervals of between 0.95-1.01 log CS. Gratings based contrast sensitivity charts have continually shown poor repeatability,[30-32] which is most likely the result of limited contrast sensitivity steps and the testing procedure; with only two choices for the target orientation patients have a 50% chance that they could guess the location correctly even when they are unable to see the target at all. Greater repeatability was found with both the distance and near Aston contrast sensitivity apps. The implementation of a randomized testing order during the study suggests that the repeatability is a function of the testing method used and not that patients are just “remembering” where they first drew the line. The best within session repeatability was with the Pelli-Robson chart with 95% confidence intervals of 0.14 logCS, which is similar to the 0.18 logCS found by Thayaparan et al.[30] However, it only assesses one spatial frequency despite taking longer than the near Aston contrast sensitivity test to perform and the good repeatability is a product of the testing method; not only is letter recognition on the Pelli-Robson chart equivalent to a 26 alternate forced choice method, but patients could be considered experienced observers as letter recognition tasks are common place. The contrast sensitivity function notches are in the order of 0.5 to 1.0log units and therefore should be detectable with the ~0.3 COR of the near and ~0.4 COR of the distance app.[18-22]

To conclude this study has demonstrated the novel Aston contrast sensitivity tests for both distance and near displayed on a tablet computer have greater repeatability than the CSV-1000 based grating chart, but less than the Pelli-Robson chart. Although contrast sensitivity decreases with age,[33] the cross-test comparison of the validity of the contrast sensitivity apps is expected to be generalizable across patient demographics. The clear advantages of reduced testing time, instant plotting of results and a wide testing range of frequencies may make the near app in particular a suitable tool for evaluating the contrast sensitivity function of patients within the clinic.

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