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Chromatic Performance of High Index Plastic Optical Materials

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Purpose: The aim of this study was the evaluation of different plastic optical materials and determination of their behaviour in front of the eye. The study was not for clinical screening but mainly for material determination purposes, where the contrast sensitivity function is inefficient and difficult to interpret.
Methods: Thirty male and female subjects with no ocular or reported systemic abnormality were selected. Twenty-two lenses of +6.00D power, made from 8 different plastic materials following requested: specifications; were edged to round shape and decentred in order to produce a 9^{Δ} prism in front of the subjects' eye. Measurements of every subject were repeated four times on Bailey-Lovie and Pelli Robson charts, for each lens used in the experiment
Results: A significant decline of visual acuity in correlation to higher index plastic lenses was observed. Also we observed a similar visual acuity decline concerning aspheric design lenses, but with a little better performance than non-aspheric design lenses of the same index material.
Conclusion: The hypothesis of this work was that the higher the index the more the chromatic aberration. The conclusion is that this hypothesis is quite correct. However, the measurement of visual performance is not a very easy task. The wearer may simply experience blur through the periphery of the lens without realising the cause, and therefore the symptoms described to the optician can be confusing.

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1. INTRODUCTION

To measure the clarity of vision or to assess the visual system's ability to resolve detail, visual acuities should be taken on every patient. Visual acuity depends on the eye's ability to focus images on the retina, the integrity of the eye's neural components, and interpretation of images by the brain. In the same way we can evaluate the vision quality through different materials (different index and Abbe values) by measuring the vision acuity of same subject looking every time through a lens made of different material. Adoption of a standard procedure for the measurement of individual differences in acuity, which gives valid and precise measurements and at the same time is simple and practical, requires consideration of the following: selection of the most suitable type of test objects, specification of the range and gradation of the sizes of test objects required, standardization of the brightness of test object and background, as well as other variable factors in the test procedure [1,2].

Several suggestions have been made for designing standardized VA charts [3,4]. These include proposals like having the same number of letters per row, uniform letter size progression, and constant inter-letter and inter-row spaces and finally the use of letters with nearly equal legibility. Furthermore, five letters per row has been considered to be most practical [4,5,6]. Therefore, letter sizes that follow a geometric progression whose ratio or multiplier is equal to 0.1 log unit or multiples of 1.2589 have been recommended [3,4]. According to McMonnies and Ho (2000), clinical comparisons of visual acuity between right and left eyes have reduced validity when the same chart is used for both eyes, because the second eye result may be improved by memory of the just completed assessment of the first eye. Similarly, the validity of test - retest assessment of the same eye may be reduced by the introduction of memorisation effects, when the same chart is used on each occasion [7,8,9]. Ideally a second test should be completed using an equivalent version of the original chart construction. For example, an equivalent chart can be one that uses the same design but different sequences of the same letters [10,11,12]. Lack of equivalence of the same nominal lines for different versions of the same chart design may occur when chance combinations of easier or harder letters in particular lines give rise to significantly different total line difficulty [5,6,9].

1.1 Common Charts to Measure Visual Acuity

Snellen acuity chart is the familiar chart with the single large optotype at the top. It is designed to test the size of letter that a person can read at a standard testing distance of 6 metres or 20 feet. Each letter on the chart has been given a specific size and is notated by a certain number. The bigger the number, the bigger the letter is on the chart. 'Normal' acuity of 6/6 or 20/20 is based on the resolution of a gap size of one minute of arc. Thus as one minute subtends 1.75 mm at 6 m, charts are usually constructed on a 5 x 5 grid so that the total height of a letter or symbol will be 8.75 mm.

The visual acuity test measures the smallest letters that you can read on a standardized chart at a distance of 6 metres (20 feet). Visual acuity (VA) is expressed as a fraction [7,8,9]. The top number refers to the distance you stand from the chart (Fig. 1). This is usually 6 m. / 20 feet. The bottom number indicates the distance at which a person with normal eyesight could read the same line you correctly read. The recorded ratio always shows the test distance (in metres or feet) as the numerator and the letter size as the denominator. For example 6/6 (or 20/20) is considered normal. 6/12 (20/40) indicates that the line you correctly read letters at 6m (20 feet), could be read by a person with normal vision at 12 m. (40 feet). This means that a person with 6/6 (20/20) visual acuity can see the bottom letter no.6 at a distance of 6 metres. A person with 6/12 (20/40) vision can read the no.6 letter at a distance of 12 metres (40 feet), and so on...

Bailey-Lovie acuity chart (Fig. 2) is used less frequently than the Snellen chart. This chart differs from the Snellen in that the standard testing distance is 3 metres, instead of 6 metres. Doubling the VA's as described above will put the VA's in the familiar 6/6 format. Another difference is that the Snellen chart has an increasing number of letters per line as the letters get smaller. The Bailey-Lovie chart has a standard 5 letters on every line no matter the letter size. The theory is that with uniform letter and line spacing, the VA's will be a more precise measurement of visual acuity. Regardless of the differences, the VA's are taken in the same manner as the Snellen chart. The letters used to construct the Bailey-Lovie charts have been described as having been found by experiment to be of similar legibility (British Standard 4274, 1968) and as being of almost equal legibility [7,8]. Almost equal letter legibility would enable almost equal line difficulty to be achieved through random combinations of any five of the 10- letter set in each line. In a study using two equivalent versions of the Bailey-Lovie chart, significant differences in letter legibility were demonstrated and the distributions for lines of threshold acuity for each chart were not uniformly proportional [9].

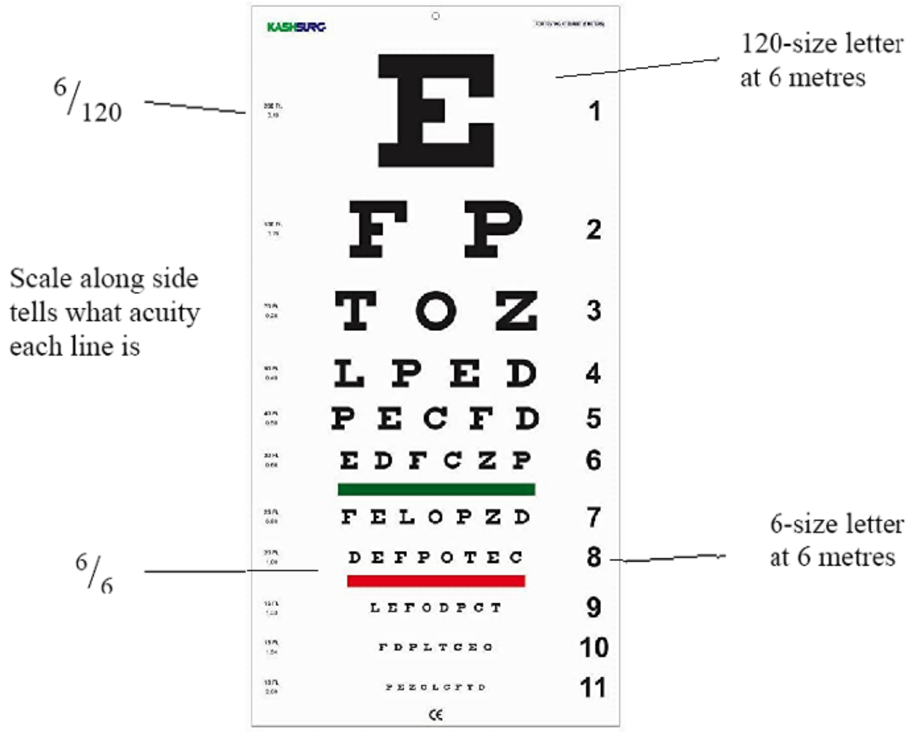

Fig. 1. Snellen acuity chart

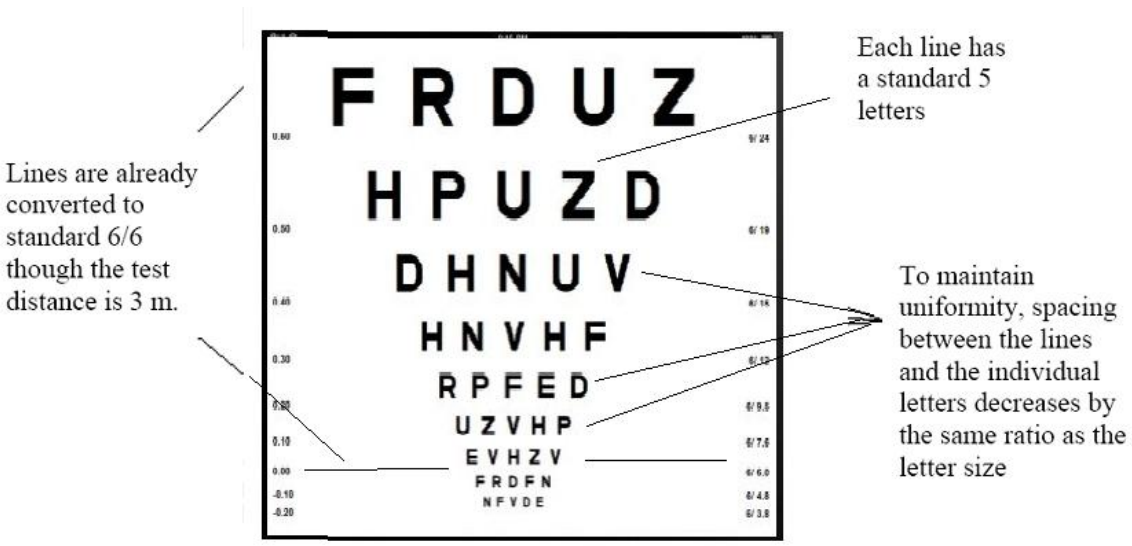

Fig. 2. Bailey-lovie acuity chart

1.2 Visual acuity vs. Contrast Sensitivity

When an optometrist tests vision by asking someone to read a row of black letters on a white chart, what is being measured is visual acuity. Acuity is a measure of contrast sensitivity – the upper limit for detecting fine detail at high contrast. Much of what we see in the real world however has a much lower contrast and has an overall shape and form in addition to detail [13]. When one measures an observer's ability to detect objects of different sizes at lower contrasts, the result is a contrast sensitivity function (CSF). The size of an object can be quantified in terms of the size of its image on the retina, typically in degrees of visual angle. With periodic patterns, such as a sine-wave grating pattern, size is specified in terms of the number of cycles per degree of visual angle (c/deg). This is a measure of the pattern's spatial frequency. A cycle consists of one complete light-dark transition. Lower spatial frequencies correspond to wider bars and higher spatial frequencies correspond to narrower bars. Contrast refers to the difference in luminance between the lightest and darkest points in a cycle [14,15].

A CSF is typically obtained by measuring an observer's contrast detection threshold for a number of different grating patterns at different spatial frequencies. A CSF is a plot of contrast sensitivity as a function of spatial frequency. One interesting aspect of the CSF is that it peaks at intermediate spatial frequencies, about 3-4 c/deg. In other words, we are best able to detect medium-sized objects when their contrast is low. As you might expect, we see smaller objects less well. The smallest objects that we can detect are around 50 c/deg and they can only be detected if their contrast is very high. In its simplest terms, contrast sensitivity refers to the ability of the visual system to distinguish between an object and its background. Contrast describes the difference in the average luminance between two visible areas. Contrast sensitivity is the measure of the ability to detect a difference in the luminance between two areas. If the two areas are adjacent to each other, the ability to detect a difference in luminance is called spatial contrast sensitivity. If the areas occur sequentially in time, the ability to detect a difference in luminance is called temporal contrast sensitivity [16].

1.3 How to Assess Contrast Sensitivity

Contrast sensitivity tests with letters as optotypes, such as the Pelli-Robson, are quick, reliable, and repeatable means for studying contrast sensitivity [15,16] and are often used in clinical research [17]. To ascertain whether a patient has decreased contrast sensitivity, normal values of the test must be available for comparison [18]. The Pelli-Robson contrast sensitivity test (Fig. 3) is a wall chart measuring. 90 X 60 cm (36 X 24 inches).

The chart comprises 8 lines of letters with different contrasts. Each line has 6 letters; the first 3 letters (a triplet) on the left have more contrast than the 3 letters on the right. The contrast also decreases downward from line to line. The size of the letters is 4.9 X 4.9 cm (2 X 2 inches). The letters on the left of the top line have the highest contrast, 1 or 100%, and the letters on the right of the bottom line have the lowest contrast, 0.006 or 0.6%. The manufacturer recommends a testing distance of 1 m, which corresponds to a spatial frequency of about 1 cycle per degree (cpd). An addition of +0.75 D can be used if a distance correction is needed [18].

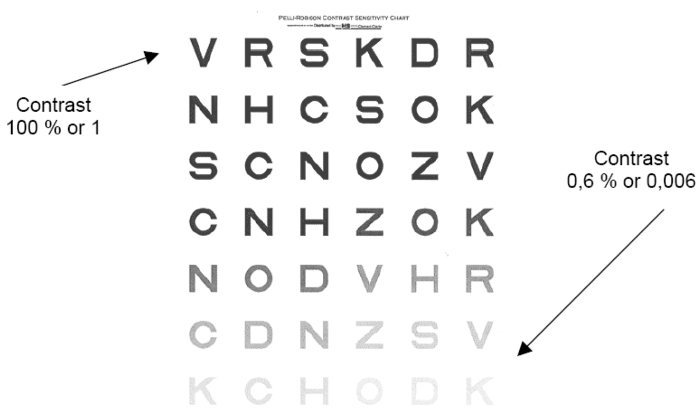

Fig. 3. The Pelli-Robson Chart (*after Denis Pelli*)

The logarithmic contrast sensitivity value of the last triplet of which at least 2 letters are correctly seen is marked as the result. The luminance of the test should be 85 candelas/m^2 (cd/m^2); the accepted range is 60 to 120 cd/m^2 [17,18].

Contrast sensitivity can be examined using grating tests (eg, the Vistech) or optotype tests (eg, the Pelli-Robson). Grating tests define contrast sensitivity in different sizes of targets as several different cycles per degree. Contrast sensitivity measurements with grating tests usually start at 1.5 cpd and go up to 18.0 cpd (or even higher with computer-based equipment). The range of the contrast levels can be from 3 to 0.004. The results give accurate information about the ability to see contrasts of small and large objects in the real world [19].

The Pelli-Robson test with optotypes (letters) only measures 1 cpd region at a recommended distance, and the examination must be done at different distances if more cycles per degree are needed. The lowest contrast level of the Pelli-Robson test (0.006) is adequate. The Regan test with optotypes (letters) measures several ranges of cycles per degree, but the contrast level is considerably higher than in the grating tests. Therefore, in measuring contrast sensitivity, grating tests would be better and more appropriate to use than optotype charts [17]. However, the examination with optotypes at a region of peak sensitivity, such as 3 cpd in the Pelli-Robson chart at 3 m distance, could give important information. It has been suggested that the scoring on the Pelli-Robson test would be more reliable if the number of all letters correctly seen was used [17,18]. However, the test's instruction for scoring is to find the last triplet of letters at which at least 2 letters are correctly seen [17,19,20].

1.4 Prisms and Vision

Imagine an eye looking at a narrow line object, which emits white light of equal-energy spectrum. When a prism with its base-apex line perpendicular to the line object, is placed before the eye a retinal image consisting of the component wavelengths of the spectrum will be formed.

Thus the line's image has been 'spread' over a portion of the retina. This is due to transverse chromatic aberration, the effects of ocular aberration and diffraction being ignored [21,22,23]. Assuming the spectral sensitivity of the eye to be in accordance with the standard photopic spectral luminous efficiency, the strength of the visual stimulus due to each wavelength will be proportional to the corresponding luminous efficiency value.

The line-spread functions for crown glass prisms of 6^{Δ} and 12^{Δ} thus obtained, were shown by El-Kadouri and Charman [22]. They showed also that a substantial loss of modulation transfer occurs at spatial frequencies <c/deg (the visually significant frequencies), even with 6^{Δ} prisms (Fig. 4).

Contrast sensitivity has also been used experimentally to determine the degradation of the retinal image. The results of these experiments showed a loss of modulation transfer, which increased with prism power, and probably also with reducing constringence [24,25].

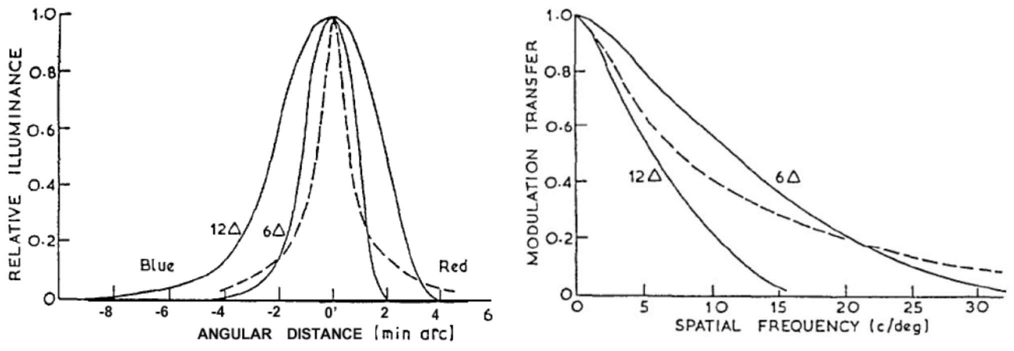

Fig. 4. Retinal line spread function (left panel) for transverse chromatic aberration produced by crown glass prisms. Ordinate, angular distance (min arc); abscissa, relative illuminance; dashed line, without prism. Modulation transfer function (right panel) for prisms. Ordinate, spatial frequency (c/deg); abscissa, modulation transfer; dashed line, for white light *(After Charman and El-Kadouri.1984)*

According to Fonseka, Khosravi in 1988 found a small but statistically insignificant reduction in Snellen letter acuity when a prism was placed before one eye [25]. However, Davis and Clotar (1956), and Meslin and Obrecht (1988) found that when chromatic aberration reaches a value of about 0.1 $^{\Delta}$ (which can be caused by a 6 $^{\Delta}$ crown glass prism), VA is significantly affected [26,27]. Jalie (1987) also gave 0.1 $^{\Delta}$ as tolerance for transverse chromatic aberration, without quoting evidence [28,29,30].

2. METHODS

2.1 Measuring Visual Acuity

The simplest method for computing the proper average visual acuity from any notation is to convert the value to the LogMAR equivalent and then take the average of the LogMAR values. The easiest way to compute the LogMAR value is to convert to decimal notation and then take the negative of the logarithm, e.g, 6/6 = 1 and the log of 1 is 0, and 6/60 = 0.10 and the negative of the log is +1.0. The average of 0 and +1.0 is 0.5 LogMAR units. Converting back from the logMAR value of 0.5, the corresponding visual acuity is 6/18.9, the correct geometric average [31].

It is common for visual acuity sets to include values in which the patient did not read all of the letters on a single line correctly. Although recording the last line that was read completely or the majority of letters (three out of five) is an acceptable method, it reduces the precision of the measurement —similar to rounding off laboratory measurements. A more accurate method is to interpolate between the values of the LogMar acuity using the fraction of the number of letters read correctly on a visual acuity line. For example, suppose our acuity chart had five letters on each visual acuity line and the patient read all of the letters on the 6/15 (LogMar +0.4) line, but only three of the five letters on the 6/12 (LogMar +0.3) line. Three-fifths (3/5 = 0.6) of the way from LogMar +0.4 to +0.3 is LogMar +0.34. The LogMar value of +0.34 is the correct value for this patient’s visual acuity.

For studies that involve large databases, where converting these values manually is tedious, there are published formulas that allow direct conversion from the Snellen acuity value to the interpolated LogMar value 0.6 These formulas only work if there are an equal number of letters on a line, as there are on the Bailey-Lovie visual acuity chart (1976) and other standardized charts [32].

Unfortunately, if the number of letters on the acuity chart is not equal on each line (as occurs on many projected and wall charts), then a table must be created that shows the conversion interpolation for each line, and a single formula is not possible.

Table 1. Corresponding visual acuities (after Holladay) [31]

Line No.	Snellen Equivalent (feet)	Snellen Equivalent (meters)	Decimal Equivalent (minutes)	Visual Angle	LogMAR* Equivalent
-3	20/10	6/3	2.00	0.50	-0.30
-2	20/12.5	6/3.75	1.60	0.63	-0.20
-1	20/16	6/4.8	1.25	0.80	-0.10
0	20/20	6/6	1.00	1.00	0.00
1	20/25	6/7.5	0.80	1.25	+0.10
2	20/32	6/6.4	0.63	1.60	+0.20
3	20/40	6/12	0.50	2.00	+0.30
4	20/50	6/15	0.40	2.50	+0.40
5	20/63	6/18.9	0.32	3.15	+0.50
6	20/80	6/24	0.25	4.00	+0.60
7	20/100	6/30	0.20	5.00	+0.70
8	20/125	6/37.5	0.16	6.25	+0.80
9	20/160	6/48	0.13	8.00	+0.90
10	20/200	6/60	0.10	10.00	+1.00
11	20/250	6/75	0.08	12.50	+1.10
12	20/320	6/96	0.06	16.00	+1.20
13	20/400	6/120	0.05	20.00	+1.30
.	.	.	.	.	.
.	.	.	.	.	.
20	20/2000†	6/600	0.01	100.00	+2.00
30	20/20000§	6/6000	0.001	1000.00	+3.00

* *Log of Minimum Angle of Resolution*
† *20/2000 = count fingers at 2 feet*
§ *20/20000 = hand motion at 2 feet*

Table 2. Visual acuity data for theoretical eyes (after Holladay) [31]

Eye No.	Measured Visual Acuity*	Snellen Equivalent	Decimal Equivalent	LogMAR Equivalent
1	20/10	20/10	2.0	-0.30
2	20/10-2	20/10-2	2.0-2	-0.26
3	20/40	20/40	0.5	+0.30
4	20/40+3	20/40+3	0.5+3	+0.24
5	20/200	20/200	0.1	+1.00
6	CF† at 2 ft	20/2000	0.01	+2.00
7	HM§ at 2 ft	20/20000	0.001	+3.00
Mean		20/142	0.141	+0.85
Standard deviation		± 11.5 lines	± 11.5 lines	±0.115

** Bailey-Lovie visual acuity chart with five letters on each line*
† Count fingers

3. MATERIALS AND SUBJECTS

3.1 Bailey – Lovie Chart

Thirty male and female subjects, ranging in age 18 to 30 years, were selected. Subjects had no ocular abnormality by direct ophthalmoscope, no reported systemic abnormality and were taking no ocular or systemic medications. Subjects with any visual complaints were excluded. Contact lens wearers were accepted. Subjects had no suppression as tested by viewing targets simultaneously seen through polarising filters. Central or eccentric fixation was not checked. However, the logMAR acuity of either eyes could not be worse than 0.2 (i.e. Snellen notation of 6/9.5) so as to eliminate amblyopic subjects [33].

Each subject was refracted; the monocular subjective prescription to “maximum acuity” without balancing was recorded for each eye. With the prescription in a trial frame (Fig. 5), monocular VA was recorded using a Snellen type chart at 6 m., converted to logMAR visual acuity and *the* values were recorded to the nearest letter. Four Snellen charts with different combinations of letters were used to eliminate the possibility of correct identification of letters by memory. The subject’s head was fixed using a headrest and he/she was reminded to keep both eyes open throughout the test.

Initially, forty subjects were examined altogether; data of ten were excluded because of unstable responses and/or because fewer than six reversals were obtained. The mean age of thirty accepted subjects was 22.48 (SD: 1.82) years. Seventeen were females and the remainder were males.

3.2 Pelli-Robson Chart

Seven subjects, who were naïve to the purpose of the experiment, participated in the study after giving informed consent. All subjects were carefully at first refracted at 4 m, the usual viewing distance. To determine the subjective refraction we used the typical clinical approach of highest plus/lowest minus spherical power commensurate with maximal visual acuity, careful cross-cylinder determination of correcting cylinder power and axis while viewing concentric ring targets and binocular balancing to reduce any accommodation. Though there is the possibility of errors in the determination of the subjective refraction [34], our confidence in the determination of the appropriate refractive correction was verified by measurements of ocular aberrations of the subjects [33,35].

During contrast sensitivity measurements each subject was seated, the non checked eye patched, head and eye movements were not restrained and contact lenses were worn, if needed. Subjects monocularly viewed the contrast sensitivity chart. Pupils of the subjects' eyes, measured using comparison hemi-circles ruler with 0.5 mm increments, ranged between 3 and 6 mm under average room illuminance of 40 lux used in most experiments [36]. Contrast sensitivity was measured with best correction. As the letter size on a Pelli–Robson letter contrast chart (Pelli *et al.*, 1988) is fixed; we altered the spatial frequency content of the letters by altering the distance of the subject from the chart [37,38,39]. The two-dimensional spatial frequency spectrum of letter targets is relatively complex. An important feature of these spectra is the "fundamental" peak of the familiar square-wave spectrum, which is related to the width of the bars or strokes composing the letters. For example, at 1 m the fundamental peak is at approximately 1 cpd, and at 4 m it is at about 3.6 cpd [40].

Letter contrast sensitivity was measured using the Pelli-Robson Chart [39] under the recommended conditions and at a working distance of one metre. Subjects were required to identify the letters and were encouraged to look at a line of letters for at least 20-30 s and forced to guess when they were not sure, as scoring depends upon a forced choice paradigm. Letter contrast sensitivity was determined where each letter counted as 0.05 log units as recommended by Elliott et al. (1991) and confusions between the letters O and C were ignored [41].

3.3 Edged Lenses

Twenty-two lenses made from 8 different plastic materials were obtained from our suppliers. The following specifications were requested: power +6.00D; edged to round shape of 38 mm. in diameter (Fig. 6) and decentred in order to produce a 9^{Δ} prism in front of the subjects' eye, after placing in the trial frame. To avoid defocus a minus equal lens (-6.00D) was used in the trial frame to neutralise the focal power of the prism lens. It was confirmed by inspection that all lenses met these specifications. The lenses were coded and tested in a different random order in each phase of the experiment.

3.4 Repeatability

Measurements of every subject were repeated four times on Bailey-Lovie and Pelli Robson charts [39], for each lens used in the experiment to achieve reliable results. Reeves et al, in their study (1993) in order to measure the reliability, of several clinical tests, which use high- and low-contrast letters, and to provide an estimate of what constitutes a significant change in performance over time, recruited patients so that the results would be representative of the population [41].

Sukha and Rubin in recent study (2017), which investigates test–retest reliability of contrast VA in healthy adults in a clinical setting, suggested good reliability of test and retest measurements of contrast VA in an adult clinical population. They also implemented two measurements (test and retest) per chart for the compensated right eyes of each of the participants [42]. On the other hand, in Osman et al. study (2021), which aims to compare the contrast sensitivity results and test/retest ±limits of agreement for the Ohio Contrast Cards and the Pelli-Robson letter contrast sensitivity chart, on two challenging groups of participants, tests were each performed twice by two different examiners within one visit [43]

3.5 Chart Projector

VA was measured with letter charts' wall-display using a Nikon NP-3S chart projector. The acuity charts consisted of high contrast black letters on a white background. Each row consisted of five letters (No 4 and 5 on Fig. 7) and, from top to bottom, decreased in size by a constant factor (0.1 log unit per row).

Letter sequence was varied from trial to trial to discourage learning effects. Testing was conducted in an otherwise dark room at a distance of 6 m. Each subject was instructed to start from the top of each chart and read down as far as possible, and was encouraged to guess when unsure. Scoring was conducted by letter with a precision of 0.02 log units (0.1 log units per five letter row). VA was scored as the log of the minimum angle of resolution (logMAR).

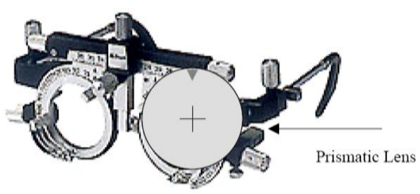

Fig. 5. Lens edged to round shape and placed on trial frame

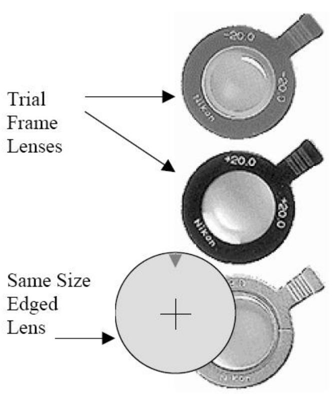

Fig. 6. Lenses edged to round shape in order to be placed in trial frame

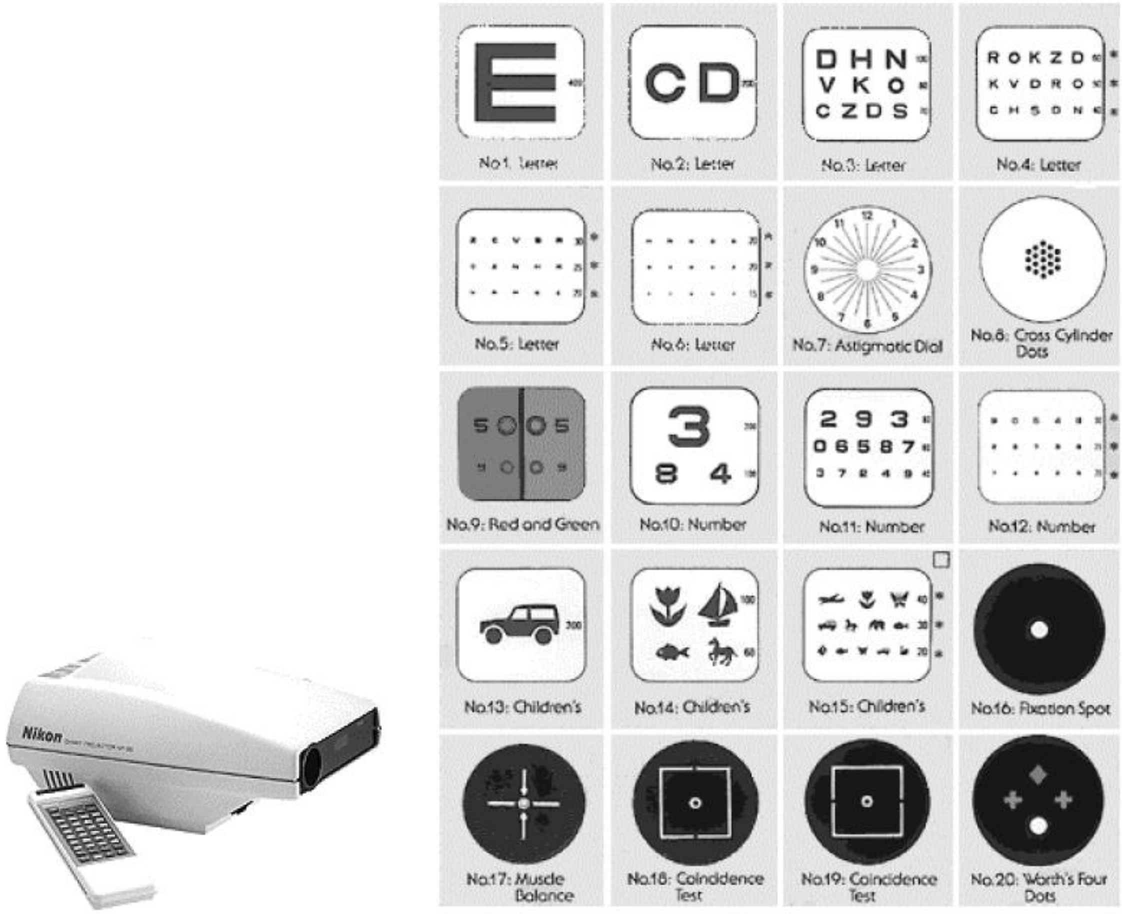

Fig. 7. Nikon NP-3S chart projector with projected optotypes consisted of high contrast black letters on a white background (and five letters at each row for No.4 and No.5) (*After Nikon NP instructions manual*)

4. RESULTS

4.1 Bailey-Lovie Chart

In Table 3, all VA measurement results for 30 participants are presented. Table also includes results for the seven different samples and VA measurement without the sample lenses (VA cor).

Table 4 illustrates the commercial plastic lenses used for the samples. The aspheric design is illustrated in italics. Before entering the test all subjects had an interview and their VA was recorded. Some of them wore contact lenses and the test took place over the contact lenses. The records of the prior interview and the test results entered up to a special form (questionnaire) for later analysis.

In Fig. 8, we observe a significant decline of visual acuity in correlation to higher index plastic lenses like Ormex (1,56) and Pentax (1,60). Against to what we expected from a lens such as Polycarbonate having an Abbe value of about 31, we notice that its performance comes better than Pentax but still worse than Ormex.

In Fig. 9, we observe a similar graph of Visual Acuity decline (in LogMAR units) but concerning Aspheric design lenses. The inclination presents a steeper decline and a performance a little better than non-aspheric design lenses. After all, Fig. 10 illustrates the comparison of %VA decrease to corresponding Abbe number.

Table 3. Results for 30 subjects' VA measurement after samples (VA1-7) and without sample lens (VA cor)

		Sola CR-39	Sola Asph	Essilor Ormex	Essilor Poly-C	Pentax HIX	Pentax Asph	Hoya Teslalid
		1.498	**1.54**	**1.56**	**1.59**	**1.60**	**1.67**	**1.71**
Subject a/a – Gend.	**VA Cor.**	**VA 1**	**VA 2**	**VA 3**	**VA 4**	**VA 5**	**VA 6**	**VA 7**
1 M	0	0.2	0.2	0.2	0.32	0.24	0.24	0.26
2 M	0	0.2	0.2	0.18	0.26	0.26	0.22	0.26
3 F	0.16	0.3	0.24	0.3	0.34	0.36	0.24	0.32
4 M	0.16	0.16	0.2	0.2	0.32	0.34	0.32	0.34
5 M	0.02	0.1	0.2	0.3	0.4	0.42	0.32	0.36
6 M	0.02	0.1	0.16	0.16	0.22	0.24	0.3	0.32
7 F	0	0.16	0.2	0.22	0.3	0.32	0.32	0.38
8 F	0.1	0.2	0.28	0.24	0.32	0.34	0.32	0.34
9 F	0.06	0.16	0.24	0.2	0.24	0.26	0.24	0.3
10 M	0.16	0.15	0.24	0.2	0.26	0.26	0.24	0.26
11 M	0.02	0.1	0.1	0.16	0.2	0.22	0.22	0.24
12 M	0	0.2	0.2	0.2	0.24	0.22	0.22	0.32
13 F	0.1	0.24	0.2	0.2	0.2	0.24	0.2	0.2
14 M	0	0.2	0.16	0.2	0.2	0.2	0.2	0.24
15 M	0.01	0.16	0.16	0.22	0.3	0.26	0.24	0.32
16 F	0	0.1	0.1	0.16	0.22	0.16	0.22	0.24
17 F	0.16	0.1	0.16	0.2	0.3	0.21	0.3	0.3
18 M	0	0.1	0.1	0.16	0.22	0.16	0.2	0.22
19 M	0.16	0.16	0.2	0.16	0.22	0.2	0.24	0.21
20 F	0.1	0.16	0.2	0.16	0.3	0.2	0.24	0.2
21 M	0	0.1	0.16	0.16	0.21	0.2	0.2	0.21
22 F	0	0.2	0.22	0.2	0.3	0.24	0.32	0.24
23 M	0	0.1	0.1	0.16	0.2	0.16	0.2	0.2
24 F	0.1	0.16	0.16	0.2	0.24	0.2	0.3	0.32
25 M	0.1	0.16	0.16	0.2	0.2	0.2	0.2	0.22
26 F	0.1	0.2	0.2	0.2	0.3	0.22	0.24	0.24
27 M	0	0.2	0.21	0.16	0.24	0.22	0.24	0.24
28 M	0.16	0.2	0.16	0.2	0.22	0.2	0.22	0.16
29 F	0	0.1	0.16	0.2	0.2	0.16	0.2	0.16
30 F	0.06	0.16	0.22	0.16	0.16	0.16	0.2	0.2

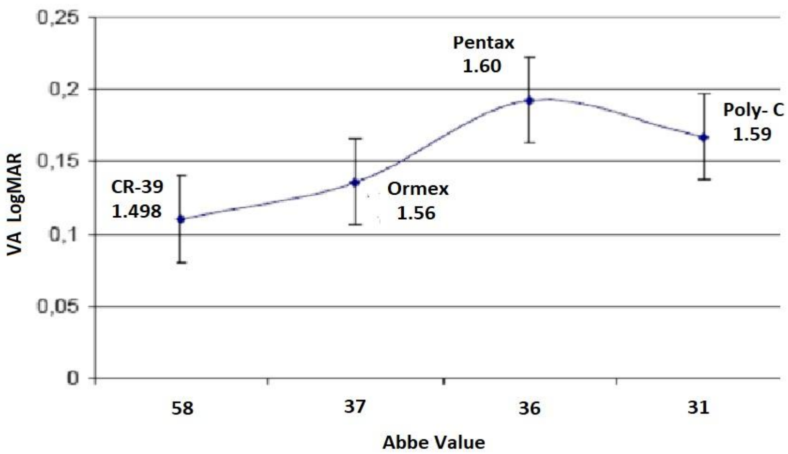

Fig. 8. Correlation between Visual Acuity and Abbe number in Plastic Lenses

Table 4. Commercial plastic lenses used for samples lenses. (Lenses in *Italics* are of aspheric design)

Trade name	n_D	ρ (gr.cm^{-3})	Abbe
Low Index			
Sola CR-39	**1.498**	**1.32**	**58**
Medium Index			
Spectralite ASL	**1.54**	**1.21**	**47**
Middle Index			
Essilor ORMEX	**1.56**	**1.23**	**37**
Poly-C Mid. Index			
Essilor Airwear	**1.59**	**1.20**	**31**
Mid-High Index			
Pentax 1.6 HIX	**1.60**	**1.34**	**36**
High Index			
PENTAX HIX Asph	**1.67**	**1.35**	**32**
Very High Index			
Hoya Teslalid	**1.71**	**1.40**	**36**

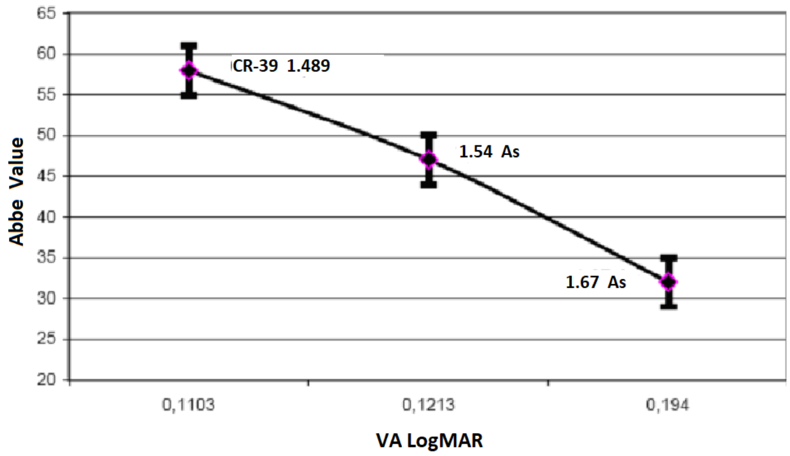

Fig. 9. Correlation between Abbe Value and Visual Acuity reduction for Aspheric design Plastic Lenses

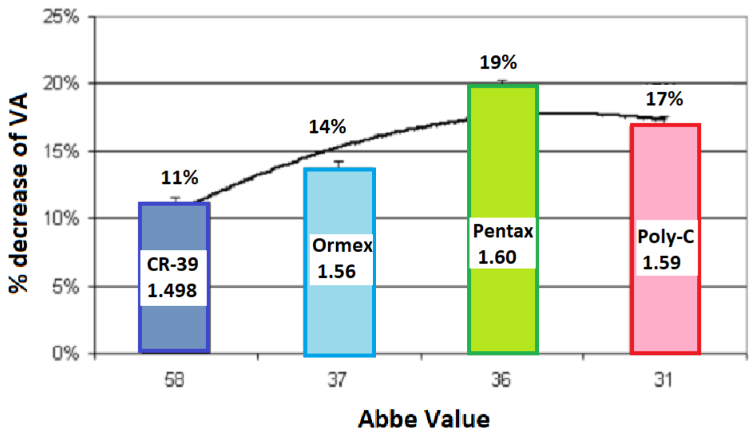

Fig. 10. Comparison of % Visual Acuity decrease and Abbe Value

4.2 Pelli-Robson chart

Table 5 demonstrates the scores for seven subjects with and without the sample lenses. The Pelli-Robson chart was placed in 1 m distance. The result paper is illustrated in Table 6. The numbers on both sides give the logarithmic contrast sensitivity corresponding to the neighbouring group of 3 letters. For instance, the number 0.60 next to the letters SCN [17] indicates a contrast of 1/10 0.60 = 0.25 or contrast of 25% for those letters.

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The currently available test that best meets the requirements laid out above is the Pelli-Robson chart [39,44]. This test measures contrast sensitivity for a single (large) letter size. Specifically, the chart uses Sloan letters (6 per line), arranged in groups whose contrast varies from high to low. The chart is simple to use, because the subject simply reads the letters, starting with the highest contrast, until she or he misses two or three letters in a single group. Each group has three letters of the same contrast level, so there are three trials per contrast level. The subject is assigned a score based on the contrast of the last group in which two or three letters were correctly read. The score, a single number, is a measure of the subject's log contrast sensitivity. Thus a score of 2 means that the subject was able to read at least two of the three letters with a contrast of 1 percent (contrast sensitivity = 100 percent or log 0).

In the instructions, most contrast sensitivity tests recommend a luminance level at which to administer the test. In the Pelli-Robson test, the recommended luminance is 85 cd/m^2 [45,46]. However, under photopic conditions, contrast sensitivity results on the Pelli-Robson were almost the same at luminance ranging from 7 to 514 cd/m^2 [37]. In this study the luminance level was exactly 100 cd/m^2 and the room level at about 20 cd/m^2.

Table 5. Results for 7 subjects' logarithmic contrast sensitivity samples (1-7) and without sample lens (contrast norm cor.) at 1 m

		Sola CR-39	**Sola Asph**	**Essilor Ormex**	**Essilor Poly-C**	**Pentax HIX**	**Pentax Asph**	**Hoya Teslalid**
		1.498	**1.54**	**1.56**	**1.59**	**1.60**	**1.67**	**1.71**
Subject	**Contrast Norm – cor.**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Sample 6**	**Sample 7**
1	1.65	1.50	1.35	1.35	1.20	1.20	1.20	1.20
2	1.50	1.35	1.35	1.20	1.20	1.20	1.05	1.05
3	1.65	1.50	1.35	1.35	1.20	1.20	1.20	1.20
4	1.60	1.35	1.20	1.20	1.20	1.20	1.05	1.05
5	1.65	1.50	1.35	1.35	1.20	1.20	1.20	1.20
6	1.80	1.65	1.50	1.50	1.35	1.35	1.25	1.25
7	1.65	1.50	1.35	1.20	1.20	1.20	1.20	1.20

Table 6. Part of the result paper of the Pelli-Robson contrast sensitivity test

%	**logCS**	**PELLI-ROBSON**		**logCS**	**%**
100	0.00	**V R S**	**K D R**	0.15	75
50	0.30	**N H C**	**S O K**	0.45	35.5
25	0.60	**S C N**	**O Z V**	0.75	18
12.5	0.90	**C N H**	**Z O K**	1.05	9
6	1.20	**N O D**	**V H R**	1.35	4.5
3	1.50	**C D N**	**Z S V**	1.65	2.2
1.6	1.80	**K C H**	**O D K**	1.95	1.1
0.8	2.10	**H S Z**	**D S N**	2.25	0.56

5. DISCUSSION

In the laboratory, contrast sensitivity is usually measured psychophysically, using patches of grating (bars) that vary over a wide range of sizes (spatial frequencies). Typically, the gratings are computer generated and displayed on a computer screen or cathode ray tube. This allows the experimenter to construct a contrast sensitivity function. However, this study was not for clinical screening, but mainly for material determination purposes where the contrast sensitivity function is inefficient and difficult to interpret. Moreover, the typical laboratory test for it requires sophisticated and specialized equipment. Ideally, a contrast sensitivity test for material performance determination should satisfy several criteria. It should be simple to administer, requiring no sophisticated electronic or computer equipment, well standardized, reliable, valid, sensitive to visual loss, and relatively insensitive to changes in focus, viewing distance, and illumination. It should provide a single score that is meaningful and can easily be compared with extensive normative data and should provide information about visual function not captured by other tests (such as high contrast acuity).

The Pelli-Robson chart is quick and easy to administer. Because it is based on reading letters, it can be easily administered to anyone who is literate; however, it is not useful with nonverbal individuals or those who are unfamiliar with the alphabet. It is simple, efficient, and provides user-friendly information by providing a single number to describe the observer's contrast sensitivity. The chart has been extensively normed and validated, and there is now an extensive literature on the reliability and validity of the test. It is actually a measure of the height of the contrast sensitivity function, similar to measuring contrast sensitivity for a luminance edge. Thus, it should be sensitive to losses that affect low and medium spatial frequencies, losses that might not be evident for high-contrast acuity, thus providing information not captured by acuity testing. The Pelli-Robson chart provides a graded index of performance (log contrast sensitivity.

Contrast sensitivity measures provide information that is related to, but is also distinct from, high-contrast visual acuity measures. For example, a number of studies have reported that the correlation between high-contrast acuity and contrast sensitivity is of the order of 0.5 to 0.6 [47,48]. It is widely believed that letter contrast sensitivity (as assessed by Pelli-Robson) reflects the contrast sensitivity near the peak of the contrast sensitivity function, while high-contrast letter acuity probably reflects sensitivity at high spatial frequencies. Does contrast sensitivity provide a unique measure of disability? It subsumes visual acuity. Thus an individual with visual acuity poorer than 20/200 is likely to have reduced contrast sensitivity, and one with a visual acuity of 20/40 or better is unlikely to have significantly reduced contrast sensitivity.

However, between those limits (acuity between about 20/50 and 20/100), contrast sensitivity may distinguish individuals with visual impairment from those with no impairment; in other words is evident that it will affect their contrast sensitivity scores. For example, people with multiple sclerosis [49,50] or visual pathway disorders [48,51] may show significant contrast sensitivity loss with little visual acuity loss and, so in order to evaluate the performance using visual acuity is very important to be sure about the subjects' visual health.

6. CONCLUSION

The hypothesis of this work was that the higher the index the more the chromatic aberration. The conclusion based on the discussion above is that this hypothesis is quite correct.

However, many important conclusions were obtained through this study. First, that chromatic aberration, as was expected, reduces visual acuity. Of course in aspheric design we notice a slight improvement, but still far from CR-39. The high and low contrast acuity loss when wearing prisms is mainly the result of distortion and chromatic aberration. Wright et al. (2008) studied тhe distortion effect and the chromatic dispersion [52].

Additional factors such as reflection from the prism facets, secondary refraction at the prism facet bases, diffraction of light by the grooves in Fresnel prisms, observers' direction of gaze and prism area variations are potential causes for a greater acuity reduction with the prism [53].

Therefore, the greater high and low contrast acuity reduction with prisms in this study, is mainly the result of chromatic dispersion than of reflection from the prism facets, secondary refraction at the prism facet bases and diffraction of light by the grooves. And that is because mainly the prisms are of the same power and size, worn at the same distance and the only difference is the Abbe value due to the material. The advantage of measuring a CSF, as opposed to a simple measure of acuity, is that it describes how the visual system performs at lower contrasts and at a range of spatial frequencies. The measurement of acuity provides only one point on the CSF. So we can be more accurate to visual acuity decline due to the material of lenses used.

Measurement of CSF reduction with prism does need care. As shown by Tang and Charman (1992), if gratings are used, then there is a considerable reduction in CSF if the prism base is perpendicular to the grating [54]. If the prism base is parallel to the ‘lines’ of the grating, then the effect is much reduced. Thus there is a great advantage is using targets such as the Pelli-Robson chart where there is not the same orientation specificity.

The goal of this study was to attempt an evaluation of the optical performance of plastic lenses in correlation to the high refractive index and consequently the chromatic dispersion of the material, and in that I think we were successful. The experiments performed in the study confirmed that as the index of refraction increases (consequently the Abbe decreases) there is a consequent trend to reduced visual performance.

Although we can measure the optical characteristics of lens materials, it still does not tell us what the real impact is on the wearer. It might be thought that a material with an Abbe value of 30 would be half as successful from the wearer’s point of view as one with a value of 60. However anecdotal evidence does not support this hypothesis, and reports of optical problems being noted by wearers of high index lenses are limited. But this does not mean they do not occur the problem is that transverse chromatic aberration induced by a low Abbe number is just one of a number of aberrations to which spectacle lenses are prone. The wearer may simply experience blur through the periphery of the lens without realising the cause, and therefore the symptoms described to the optician can be confusing. Furthermore, single vision lens wearers can easily develop a coping strategy where they simply turn their head for clearer vision through a point on the lens free from obvious aberration [54].

Perhaps the lens wearers of most interest are users of bifocal or progressive lenses. Here, the near zones of the lenses are typically some distance from the optical centre of the major portion, and hence prone to transverse chromatic aberration.Thus the proposed next experiment would be to compare a group of presbyopes with two versions of the same design of progressive lens. One would be normal index CR39, the other a high index material with a low Abbe number. The ideal comparison would be Polycarbonate, as that has a low Abbe number without a large change in refractive index [55]. Hence the overall lens design in the two materials would be similar. Near vision contrast sensitivity testing would then give a good indication of the effect of chromatic blur.

In conclusion, it is perhaps ironic that high refractive index materials were developed when large aperture spectacle frames were fashionable. With small frames probably there is very little requirement for such materials in the vast majority of prescriptions. But fashion turned again to large frames, and these lens materials now came into their own.

CONSENT

As per international standard or university standard, Participants’ written consent has been collected and preserved by the authors.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Sloan LL. Measurement of visual acuity. Arch Ophthalmol. 1951;45:704-725.
2. Marsden J, Stevens S, Ebri A. How to measure distance visual acuity. Community Eye Health. 2014;27(85): 16.
3. Bailey IL, Lovie JE. New design principles for visual acuity letter charts. Am. J. Optom. Physiol. Opt. 1976;53:740-745.
4. Bailey IL, Lovie JE. Visual acuity testing. From the laboratory to the clinic Vision Research. 2013;90:2–9.
5. Ferris FL, Kasso A, Bresnick GH, Bailey I. New visual acuity chart for clinical research. Am. J. Opthalmol. 1982;94:91-96.

6. Strong G, Woo G. A distance visual acuity chart incorporating some new design features. Arch. Ophthalmol. 1985;103:44-46.
7. Williams MA, Moutray TN, Jackson AJ. Uniformity of Visual Acuity Measures in Published Studies. Invest. Ophthalmol. Vis. Sci. 2008;49(10):4321-4327.
   DOI: https://doi.org/10.1167/iovs.07-0511.
8. McMonnies CW, Ho A. Letter legibility and chart equivalence. Ophthal.& Physiol. Opt. 2000;20(2):142-152.
9. Mathew JA, Sabah SA, Simon JW. Varying Difficulty of Snellen Letters and Common Errors in Amblyopic and Fellow Eyes. Arch Ophthalmol. 2011;129(2):184-187.
10. Cooke MD, et al. An innovative visual acuity chart for urgent and primary care settings: validation of the Runge near vision card. Eye; 2019. Available:https://doi.org/10.1038/s41433-019-0372-8
11. Arditi A, Cagenello R. On the statistical reliability of letter chart visual acuity measurements. Investigative Ophthalmology and Visual Science. 1993; 34(1):120-129.
12. Raasch TW, Bailey IL, Bullimore MA. Repeatability of visual acuity measurement. Optom. Vis. Sci. 1998;75: 342-348.
13. Sánchez-González MC, García-Oliver R, Sánchez-González JM, Bautista-Llamas MJ, Jiménez-Rejano JJ, De-Hita-Cantalejo C. Minimum Detectable Change of Visual Acuity Measurements Using ETDRS Charts (Early Treatment Diabetic Retinopathy Study). Int. J. Environ.Res. Public Health. 2021;18: 7876. Available:https://doi.org/10.3390/ ijerph18157876
14. Hirvela¨ H, Koskela P, Laatikainen L. - Visual acuity and contrast sensitivity in the elderly. Acta Ophthalmol Scand. 1995;73: 111–115.
15. Andrew Kc Lam, Cecilia Tong, Jimmy Tse, Man Yu. Repeatability of near visual acuity measurement at high and low contrast, Clinical and Experimental Optometry. 2008;91(5):447-452.
   DOI: 10.1111/j.1444-0938.2007.00235.x
16. Mohammed I, Amer A. A Study of Contrast Sensitivity Evaluation in Young Adults and Elderly People With and Without Diabetes Mellitus. 2018;67-76.
17. Mäntyjärvi M, Laitinen T. Normal values for the Pelli-Robson contrast sensitivity test. J Cataract Refract Surg. 2001;27(2):261-6.
   DOI: 10.1016/s0886-3350(00)00562-9
18. Elliott DB, Whitaker D, Bonette L. Differences in the legibility of letters at contrast threshold using Pelli-Robson chart. Ophthalmic Physiol Opt. 1990;10: pp.323–326
19. Elliott DB, Pesudovs K, Mallinson T. Vision-related quality of life. Optom Vis Sci. 2007;84(8):656-8.
   DOI: 10.1097/OPX.0b013e31814db01e
20. Parede Tais, Torricelli Andre, Mukai Adriana, Netto Marcelo, Bechara Samir. Quality of vision in refractive and cataract surgery, indirect measurers: Review article. Arquivos Brasileiros de Oftalmologia. 2013;76:386-90.
   DOI:10.1590/S0004-27492013000600016.
21. Simon Winter, Mohammad Taghi Fathi, Abinaya Priya Venkataraman, Robert Rosén, Anne Seidemann, Gregor Esser, Linda Lundström, Peter Unsbo. Effect of induced transverse chromatic aberration on peripheral vision. J. Opt. Soc. Am. 2015;A 32:1764-1771.
22. El-Kadouri A, Charman WN. Chromatic aberration in prismatic corrections. In the Frontiers of Optometry, Vol. 2 (ed W. N. Charman). British College of Ophthalmic Opticians, London, UK. 1984;154-160.
23. Sun Wen-Shing, Tien Chuen-Lin, Sun Ching-Cherng, Lee Ching-Chun. A Low-cost Optimization Design for Minimizing Chromatic Aberration by Doublet Prisms. Journal of the Optical Society of Korea. 2012;16.
   DOI: 10.3807/JOSK.2012.16.4.336.
24. Winter S, Fathi MT, Venkataraman AP, Rosén R, Seidemann A, Esser G, Lundström L, Unsbo P. Effect of induced transverse chromatic aberration on peripheral vision. J Opt Soc Am A Opt Image Sci Vis. 2015;32(10):1764-71.
   DOI: 10.1364/JOSAA.32.001764.
25. Fonseka CMR, Obstfeld H. Effect of the constringence of afocal prismatic lenses on monocular acuity and contrast sensitivity Ophthal. Physiol. Opt. 1995;15:73-78.
26. Davis JK, Clotar G. An approach to the problem of a corrected curve achromatic cataract lens. Am. J. Optom. Arch. Am. Acad. Optom. 1956;33:643-660.
27. Amigo-Frances A, Castillo-Gomez A, Carmona-Gonzalez D, Martinez-Sorribes P, Amigó A. Comparative study of visual

results obtained with two Trifocal lens models in cataract surgery. J Clin Res Ophthalmol. 2020;7(2):054-060. DOI: 10.17352/2455-1414.000074
28. Meslin D, Obrecht G. Effect of chromatic dispersion of a lens on visual acuity. Am. J. Optom. Physiol. Opt. 1988;65:25-28.
29. Fernadez EJ, Artal P. Achromatic doublet intraocular lens for full aberration correction Biomedical Optics Express. 2017;8(5).
30. Jalie M. Use, and abuse, of high refractive index media. Optician. 1987;194:16-20.
31. Holladay T. Proper method for calculating average visual acuity. Journal of Refractive Surgery. 1997;13:388-391.
32. Tiew S, Lim C, Sivagnanasithiyar T. Using an excel spreadsheet to convert Snellen visual acuity to LogMAR visual acuity. Eye. 2020;34:2148–2149 Available:https://doi.org/10.1038/s41433-020-0783-6
33. Millodot M, Thibault C. Variation of astigmatism with accommodation and its relationship with dark focus. Ophthal. Physiol. Opt. 1985;5:297-301.
34. Rosenfield M, Chiu NN. Repeatability of subjective and objective refraction. Optom. Vision Sci. 1995;72:577–579.
35. Radhakrishnan Hema, Charman W. Changes in astigmatism with accommodation. Ophthalmic & Physiological Optics: The Journal of the British College of Ophthalmic Opticians (Optometrists). 2007;27:275-80. DO: 10.1111/j.1475-1313.2007.00474.x.
36. Strang NC, Atchison DA, Woods RL. Effects of defocus and pupil size on human contrast sensitivity. Ophthal. Physiol. Opt. 1999;19:415–426.
37. Zhang L, Pelli DG, Robson JG. The effect of luminance, distance, and defocus on contrast sensitivity as measured by the Pelli-Robson chart. Invest Ophthalmol Vis Sci. 1989;30(suppl):406-126.
38. Venkataraman AP, Winter S, Unsbo P, Lundström L. Blur adaptation: Contrast sensitivity changes and stimulus extent. Vision Research. 2015;110(Pt A):100–106. Available:https://doi.org/10.1016/j.visres.2015.03.009
39. Pelli DG, Robson JG, Wilkins AJ. The design of a new letter chart for measuring contrast sensitivity. Clin. Vision Sci. 1988; 2:187–199.
40. Woods LR, Strang CN, Atchison AD. Measuring contrast sensitivity with inappropriate optical correction .Ophthal. Physiol. Opt. 2000;20:442-451.
41. Reeves BC, Wood IM, Hill AR. Reliability of high- and low-contrast letter charts. Ophthalmic and Physiological Optics. 1993;13:17-26. Available:https://doi.org/10.1111/j.1475-1313.1993.tb00421.x
42. Sukha A, Rubin A. Test–retest reliability of contrast visual acuities in a clinical population. African Vision and Eye Health. 2017;76(1):9. Available:https://doi.org/10.4102/aveh.v76i1.376
43. Osman M, Njeru SM, Hopkins GR 2nd, Brown AM. Test-retest Repeatability of the Ohio Contrast Cards. Optom Vis Sci. 2021;98(9):1070-1077. DOI: 10.1097/OPX.0000000000001771
44. Elliott DB, Bullimore MA, Bailey IL. Improving the reliability of the Pelli-Robson contrast sensitivity test. Clin. Vis. Sci. 1991;6:471-475.
45. Njeru SM, Osman M, Brown AM. The Effect of Test Distance on Visual Contrast Sensitivity Measured Using the Pelli-Robson Chart. Trans. Vis. Sci. Tech. 2021;10(2):32. DOI: https://doi.org/10.1167/tvst.10.2.32.
46. Pelli DG, Bex P. Measuring contrast sensitivity. Vision Research. 2013;90:10–14. Available:https://doi.org/10.1016/j.visres.2013.04.015
47. Rubin GS, West SK, Muñoz B, Bandeen-Roche K, Zeger S, Schein O, Fried LP. (1997) A comprehensive assessment of visual impairment in a population of older Americans. The SEE Study. Salisbury Eye Evaluation Project. Invest Ophthalmol Vis Sci.;38(3):557-68
48. Gupta P, Vu TA, Lamoureux EL. Beyond visual acuity-a comprehensive assessment of vision and cognition in older adults with visual impairment. JAMA Netw Open. 2021;4(7):e2119033. DOI:10.1001/jamanetworkopen.2021.19033.
49. Balcer LJ, et al. Validity of low-contrast letter acuity as a visual performance outcome measure for multiple sclerosis Multiple Sclerosis Journal. 2017;23(5). Available:https://doi.org/10.1177/1352458517690822
50. Schinzel J, Zimmermann H, Paul F, et al. Relations of low contrast visual acuity, quality of life and multiple sclerosis

functional composite: a cross-sectional analysis. BMC Neurol. 2014;14:31. Available:https://doi.org/10.1186/1471-2377-14-31
51. Regan D, Neima D. Low-contrast letter charts as a test of visual function. Ophthalmology. 1983;90(10):1192-1200.
52. Wright D, Firth AY, Buckley D. Comparison of the visual effects of Fresnel prisms in normal and amblyopic eyes. J AAPOS. 2008;12(5):482-6.
DOI: 10.1016/j.jaapos.2008.03.015
53. Cheng D, Woo GC. The effect of conventional CR39 and Fresnel prisms on high and low contrast acuity. Ophthalmic Physiol Opt. 2001;21(4):312-6.
DOI: 10.1046/j.1475-1313.2001.00570.x.
54. Tang CY, Charman WN. Effects of monochromatic and chromatic oblique aberrations on visual performance during spectacle lens wear. Ophthal. & Physiol. Opt. 1992;12:340-349.
55. Chandrinos A. A Review of polymers and plastic high index optical materials. Journal of Materials Science Research and Reviews. 2021;7(4):1-14.

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