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The practical near acuity chart (PNAC) and prediction of visual ability at near[1]

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Summary

Objective: To improve on present reading chart designs, providing a quick and accurate method to measure the near acuity threshold, of particular importance with low vision patients.

Design: The Practical Near Acuity Chart (PNAC) uses a single paragraph with 3 simple related words on each line (12 lower case letters). The line print size decreases in a logMAR progression (N80-N5).

Methods: The time taken to measure near acuity of 53 subjects aged 9–91 years with the PNAC and Bailey–Lovie near chart was recorded and compared to their distance acuity (Bailey–Lovie chart), contrast sensitivity (Melbourne Edge Test) and ability to read extracts of newsprint.

Results: There was no difference in near acuity threshold using related or un-related words. There was a high correlation ($r = 0.97$) between near acuity measured with the PNAC and Bailey–Lovie charts. However, the time taken to measure near acuity was significantly faster with the PNAC (32 ± 2 s vs 76 ± 4 s, $p < 0.001$). Near acuity measured with either chart was highly correlated ($p < 0.001$) to distance acuity ($r = 0.74$), contrast sensitivity ($r = 0.62$) and ability to read newsprint ($r = 0.87$). The PNAC was shown to have high test-reliable ($r = 0.99$).

Conclusions: The PNAC offers a quick but accurate way to measure near acuity and shows a high degree of correlation with distance acuity, contrast sensitivity and the ability to read newsprint. © 2000 The College of Optometrists. Published by Elsevier Science Ltd. All rights reserved.

Introduction

There are many different types of reading cards designed to measure the near acuity threshold. This is an important measure of visual function as many visually demanding tasks are performed close to the eyes

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and certain eye conditions can affect near and distance visual resolution differently, particularly if areas of the visual field are distorted or absent (Sloan and Brown, 1963). For normally-sighted individuals, most printed materials encountered in everyday life are well within the limit of resolution (N5 at 25 cm is roughly equivalent to 6/15 at distance for example) and measurement of near visual acuity is not critical. Visual impairment significantly affects near acuity and limits the ability to perform near visual tasks, which are of prime importance to low vision patients (Kleen and Levoy, 1981). Thus near acuity becomes of critical importance, particularly in the way it relates to the ability to perform

visual tasks and hence enables people to have a high quality of life. Near vision prescribing decisions, especially in the form of magnifying aids, also hinge on near visual acuity findings.

Present designs of reading cards are often slow to establish a near acuity threshold, especially with those who have reduced vision, poor language or cognitive skills and often lack realism to commonly performed near tasks. They have features to measure the acuity threshold such as print sizes smaller than N5, equal number of words and letters on a line, a regular progression of print sizes and using un-related words. Many also incorporate features designed to make the task relevant to visual ability for near tasks such as using extracts from telephone books or music, using words rather than letters, and using related word paragraph designs. This conflict between measuring practical ability or threshold near visual acuity was noted as early as Lebensohn (1958), during a period when much attention was paid to the design of near charts.

For example, the Fonda–Anderson reading card has 8 print sizes between N4 and N24 with everyday near task samples (such as a telephone directory and music) on the reverse side (Fonda and Anderson, 1988). However, it does not cover the upper ranges of near acuity threshold which are commonly needed for visually impaired patients. The Bailey–Lovie near chart (Bailey and Lovie, 1980) has been a very successful tool for measuring near acuity threshold in low vision patients. However, clinical experience suggests that it can be slow to perform with children and those with poor language, reading or cognitive skills. Due to its compact nature, starting mid-chart is difficult for many patients and larger print sizes have less words, compromising the "equality of task" for each acuity level.

The velocity of reading is important to note as the slowing of speed can be taken to indicate the limit of the reserve of resolving power (Flom, 1966). Snellen acuity has been found to account for 10% of the variance in reading speed (clinical predictors only accounting for about 30% in total), with age being a better predictor (Legge *et al.*, 1992). Reading speed decreases significantly with the level of impairment, with optimal speed requiring print size of 4× the acuity threshold and 20 times the contrast threshold (Bowers and Reid, 1997). Several reading charts have been designed with supra-threshold print to determine reading speed alone (not near acuity threshold) as this had been shown to be highly correlated to the ability to perform common near tasks such as reading newsprint (Baldasare *et al.*, 1986; Ahn *et al.*, 1995). However, the print size at which reading becomes laboured can be easily noted by the examiner and physical measurement of reading speed at different near acuity

levels, such as with the MnRead chart (Ahn *et al.*, 1995), is time consuming.

One of the main reasons why near acuity in the consulting room can be misleadingly good (Cullinan *et al.*, 1979) is due to the high luminance of the chart and the high contrast of the print (typically >90%). Visual acuity has been shown to decrease with decreasing luminance, although the reduction in contrast sensitivity is more severe (Rabin, 1994). The quality of paper can have a significant effect on the visibility of print type, especially with newspapers which tend to yellow with age. Sloan (1957) reviewed the effects of illumination and contrast on visual acuity showing they are highly correlated. Increasing contrast and or illumination allows significantly improved reading ability. Differences in distance and near acuity can occur due to factors such as the effect of ocular pathology and smaller (lower-case) letter separation on reading cards compared to (usually capital letter) distance charts (Sloan and Brown, 1963).

The basic principle of measuring visual acuity with letter test charts is that the smallest letters which can just be read satisfactorily provide an index of visual acuity. Letters are a suitable optotype for testing visual resolution, but despite suggestion that visual demand of letters is equivalent if they are lowercase and equal in width and height (Sloan, 1957; Lebensohn, 1958), more recent studies have found legibility of lowercase letters to be variable (Elliott *et al.*, 1990; Alexander *et al.*, 1997). Bailey and Lovie (1980) used lower case "Times Roman" typeface words as it is that customarily used in newspapers and books. The style of typeface can influence the legibility of print (Mansfield *et al.*, 1996), although the perceptual system appears to become tuned to the regularities of a particular font to process visual information efficiently (Sanocki, 1988).

The aim of this study was to develop a Practical Near Acuity Chart (PNAC) which can establish a low vision patients near acuity as accurately as presently available charts, but in less time. Its sensitivity in predicting the ability to read newspaper, the most common task affected by visual impairment, was also assessed along with the relationship of distance acuity and peak contrast sensitivity (as visual tasks are often of low to moderate contrast) with the PNAC acuity.

Design features

Bailey and Lovie (1976) advocated that the reading task of a near chart should be essentially the same at each print size level. It is important that reading cards cover a wide enough range of reading sizes to encompass those with good and poor vision. The progression of print sizes should be regular, the logarithmic scale being preferred (Sloan, 1957; Bailey and Lovie, 1976).
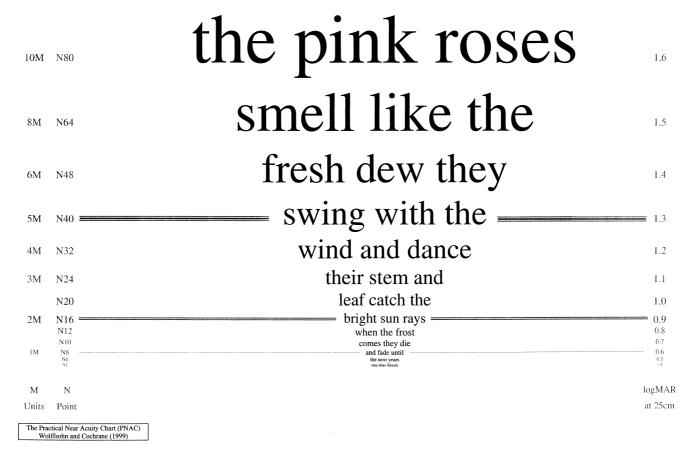
10M	N80	the pink roses	1.6
8M	N64	smell like the	1.5
6M	N48	fresh dew they	1.4
5M	N40	════════ swing with the ════════	1.3
4M	N32	wind and dance	1.2
3M	N24	their stem and	1.1
	N20	leaf catch the	1.0
2M	N16	════════ bright sun rays ════════	0.9
	N12	when the frost	0.8
	N10	comes they die	0.7
1M	N8	─────── and fade until ───────	0.6
	N6	the next years	0.5
	N5	one does bloom	0.4
M	N		logMAR
Units	Point		at 25cm

The Practical Near Acuity Chart (PNAC)
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Figure 1. The PNAC. The chart allows rapid and accurate measurement of the near acuity threshold. The opposite side (not shown) has columns of common print sizes for practice reading a particular size of print once the near acuity threshold has been determined.

The separation between successive lines should be in relation to the acuity size of the print to maintain the resolution demand of the words. Also, the number of words and letters on each line should be kept constant to maintain the lines as an equivalent task and to keep variability at a minimum (Raasch *et al.*, 1998). The PNAC was designed to incorporate these important acuity chart features.

1. The PNAC encompasses print sizes from large (N80, such as newspaper headlines) to small (N5, such as a telephone directory entries). Print sizes smaller than N5 were not included to avoid demoralisation of patients (at seeing how many lines they are not able to read) and due to the practical irrelevance of smaller sizes of print (*Figure 1*). Near acuity threshold cannot be measured by the PNAC for normally sighted observers therefore, due to floor effects.

2. A regular decreasing progression of print size and line spacing (0.1 logMAR) was used. "N point" notation was used as well as logMAR notation as it specifies a size (each point size is 1/72 of an inch) and is thus independent of distance (which should be recorded alongside the N point). It has also become the standard unit of print size with computers, which are responsible for the production of many near-work tasks. M units (1 M is equivalent to N8) devised by Louise Stone (Sloan and Brown, 1963) were also included.

3. Equal numbers of words were used on each line (three). The Bailey–Lovie near chart attempted to have equal numbers of words and letters on each line, but failed to manage this for larger print sizes due to space restrictions.

4. One three letter word, one four letter word and one five letter word was used on each line. Thus each line has an equivalent task demand having 12 letters split into 3 words. It is suggested that the five letter word should be scored at 0.04 logMAR, with the four and three letter words scored at 0.03 logMAR (adding to 0.10 logMAR units for each line).

5. Related words sequences were established to make the task of establishing a near acuity threshold less onerous, more practical and relevant. Using related words in a near chart was shown to give a similar acuity threshold to using un-related words (see

Appendix A). Several word sequences for the chart have been printed to prevent learning effects with repetition.

6. The words used are easy to recognise by children (chosen from internet English word lists to be in the vocabulary of children in grade 4, aged 9, and above) and those with poor language and cognitive skills. Patients with poorer English (such as immigrants) appear to struggle with longer, less commonly used English words such as the 10 letter words found on the Bailey–Lovie near chart.

7. The PNAC uses "Times Roman" font as it is a print type commonly used in newspapers and books and was designed to have a high level of legibility and proportionality. Lower case letters were used and punctuation excluded to minimise irregularities in acuity demand and clutter.

8. Paragraphs of the most commonly used print sizes are located on the reverse side of the chart so reading a set size of print can be practiced once the near acuity threshold has been established. These passages can be used to determine reading speed and fluency.

Method

Subjects consisted of 53 visually impaired patients from the Association for the Blind's Kooyong low vision clinic. They ranged in age from 9–91 years old (median age 80 years). Subjects had a wide range of visual conditions causing visual impairment (*Table 1*). The project was approved by the Institutional review boards of the Vision Australia Foundation and the Victoria College of Optometry.

Subjects wore their best distance visual correction mounted in a trial frame. Distance visual acuity was measured monocularly on a Bailey–Lovie distance chart back-lit to a luminance of 160 cd/m^2. A +4.00D near addition was then inserted into the trial frame and the near acuity was measured monocularly at 25 cm using the PNAC chart and the Bailey–Lovie near chart in a randomised order.

Subjects were asked to read from the top of the chart, stopping when they could no longer manage any of the words on a line, even at a guess. They were unaware that the time taken to complete the measurement was recorded (to the nearest second), to prevent reading pressure or rushing. Subjects were also required to attempt to read newspaper extracts mounted on white card, with the smallest print that they could manage with effort being recorded (as 1–6). All the reading tasks were performed under the same illumination (550 lux). Six sizes were used, representing the sizes of newsprint commonly found, with lower case letter heights of:

1. 1 mm—Classified advertisements ~N5
2. 2 mm—Normal text ~N8
3. 3 mm—Large text ~N16
4. 5 mm—Sub-headline ~N32
5. 1 4 mm—Main headline ~N80
6. 2 0 mm—Front page headline > N80

The subjects contrast sensitivity was measured using the Melbourne Edge Test (MET). The chart was held at 40 cm with a luminance of 47 cd/m^2 and subjects were required to identify the direction (either vertical, horizontal, sloping left or sloping right) of the edge separating the lighter from the darker half of each circle (Greeves *et al.*, 1987). The contrast difference between the circles progressively decreases and the threshold is reached when two successive plates are scored incorrectly (recorded in decibels).

Test–retest reliability was measured in a subset of 8 patients (16 eyes) whom were found to have a near acuity in each eye between N6 and N80. Their near acuity threshold was measured four time with PNAC charts of different texts.

Statistical analysis

Multivariate analysis correlation coefficients were

Table 1. Primary conditions causing visual impairment (*n* = 53)

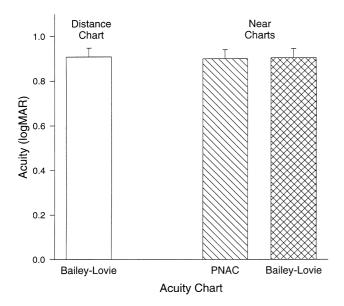| Primary condition causing visual impairment	Subjects with condition (%)
Atrophic age-related macular degeneration	52.8
Exudative age-related macular degeneration	13.2
Albinism	7.5
Diabetes	7.5
Glaucoma	3.8
Nystagmus	3.8
Cataracts (senile)	3.8
Cerebral vascular accident	1.9
Retinitis pigmentosa	1.9
Other	3.8

Figure 2. Mean acuity of subjects for distance, PNAC and Bailey–Lovie near charts. There was found to be no difference between the acuities measured (n = 94) eyes. Error bars=1 SEM.
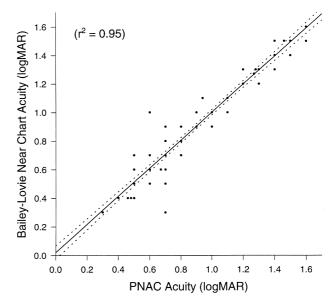

Figure 3. Comparison of visual acuity measured using the PNAC and Bailey–Lovie near chart. There was a strong correlation between the two charts (r = 0.97, n = 94 eyes). Dotted lines indicate 95% confidence limits.

calculated between measures and the bias between measures (the mean difference and its standard deviation and 95% confidence limits) were calculated as suggested by Bland and Altman (1986) and compared to zero using a one-sample t-test. Comparison between means were performed using paired t-tests.

Results

Twelve subjects had one eye with which they were unable to read N80 print at 25 cm with a +4.00D near addition and therefore the data from that eye was not included in the analysis. Analysis of the data using the better eye or worse eye of each subject was shown to be identical and therefore the data was merged. Distance visual acuities ranged from 6/6 to $2/60^{-1}$ with a mean of 6/48 (0.91 ± 0.04 logMAR; *Figure 2*). Near acuity measured by the PNAC chart was highly correlated to distance acuity (r = 0.74, p < 0.001; bias mean difference -0.01 ± 0.28 logMAR, difference from zero p = 0.77, 95% confidence interval = 0.06) suggesting that near acuity can be predicted to a large degree from a persons distance acuity. This finding is in agreement with previous findings (e.g., Lebensohn, 1958) which also showed a close correlation between best corrected distance and near visual acuity in those with no accommodation.

The near acuity threshold measured by PNAC and Bailey–Lovie near chart were highly correlated (r = 0.97, p < 0.001; bias mean difference = 0.00 ± 0.09 logMAR, 95% confidence interval = 0.02; *Figure 3*). This

was the case both for smaller print size acuities $\leqslant 1.0$ logMAR (bias mean difference = 0.01 ± 0.06 logMAR, 95% confidence interval = 0.03) and for larger print size acuities > 1.0 logMAR (bias mean difference = 0.00 ± 0.09 logMAR, 95% confidence interval = 0.02). None of these mean difference between the near acuity threshold measured by PNAC and Bailey–Lovie charts were significantly different from zero (p = 0.63, p = 0.61, p = 0.96, respectively; *Figure 2*). The correlations between the PNAC or Bailey–Lovie near chart and distance visual acuity, contrast sensitivity or the ability to read newsprint print were similar, supporting this finding. The near acuity threshold was measured faster using the PNAC chart compared to the Bailey–Lovie near acuity chart in every subject, on average in under half the time (32.0 ± 1.8 s vs 76.1 ± 4.0 s, p < 0.001).

Near acuity measured using the PNAC chart was highly correlated to the ability to read newsprint print (r = 0.87, p < 0.001). Therefore, although other factors such as the contrast sensitivity play a role in determining how well newsprint print is distinguished (r = 0.64), near acuity threshold would appear to be the principal determinate. *Table 2* shows the percentage of subjects able to read the different sizes of newsprint extracts with respect to the near visual acuity measured by the PNAC. Sharp cut off values are shown, so a patient with a near acuity of N16 (0.9 logMAR) should be able to read large text (75% chance), whereas someone with a near visual acuity of N32 (1.2 logMAR is unlikely to be able to (only an 8% chance). This result would partly be expected due to the limited

Table 2. The percentage of eyes with a certain PNAC acuity that can manage newsprint of a set size (1: classified advertisements; 2: normal text; 3: large text; 4: sub-headlines; 5: main headlines; 6: front page headlines, $n = 94$ eyes)

Near acuity (logMAR)	No. of eyes	Eyes that can read newsprint type (%)					
		1 (N5)	2 (N8)	3 (N16)	4 (N32)	5(N80)	6 (<N80)
0.4–0.5	22	59	91	100	100	100	100
0.6–0.7	25	16	64	96	100	100	100
0.8–0.9	8	13	25	75	100	100	100
1.0–1.1	8	0	0	25	88	100	100
1.2–1.3	13	0	0	8	16	100	100
1.4–1.5	14	0	0	0	14	93	100
1.6+	4	0	0	0	0	0	100

number of sizes of newsprint used, although the data is helpful in interpreting how well a subject should perform at reading newspaper print, given their particular near acuity threshold. Near acuity measured with the PNAC chart was also highly correlated to the contrast sensitivity measured with the Melbourne Edge Test ($r = 0.62$, $p < 0.001$). Thus patients with conditions causing visual impairment are also likely to have reduced ability to discriminate lower contrast targets, therefore being further impaired.

Test–retest reliability was found to be high ($r = 0.99$) with no more than 1 line difference between near acuity measures.

Conclusions

The Practical Near Acuity Chart (PNAC) establishes the near visual acuity threshold in an accurate and reliable manner. Although the PNAC only uses 3 words on each line, it was shown to be as accurate as the Bailey–Lovie near chart, both for larger print sizes where less words are used and smaller sizes where more words are used by the Bailey–Lovie near chart. This suggests that the use of 3 words (12 letters) at each print size level is adequate for establishing an accurate reading threshold. It also allows a systematic scoring method to be used enabling increased sensitivity in those cases where not all the words on a line can be read.

The PNAC will assist eye-health professionals in their need to establish a near visual acuity threshold quickly and accurately, to monitor disease, determine visual status and to assess the need for low vision rehabilitation. It is also essential to determine what difficulties a patient may be experiencing or is likely to have and to assist in calculating the most suitable form of magnification that will assist them. Near acuity threshold was measured in half the time using the PNAC than the Bailey–Lovie chart. This result was similar to Lovie's finding that un-related words slowed reading time by almost double compared to re-

lated words (Lovie, 1976; Latham and Whitaker, 1996). However, the number and length of words will also be a factor between the time taken to establish a near acuity threshold with the PNAC or Bailey–Lovie near acuity chart. The Bailey–Lovie chart has approximately 1.3 times as many words and 2.5 times as many letters as the PNAC chart between acuities of N80 and N5. Subjects needn't be asked to read from the top with a reading chart. However, starting from the lowest line they can manage or from a set sentence can be difficult especially in crowded text, even with the reference lines provided on the Bailey–Lovie near chart.

Although the distance visual acuity was correlated to the ability to read newsprint ($r = 0.77$), the correlation between reading newsprint and the PNAC threshold was higher ($r = 0.87$). This finding suggests that much information about ability to read newsprint can be discerned from the near visual acuity. The mean distance visual acuity in logMAR notation had a similar value to the mean near acuity (measured by the PNAC or Bailey–Lovie near chart). Therefore the formula of dividing the denominator of the distance visual acuity Snellen fraction by three to give the near acuity at 25 cm in "N" point notation would appear to hold for this low vision population.

Un-related words are not necessary for accurate measuring of near threshold and therefore near charts can use the more natural paragraph style design. This approach makes sense as even if people have widely differing reading styles, they are likely to use the same approach whether the words are related or not. It was found that most people can read newspaper headlines with a near acuity of N48 (1.4 logMAR), large text (such as children's books) with N20 (1.0 logMAR) and normal newspaper text with N6 (0.5 logMAR) or better at 25 cm. The ability to read the very smallest size of print such as that found in telephone directories and classified advertisements (N5 at 25 cm, 0.4 logMAR) was only managed by approximately 60% of those with better than N6 ($\leqslant$0.5 logMAR) near acuity. This difficulty in reading small print is restricted by

poor quality and sometimes coloured paper, which reduces the contrast of the print. Emphasis on the need for close focal lighting (inverse square law of illumination) is the best method for trying to overcome this impairment. However, some patients will need extra magnification (preferably internally illuminated) to improve their near acuity adequately to perform such a fine detailed task, such as those with age-related macular degeneration (Eldred, 1992). The near acuity thresholds measured in this study are likely to be better than those found in the home due to poorer lighting conditions in the living environments of the elderly (Cullinan *et al.*, 1979). However, all the correlation comparisons should still hold as the reading measures will be similarly affected by decreased luminance.

In conclusion, the PNAC offers a rapid and reliable method of establishing the near visual acuity threshold in the visually impaired. This measurement is crucial to our understanding of their visual abilities and allows us to provide suitable rehabilitation, offering them an improved quality of life.

Acknowledgements

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Appendix

An important issue in determining whether a new reading chart could be designed to establish the near acuity threshold in a faster time is whether charts using un-related words establish a different threshold than charts using related words. Bailey and Lovie (1980) state that their experience had led them to believe that un-related words rather than sentences were better for testing the visual capacity for reading. More recent data on contextual effects on reading (e.g., Latham and Whitaker, 1996) suggest that context does enhance reading rate, but the amount depends on whether central vision is used for fixation. Contextual clues may result in an overestimation of the reading
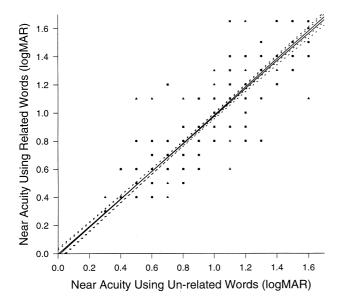
Figure 4. Comparison of near visual acuity (both comfortable ■ and threshold ▲) measured by a chart using related (NVRI magnification chart) or un-related words (Bailey–Lovie near chart). There was a strong correlation between the two methods of measuring comfortable (r^2=0.92) and threshold (r^2=0.90) near acuity (n = 234 eyes). Dotted lines indicate 95% confidence limits.

acuity and assist fluency, even when only some of the letters can be resolved. They also noted that using continuous text led to wide individual variation in reading behaviour that was not related to visual ability, although they gave no scientific data to support these claims. On the other hand, reading with contextual clues is a more normal reading task.

Lovie (1976) showed that reading acuity of un-related words was correlated with distance letter chart acuity (both projected and externally illuminated) whereas continuous text was only weakly correlated with a projected distance letter chart. However,

reading time for unconnected words was about twice as long as for paragraphs of text. Unfortunately only a small number of subjects with only one condition causing visual impairment were examined. Her near chart also only measured near acuities up to 0.95 logMAR (N18@25 cm), so that many subjects had to use a magnifier to see the print confounding the study. Lebensohn (1958) also suggested the pitfalls of context and word configuration could be avoided by using unconnected words composed wholly of lower-case letters. It was therefore important to firstly re-examine the issue of whether un-related words are necessary to measure the true near acuity threshold.

The clinic files of 256 low vision patients aged 6 to 101 years old (median 80 years) with a range of distance acuities from 6/7.5 to 1/60 were reviewed respectively. Near acuity data from the Bailey–Lovie and National Vision Research Institute (NVRI) magnification near chart (held at 25 cm under an illuminance of 550 lux, read with the best distance correction and a +4.00D near addition) was recorded for each subject. The two charts share many of the same design characteristics such as the logMAR progression of print sizes and line spacing. However, the NVRI magnification chart has paragraphs of related words (varying in difficulty and length with a mixture of lower and upper case letters and punctuation) compared to the Bailey–Lovie logMAR near chart, which uses un-related lower-case words.

There was a high correlation (r = 0.94; bias mean difference = 0.02 ± 0.13 logMAR) and no significant difference (0.79 ± 0.37 vs 0.78 ± 0.35; p = 0.62) between near acuity threshold measured using either a Bailey–Lovie near acuity chart or NVRI magnification chart. Data for both comfortable and threshold near acuities are given in *Figure 4*.