Original Article

A standardized logarithm of the minimum angle of resolution visual acuity chart in Hindi

Ananth Sailoganathan[1,2], Ebi Peter Osuobeni[1], John Siderov[1]

Purpose: The purpose of this study to develop and calibrate a new Hindi logarithm of the minimum angle of resolution (logMAR) visual acuity chart. **Methods:** A new Hindi visual acuity chart was designed to logMAR specifications using Hindi optotypes experimentally selected to have similar relative legibility under equivalent spherical and cylindrical defocus. The chart calibration study was carried out in a large clinical setup in India. Participants who were literate in English and Hindi participated in the study. Visual acuity was measured with the new Hindi logMAR chart and a modified ETDRS (m-ETDRS) logMAR chart. The method of presentation was randomized between the charts. Repeat visual acuity was measured on a subsequent day with a second version of the Hindi logMAR chart. **Results:** The Hindi logMAR chart correlated highly with the m-ETDRS logMAR chart (r^2 = 0.92); however, the mean visual acuity difference (Hindi logMAR-m-ETDRS logMAR) was nearly one and half lines (0.13 logMAR, 95% confidence interval [CI] = ±0.15 logMAR). The Hindi logMAR chart also proved to be highly repeatable (r^2 = 0.99; mean difference 0.005, 95% CI = ±0.04 logMAR). **Conclusion:** This study reports the first standardized visual acuity chart developed in Hindi incorporating equal letter legibility and logMAR chart design features. The Hindi logMAR visual acuity chart provides a valid and repeatable tool for the measurement of visual acuity in native Hindi language speakers. Future use of the new Hindi chart should incorporate an increase in optotype size of 0.13 logMAR.

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The measurement of visual acuity is fundamental to any eye examination and is used to help determine the integrity of the visual system and to monitor the status of ocular disease. Although the use of the Snellen chart format is widespread, the limitations in Snellen acuity charts are widely recognized[1,2] and the use of logarithm of the minimum angle of resolution (logMAR)-based vision charts, with the same number of letters in each row, and equal logarithmic acuity steps between rows are now accepted as the norm when accurate assessment of vision is required for both adults[1,3,4] and children.[5]

A variety of letter charts based on the original logMAR chart format have been designed in a number of different languages including Arabic,[6] Chinese,[7] Indian,[8,9] Thai,[10] a tumbling E version for use with illiterates,[11] and a version for use with native Australian populations.[12] Recently, a modified ETDRS (m-ETDRS) chart[4] has also been developed for use with pan-European patients.[13] The development of such charts is important to provide better methods of assessment of vision in both clinical and research settings but particularly in regions where the prevalence of visual impairment is high.

India has one of the highest recorded rates of visual impairment in the world.[14] Given such obvious eye care needs in India, visual assessment using logMAR vision charts is important for both clinical and research needs. While the use of the ETDRS chart could meet such requirements, logMAR-based vision charts in native Indian languages would be preferred. Recently, new logMAR-based charts in Tamil[9] and Gujarati[8] have been developed and validated. Hindi is one of the world's most commonly spoken languages after Chinese and Arabic.[15] It is estimated to be the native language of more than a third of India's population and many others speak Hindi as a second language,[16] and given the importance of using a visual acuity chart based on accepted standards,[1,3,4] it is surprising that research into the design and calibration of a standardized logMAR-based visual acuity chart in Hindi is limited. Khamar *et al.*[17] developed a logMAR-based chart in Hindi and Gujarati, but their charts have not gained widespread use, possibly due to limitations in their choice of letter optotypes and the lack of validation against an appropriate standard. Although standardized charts exist for use with illiterates,[11] development of standardized visual acuity charts in local languages is important. Therefore, the aim of the present study was to

[1]Department of Vision and Hearing Sciences, Anglia Ruskin University, Cambridge, CB1 1PT, United Kingdom, [2]School of Optometry, National Institute of Ophthalmic Sciences, Tun Hussein Onn National Eye Hospital, 46200 Petaling Jaya, Selangor, Malaysia

Correspondence to: Dr. Ananth Sailoganathan, Department of Vision and Hearing Sciences, Anglia Ruskin University, Cambridge, CB1 1PT, United Kingdom, National Institute of Ophthalmic Sciences, Tun Hussein Onn National Eye Hospital, Lorong Utara B, 46200, Petaling Jaya, Selangor, Malaysia. E-mail: dr.ananth@thoneh.com

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develop and calibrate a new visual acuity chart in Hindi using logMAR principles.

Methods

Experiment one – letter legibility and selection

Protocol

A commonly used Hindi font type in Indian language newspapers and magazines, Jagran, was selected for use. Eighteen Hindi letters were initially selected for measurement of legibility, based on their relative similarity. Digital versions of these optotypes were individually fitted into 5 × 5 grids using standard photo-editing software (Adobe Photoshop™, Edition 6) and scaled so that the height and width of each optotype subtended 5 arc min at 6 m (equivalent Snellen 6/6). To maintain the appearance and therefore their meaning, stroke widths of individual Hindi letters were not modified from their original font. The set of Sloan letters (Z, N, H, R, V, K, D, C, O, and S) was also digitized and each letter scaled to subtend 5 arc min.

The aim of the first experiment was to determine relative letter legibility for both the Hindi and Sloan letters. We followed a procedure described in detail by Strong and Woo[18] using recommended protocols.[1,3,4] Isolated black letters on a white background (Weber contrast of −85%) were presented at the center of a 15-inch color monitor. Participants were first optically defocused using spherical and astigmatic blurring lenses mounted in a trial frame (+1.00DS; +2.00Dcyl, axis 180 and 90). Subsequently, participants were moved slowly from a position where they could not identify the letters, toward the monitor until they could just correctly identify the letter displayed. The distance from the monitor to the participant's eyes was recorded. These distances were converted to relative legibility scores by dividing the distance of correct recognition for an individual letter by the average distance for all of the letters tested.[18,19] The procedure was randomized across the three different defocus conditions and repeated twice for each letter set (Hindi and Sloan). The average distance for each defocus condition was used to calculate the relative letter legibility. Participants were acquainted with the experimental procedure before data collection. One eye, chosen at random, was used for the experiment and the other eye was occluded. Normal room illumination was employed throughout the experimental process. All experimental work was carried out in our university laboratory.

Subjects

Nine adult participants with normal or corrected to normal visual acuity (at least 6/6 in each eye), who were fluent in Hindi and English and who were free from ocular disease, were recruited to the study. The research followed the tenets of the Declaration of Helsinki, and approval of the experimental protocol was obtained from the Institutional Human Research Ethics Committee. Informed consent was obtained from all participants after the nature, and consequences of the study were explained to them.

Results

Experiment one – letter legibility and chart construction

The relative legibility of the Hindi and Sloan letters obtained under each defocus condition is shown in Table 1. To select letters whose relative legibility was most similar, we compared the relative legibility obtained under astigmatic defocus to that obtained with spherical defocus. Fig. 1 plots the percentage difference in relative legibility for each letter under astigmatic defocus (axis 180 and 90) relative to the spherical defocus condition. Most of the astigmatic defocus results are within 10% of the spherical reference condition with 2 Sloan letters and 4 Hindi letters outside of this range.

Letters were selected for inclusion in the new charts on the condition that their percentage legibility difference under cylinder defocus was no more than about 10% of the spherical defocus condition [represented by the broken lines in Fig. 1].[6] This method of analysis yielded 14 letters in Hindi (ल, क, ग, ज, प, ड, फ, त, म, य, न, र, स, ह). On average, the mean recognition distance across the three defocus conditions was greater for the Sloan letters (2.5 m) than the Hindi letters (1.2 m), indicating that the Hindi letters were harder to see compared to the Sloan letters for the same angular size. Although our relative legibility scores for the Sloan letters were similar to previous results,[20] not all of the Sloan letters were equally legible under the different defocus conditions and the letter S was quite a way outside of our criterion range. To maintain equivalence in our comparisons, we omitted the S from our m-ETDRS comparison chart for this reason. Therefore, new Hindi and m-ETDRS logMAR vision charts were constructed using the selected letters as described below [Fig. 2].

Experiment two – chart construction, calibration, and repeatability

Protocol

Based on the results of experiment one, a set of 14 Hindi optotypes was selected to construct the Hindi logMAR chart

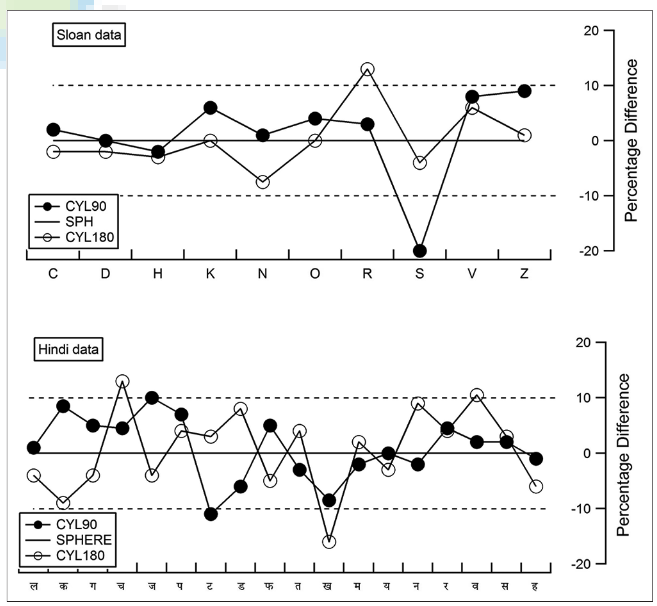

Figure 1: Plotted in the top panel is the percentage difference in relative letter legibility of the astigmatic defocus conditions relative to spherical defocus for the 10 Sloan letters. The bottom panel depicts the same type of data but for the 18 Hindi letters. In both panels, open symbols represent data obtained using astigmatic defocus at axis 180 and closed symbols astigmatic defocus at axis 90. The solid straight line represents the spherical defocus baseline and the broken lines the 10% difference

Table 1: Relative legibility for the original 18 Hindi and 10 Sloan letters selected under spherical (sphere) and astigmatic (cylinder) defocus (axis 180 and 90) conditions. Also shown are the average optotype recognition distances for the two optotype groups (Hindi and Sloan) and defocus conditions

	Hindi				Sloan		
	Sphere	Cylinder 180	Cylinder 90		Sphere	Cylinder 180	Cylinder 90
ल	1.05	1.06	1.04	Z	1.08	1.07	1.18
क	1.05	1.14	0.97	N	1.07	1.15	1.06
ग	1.01	1.05	0.96	H	0.95	0.98	0.97
ज	1.01	1.05	0.95	R	1.00	0.87	0.93
प	0.96	0.92	0.89	V	1.03	0.97	0.95
फ	0.98	1.05	0.95	K	0.99	0.99	0.93
त	1.00	0.94	1.03	D	0.93	0.95	0.93
म	0.98	0.96	1.00	C	0.95	0.97	0.93
न	0.99	0.90	1.01	O	0.90	0.90	0.86
र	1.10	1.06	1.05	S	0.96	1.00	1.15
व	0.95	0.85	0.93				
स	1.02	1.01	1.00				
ह	0.98	1.05	0.99				
य	0.95	0.98	0.95				
च	0.94	0.82	0.90				
ड	1.00	0.90	1.04				
ट	1.00	0.97	1.11				
ख	0.95	1.10	1.03				
Average distance (m)		1.2				2.5	

Figure 2: The new Hindi logarithm of the minimum angle of resolution chart used in the experiments (version 1) is depicted. For clarity, the chart is shown in its nonmirror format as it would appear to the patient

and a set of 9 Sloan letters to construct a m-ETDRS. Two versions of the Hindi chart were produced for calibration and repeatability. The two versions were identical except that the order of letter presentation was different in each. All charts were constructed for a 6 m test distance (using a mirror) based on principles previously described[1] and comprised 14 rows of 5 letters beginning with logMAR 1.0 and decreasing in 0.1 log steps to logMAR −0.3 [Fig. 2]. The average relative legibility for each row was controlled by arranging letters to ensure consistency of row legibility. This resulted in inter-row average relative legibility variation not >9% between rows in the Hindi chart and 5% for the m-ETDRS chart. Rows were labeled with the Snellen fraction and logMAR equivalent. The charts were printed onto high-quality matt white vinyl plastic sheets that could be rolled up for ease of transport and measured approximately 105 cm × 85 cm. The Weber contrast between letter and background was −90% for all charts.

For consistency, all measurements were obtained by a single experienced optometrist at a 6 m test distance using a polished ophthalmic mirror. For each participant, measurement of monocular (either right or left eye) uncorrected visual acuity was obtained using the m-ETDRS and version 1 of the Hindi chart (Hindi 1). The fellow eye was occluded. Participants were asked to read the letters beginning from the top left side of the chart and continue to their limit of recognition. Pointing to the letters was not used. The end point was reached when the participants read three or more letters incorrectly on any given line (>50%). The end point visual acuity was taken as the visual acuity of the previous line read (i.e. at least three letters read correctly) and each correctly read letter was scored as 0.02 logMAR. The order of chart presentation was randomized between participants. For each individual participant, measurements were repeated on another day on the same eye but using the second version of the Hindi logMAR chart (Hindi 2). Data were recorded on separate record sheets, and the results of the first measurements were not referred to during the repeatability phase of the study. All experimental work was carried out on location in a hospital setting in India and completed within a period of 2 weeks. Data were analyzed using parametric statistics (Student's *t*-test and Pearson correlation), using a standard statistical package (STATISTICA™ StatSoft, Tulsa, OK). Repeatability of measurements was assessed by obtaining the difference between test and retest measurements of visual acuity and determining the 95% limits of agreement following the method of Bland and Altman.[21]

Subjects

Two hundred and fifty adult participants from a hospital population aged between 21 and 80 years (158 males and 92 females) who were literate in English and Hindi with unaided vision of not <6/60 and with no history of trauma or surgery were recruited to the study. Participants were not preselected in any other way and those who met the selection criteria and consented to the protocol were recruited. This sample size was sufficient to determine a difference in visual acuity measurements between the various charts of 0.1 logMAR (power 80% with $P < 0.05$).[22,23] The study was approved by the Institutional Human Research Ethics Committee and the appropriate local ethics review process in India. All procedures involving human participants complied with the Declaration of Helsinki. Written informed consent was obtained from all participants after the nature and consequences of the study were explained to them.

Experiment two – chart calibration and repeatability

Twenty-eight participants were unable to read any letters on the Hindi chart except the largest (designated as 6/60). We, therefore, took the decision to omit the results of these 28 participants from the analysis. Consequently, the results and analysis described were based on complete data from 222 participants aged between 21 and 80 years (136 males and 86 females).

The difference in mean logMAR between the two Hindi charts was 0.005 (±0.02) (i.e. slightly better on the second measurement), which although statistically significant (paired *t*-test, $P < 0.05$) is equivalent to only about one-quarter of a letter improvement between the charts. The difference in mean logMAR between the Hindi and m-ETDRS logMAR charts (0.13 ± 0.08 logMAR) was also statistically significant (paired *t*-test, $P < 0.05$) and is equivalent to more than one acuity row (6.5 letters on a logMAR scale).

The top panel in Fig. 3 plots the results for the first Hindi chart (Hindi 1) and m-ETDRS logMAR results. The straight line through the data represents the best-fitting linear regression and depicts close to a 1:1 relationship between the data. There is a significant positive correlation between the two sets of results ($P < 0.001$, $r^2 = 0.92$). The lower panel in Fig. 3 plots the difference between the m-ETDRS and Hindi logMAR results against their average.[21] The mean difference between the charts was 0.13 logMAR (95% confidence interval [CI] = ±0.15 logMAR).

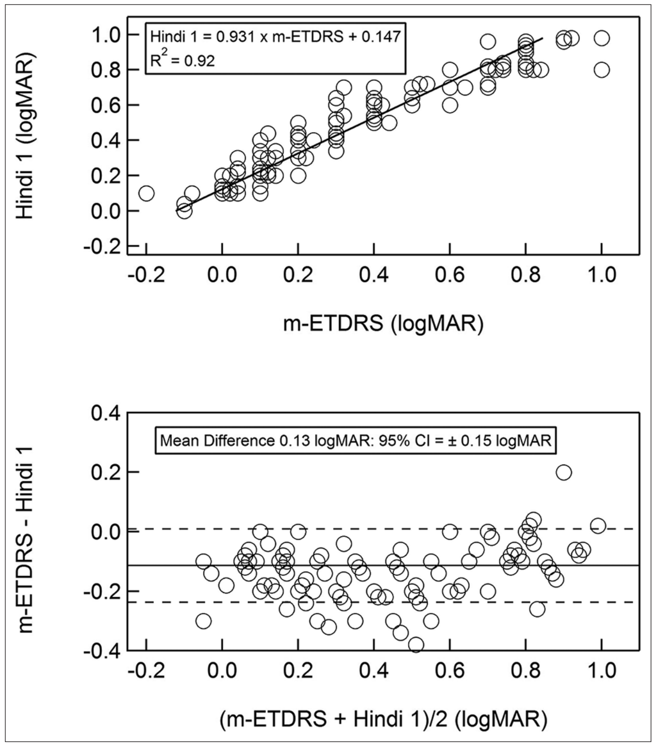

Figure 3: The top panel plots the visual acuity data (logarithm of the minimum angle of resolution) obtained using the Hindi (version 1) chart against the results using the modified ETDRS. The best fitting linear regression equation is shown and depicted by the straight line through the data. The bottom panel depicts the difference between the two measurements as a function of their mean after Bland and Altman. The solid line represents the mean difference. The 95% confidence intervals are shown and depicted by the broken lines (see text)

The top panel in Fig. 4 compares the Hindi logMAR results for charts 1 and 2. The straight line through the data represents the best-fitting linear regression and shows a 1:1 relationship between the two Hindi visual acuity measurements. There is a significant positive correlation between the two sets of results ($P < 0.001$, $r^2 = 0.99$). The lower panel in Fig. 4 plots the difference between the two Hindi logMAR results against their average.[21] The mean difference between the two Hindi charts was 0.005 logMAR (95% CI = ±0.04 logMAR).

Discussion

The new Hindi logMAR visual acuity chart was well accepted by the participants and those who could see the letters were able to successfully complete the measurements. The main result of this study showed that (unaided) visual acuity measured with the newly designed Hindi logMAR chart was highly correlated with the visual acuity measured with the m-ETDRS logMAR chart. Participants had higher visual acuity (i.e. lower logMAR), on average, with the m-ETDRS chart compared to the Hindi logMAR chart by 0.13 logMAR, equivalent to 6.5 letters. Both the Hindi and m-ETDRS charts were constructed using accepted principles for vision chart construction,[1,4] and letter selection was based on rigorous legibility criteria; therefore, this result cannot be explained by deficiencies or differences in chart construction. However, a difference in legibility between the Hindi and Sloan letters

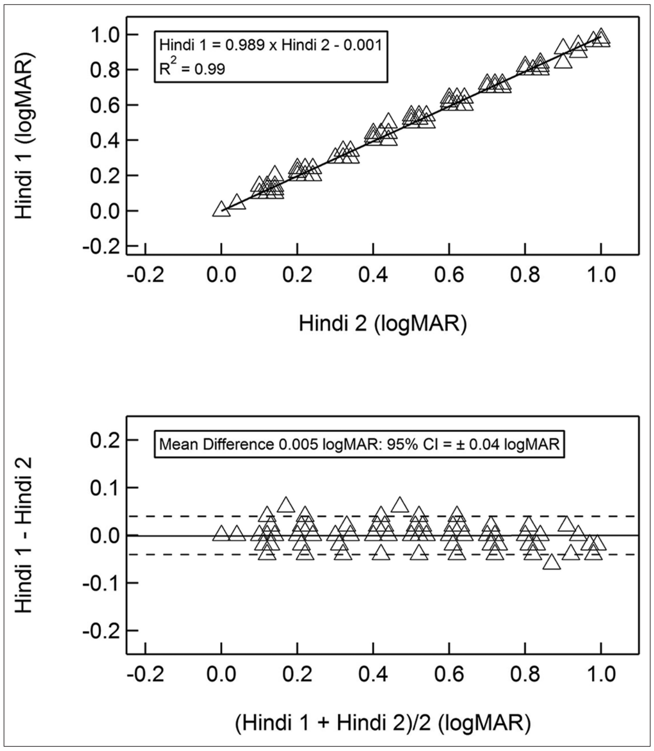

Figure 4: The test–retest repeatability of the new Hindi logarithm of the minimum angle of resolution charts is shown. The top panel plots the correlation between measurements taken on consecutive days. The best fitting linear regression equation is shown and depicted by the straight line through the data. The bottom panel depicts the difference between the two measurements as a function of their mean after Bland and Altman. The solid line represents the mean difference. The 95% confidence intervals are shown and depicted by the broken lines (see text)

for the same optotype size was apparent in experiment 1 as the average recognition distance for the Hindi letters was 1.2 m and for the Sloan letters 2.5 m (Hindi letters were more difficult to discern). The difference in legibility between the Hindi and Sloan optotype sets noted in Expt. 1 (legibility experiments) was also evident in the results of Expt. 2 (field trial); however, the magnitude of the difference was greater in the former experiment. This difference could reflect differences in the methodology used in each experiment which may have influenced the end point criterion used by participants (e.g., participants in Expt. 1 may have been more hesitant in their response to the Hindi optotypes). We did not incorporate this difference into the letter chart construction as the relative letter legibilities between the Sloan and Hindi optotypes were similar, and the aim of Expt. 2 was to calibrate the Hindi chart against the m-ETDRS standard.

All participants were screened to ensure literacy in both English and Hindi, but given that Hindi was the native language of the participants in Expt. 2, any potential differences due to unfamiliarity with the letters would have made the m-ETDRS and not the Hindi chart more difficult. However, one possibility is that intra-optotype differences between Sloan and Hindi letters made the Hindi letters more difficult to recognize for the same optotype size because of an internal crowding effect. Zhang *et al*.[24] showed that intra-optotype complexity in Chinese characters contributes to their legibility so that the more complex the character (i.e. more internal features) the more difficult it was to recognize. They called this effect of complexity "within-character crowding." The Hindi optotypes are also comprised of a variety of stroke patterns quite unlike the Sloan optotypes, so a similar process could be responsible for the relative difficulty observed in recognizing the Hindi letters. A similar effect has been noted previously with a children's visual acuity test chart using picture optotypes,[25] where the picture optotypes had to be scaled to twice the size of the equivalent Snellen letters, presumably as a result of the increased complexity of the individual pictures. Therefore, a modification of the new Hindi logMAR chart making the letters 1.35 times larger (0.13 logMAR) equating to a 35% increase in letter size compared to the m-ETDRS logMAR chart should result in the data from such a Hindi logMAR chart to have good agreement with the ETDRS chart. Such a chart may maintain all of the important features of the ETDRS chart including a constant inter-letter separation of 1-optotype width. This could maintain constant crowding within the Hindi chart.

The results of the present study are consistent and comparable to other chart calibration studies that have utilized the ETDRS logMAR chart (or similar) as a standard for comparison.[8-10,12,19] A previous study has produced a Hindi letter chart based on the ETDRS format but selected letters using difficulty scores based on percent-correct recognition rather than equal legibility and did not provide calibration data to support their design.[17] The high correlation and small limits of agreement between the results from the newly designed Hindi logMAR chart and the m-ETDRS logMAR chart indicate that the new Hindi logMAR chart yields a measure of visual acuity comparable to the m-ETDRS chart. By increasing the size of the Hindi optotypes by 0.13 logMAR, the Hindi visual acuity scores would, on average, equate with the m-ETDRS scores making the Hindi chart more precise and resulting in equivalent scores of visual acuity.

Our decision to use a m-ETDRS chart for comparison to our new Hindi chart was based on the results of our legibility experiments where we wished to keep the selection criterion for the Hindi optotypes the same as that employed for the Sloan optotypes. Our m-ETDRS chart comprised 9 of the 10 Sloan letters, omitting the letter "S" based on the defocus responses described in the methods. However, in all other aspects, our m-ETDRS chart was comparable to the standard ETDRS. Participants were not told how many different letters would be displayed in either the Hindi or m-ETDRS charts, and hence, the reduction in the number of available letters from 10 to 9 in our m-ETDRS chart is not likely to have any effect on our main results or conclusions.

For consistency, we used a single experienced optometrist to take the measurements of acuity between the Hindi and m-ETDRS chart. As a result, the examiner would have been aware of the first acuity measurement which may have inadvertently influenced the second measurement. However, for the initial measurements of acuity, the order of chart presentation was randomized between participants and these data were not available to the examiner during the repeatability measurements. We would have expected that bias due to examiner knowledge would have brought the results between the Hindi and m-ETDRS chart much closer than what was found. In addition, the repeatability data were obtained out of sight of the initial measurements on a different day and on 222 participants. We, therefore, conclude that any bias resulting from the use of a single examiner was either minimal or nonexistent and was outweighed by the need to ensure consistency in the methods.

A small improvement in the mean visual acuity measurements (0.005 logMAR) was found between measurements of visual acuity obtained using the two versions of the Hindi logMAR charts. Although this improvement may have reflected a learning effect, it was very small and not clinically significant. The limits of agreement for test–retest measures of visual acuity were <1 line and surprisingly small with a range of four letters. Previous work has shown that the repeatability of visual acuity measurements for charts based on the ETDRS or Bailey-Lovie format can be as much ± 1–1.5 lines of acuity (a range of 10–15 letters) on a logMAR scale.[22,23,26,27] Our narrow test–retest results for the Hindi charts may reflect underlying methodological differences compared to other studies. Although we used a single examiner and repeated testing without direct knowledge of the initial test results, there is a possibility that some examiner bias may have remained from test to retest measurements. However, such a bias should also have been evident in the m-ETDRS and Hindi comparisons. On the contrary, we found a marked difference between these results. The end point acuity was specified when the participants read three or more letters incorrectly on a line and recorded as the previous line correctly read. This is akin to line-by-line scoring previously described although we did score individual letters on the criterion line. However, line-by-line scoring has been shown to result in poorer test–retest repeatability due to the relative coarseness of the scale,[26,28] and as a result, the end point criterion we used does not explain the narrow repeatability results although it is reflected in our results as a relative clustering of data around the acuity steps in Figs. 3 and 4.

An alternative explanation for the relatively narrow test–retest limits of agreement may be due to relatively steep underlying psychometric functions for Hindi letter acuity. Although we could not derive the psychometric functions from the data, steeper psychometric functions for Hindi letter acuity compared to those for Sloan letter acuity could produce Hindi test–retest acuity data with relatively narrow limits of agreement. If, as we suggested earlier in our discussion, the Hindi optotypes exhibited characteristics of within-character crowding similar to those described in Chinese characters,[24] an increase in steepness of the psychometric function might be expected. However, the slopes of the psychometric functions for acuity of Chinese characters are not significantly different compared to Sloan letters, despite evidence of within-character crowding.[29] A similar result has also been reported for other font types including "meaningless" alphabets.[30] We, therefore, suppose that the psychometric function for acuity of Hindi letters is not significantly different to that of the Sloan letters and that a steep psychometric function for Hindi letter acuity is not the explanation for our narrow test–retest limits of agreement.

The Hindi repeatability data (95% CI = ±0.04 logMAR) are consistent with a study performed independently on the design of a Tamil language chart. Varadharajan *et al*.[9] using letter-by-letter scoring reported a mean difference between repeated measurements of a Tamil language chart of 0.02 ± 0.04 logMAR. While they did not offer a detailed explanation of their narrow test–retest results, they suggested that it may have resulted from the short time interval of only a few minutes between test and retest. They also showed a similarly narrow repeatability range using a standard internally illuminated ETDRS chart.

The newly designed Hindi logMAR visual acuity chart is capable of providing an accurate and reliable tool for the measurement of visual acuity in literate Hindi language speakers. Both versions of the Hindi logMAR charts had high test–retest repeatability. A corrected version for use in clinical practice can be made with Hindi optotypes 1.35 times larger than the size used in this study, equal to a 35% increase in letter size when compared to ETDRS optotypes for a 6 m test distance.

Conclusion

This study reports the first standardized visual acuity chart developed in the Hindi language taking into account the important chart design parameters of equal letter legibility and equal inter-row legibility. The charts are an added advantage in research studies and in conventional clinical practice for standard measurement of visual acuity in regions of the world with high rates of visual impairment where Hindi is the native language of the inhabitants.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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