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LOW VISION

Feasibility of the Radner Reading Charts in low-vision patients

Marloes C. Burggraaff · Ruth M. A. van Nispen · Sharon Hoek · Dirk L. Knol · Ger H. M. B. van Rens

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Abstract
Background Being unable to read is a major problem for visually impaired patients. Since distance visual acuity (VA) does not adequately reflect reading ability, it is important to also evaluate near VA. The Radner Reading Charts (RRCs) are available to measure patients' reading performance. The present study tested the inter-chart and test-retest reliability of the RRCs in Dutch low-vision patients (i.e., visual acuity ≥0.3 logMAR) with various eye disorders.
Methods Thirty-eight patients read the three RRCs in random order. Then, about 1 month after the initial measurements, a test-retest procedure was performed in 15 of the 38 patients. Tested variables were reading acuity (logRAD), logRAD score, logRAD/logMAR ratio, maximum reading speed (MRS), and critical print size (CPS). Both MRS and CPS were calculated in two different ways. To determine the variability, a mixed-model analysis was used.
Results For all variables, the largest part of the variance was explained by the individual subject (86–89%) whereas the chart accounted for only 0–0.78% of the variability. Therefore, the inter-chart and test-retest reliability was high, except for the CPS which had a poor to moderate reliability (31–62%) when calculated in the two different ways.
Conclusions The inter-chart and test-retest results showed high reliability in patients with low vision due to various diseases; therefore, the charts are feasible to determine effects in large groups.

Keywords Radner Reading Charts · Reliability · Low vision · Reading acuity

Data The authors have full control of all primary data and agree to allow Graefe's Archives for Clinical and Experimental Ophthalmology to review the data upon request.

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M. C. Burggraaff (✉) · R. M. A. van Nispen · S. Hoek · G. H. M. B. van Rens
Department of Ophthalmology, VU University Medical Center, De Boelelaan 1117, PO Box 7057, 1007 MB Amsterdam, The Netherlands
e-mail: m.burggraaff@vumc.nl

M. C. Burggraaff · R. M. A. van Nispen · S. Hoek
EMGO Institute for Health and Care Research, VU University Medical Center, Amsterdam, The Netherlands

D. L. Knol
Department of Epidemiology and Biostatistics, VU University Medical Center, Amsterdam, The Netherlands

G. H. M. B. van Rens
Department of Ophthalmology, Elkerliek Hospital, Helmond, The Netherlands

Introduction

A major problem reported by visually impaired persons is the decreased ability to read [1]. Routine measurements of distance visual acuity (VA) have no predictive value for actual reading ability [2–4] and provide no information about the degree of disability in carrying out near tasks. Therefore, reading performance tests are necessary to allow clinical evaluation of reading function and to provide more detailed information on the visual impairment [5].

Several reading charts or reading card tests have been developed to measure reading performance, such as the Sloan M Cards, the Bailey Charts, the MN-Read and the Radner Reading Charts [6–10]. Recently, the strict principles of the Radner Reading Charts (RRCs) [10] were used

to develop a Dutch-language [11] version of these charts, as well as versions in Spanish [12], English, Swedish, and Hungarian. Other language versions are in print or in progress [13]. These charts have an advantage over other national [14] and international [6–9] reading charts in using 'sentence optotypes', which are highly comparable sentences in terms of number of words, word length, position of words, lexical difficulty and syntactical complexity. In both the original German and the Dutch RRCs, of the total 32 sentences the 24 most similar ones were statistically selected and used for the charts [10, 11]. Moreover, the German sentence optotypes have been statistically selected in 198 subjects [15]. Geometric proportions are kept constant at all distances to achieve accurate and standardized measurements of reading acuity and reading speed. The only stimulus variable is print size, which is graduated with 0.1 log unit steps (range 1.2–1.1 and 0.9 – -0.2 logRAD) [10, 15].

Studies by Stifter et al. (German RRCs) and Maaijwee et al. (Dutch RRCs) have shown a high inter-chart and test-retest reliability of the charts in patients with normal to low vision [5, 16]. However, both latter studies focused on patients with macular disease only, thereby excluding other causes of low vision. Therefore, it is unclear whether the RRCs are feasible for patients with low vision caused by a variety of eye conditions, in addition to macular disease.

Since low-vision patients have a reduced reading ability and often use modified viewing techniques, the feasibility of a reading chart for such patients is of interest. Low vision is defined (according to the WHO criteria) as VA >0.5 but ≤1.3 logMAR, or a corresponding visual field of ≤20° in the better eye with best possible correction [17]. In the USA and Australia, low vision is defined as a best-corrected VA ≥0.3 logMAR [18]. In the present study, patients with a VA ≥0.3 logMAR were included since Dutch society is organized such that these patients increasingly ask for visual rehabilitation services [19, 20].

Although many studies have used reading performance tests in low-vision patients, to our knowledge they have not often been validated in this specific population in a clinical setting. Therefore, the present study investigated the RRCs by replicating the studies of Stifter et al. and Maaijwee et al. in a Dutch low-vision population (i.e., patients with age-related macular degeneration as well as other relevant causes of vision loss). The inter-chart and test-retest reliability of the RRCs was tested in this specific population.

Methods

Subjects

Subjects with a VA ≥0.3 logMAR or a visual field ≤20°, who were able to read and understand the Dutch language, were invited to read the charts. Patients were ineligible for the study if their disease had changed in the last 3 months and if reading performance was influenced by non-ocular disease, medication, or drugs. At two Dutch hospitals, 51 patients were invited to read the charts. However, of this group, 11 could not read the largest print size on the charts at 40 cm because of severe low vision and two patients had medication-based pupil dilation. Therefore, 38 patients (mean age 80.5) were included in the study. Informed consent was obtained from all patients prior to their inclusion in the study. The study was approved by the Institutional Review Board of the VU University Medical Center Amsterdam, and was conducted according to the principles of the Declaration of Helsinki.

Testing procedure

The RRCs were read monocularly at a distance of 40 cm. The charts were read with an illumination of 80–90 cd/m^2, with the patient's optimal refractive correction. At the second testing procedure, about 1 month later, the same refractive corrections were used.

Distance VA was determined at both testing sessions using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart at 4 m, or the Rodenstock chart projector at a distance of 6 m in case the ETDRS chart was not available. In both sessions, the same charts for distance VA were used. Snellen ratings were converted to the logMAR scale (^{10}log 1/VA). If distance VA had changed between the two testing sessions with a difference of more than one line above or below the line that was read the first time (or five optotypes on the ETDRS chart) the patient was withdrawn from the study.

To counterbalance the learning effect, the three reading charts were read randomly according to a 'Latin square design' defined by charts, time, and order [21]. The patients had to read the sentences aloud, as quickly and accurately as possible, without correcting reading errors [5, 10, 11, 15, 16]. All testing procedures were monitored with video/audio-recording to accurately determine the reading speed and number of syllables of the missed, mispronounced, or repeated words [5].

Analysis of the measurements

Reading acuity is expressed in logRAD (i.e., logarithm of the reading acuity determination), which is the reading equivalent of logMAR. Other variables that were analyzed were logRAD score (reading acuity + number of syllables misread × 0.005) and logRAD/logMAR ratio ([1-logRAD] x 100 / 1-logMAR). Furthermore, reading speed was investigated, which is calculated in words per minute (number of

words/reading time) [5, 16]. Reading time was measured with a stopwatch.

In the present study, the maximum reading speed (MRS) represents the absolute MRS, e.g., the greatest number of words a patient reads per minute. The average reading speed is the mean reading speed of all sentences the patient has read. The MRS (as calculated according to the methods of Maaijwee et al.) is the average reading speed from print size 0.9 logRAD up to the critical print size (CPS). The first two print sizes of 1.2 and 1.1 logRAD were excluded, since reading speed decreases from optimum reading speed for small and very large print sizes [5].

The CPS is the smallest print size that patients can read with maximum speed [16]. To define the CPS, reading speed was plotted on a graph for each chart per patient; the print size where reading speed suddenly dropped (i.e., the point with the steepest declining slope) was defined as the CPS [5]. An example of these plots (from two different patients) is given in Fig. 1. Cheung et al. used non-linear mixed effects (NLME) modeling to calculate the MRS and CPS [22]; to calculate the MRS, they used the logarithm of maximum reading speed (logMRS). In the present study, the methods of both Maaijwee et al. and Cheung et al. are used to calculate these variables.

Statistical analysis

To identify which part of the total variability of the RRCs could be attributed to which source, a linear mixed-model analysis was used similar to the studies by Stifter et al. [16] and Maaijwee et al. [5]. The sources of variation were: subject (n=38), session (n=2), chart (n=3) and (residual) error, which were considered to be random effects. The time within-session order effect was considered a fixed effect [16]. The contribution of each source to the total variability was calculated as a percentage. The relative contribution of subject variance to the total variance determines the reliability of the measurement, i.e., the intra-class correlation coefficient (ICC) [5]. The variance components were obtained by the method of restricted maximum likelihood. All available data on measurements made at baseline (n=38) and at follow-up (n=15) were used to estimate the inter-chart and test-retest reliability of the RRCs. It was assumed that the missing follow-up data could be classified as missing at random (MAR). A non-response process is considered MAR if, conditional on the observed data, missingness is independent of the unobserved measurements [24, 25]. In the present study, the variance component analysis with restricted maximum likelihood can be considered a direct likelihood method, where all observed data are used without deletion [26] (and is in contrast to other studies where complete case analysis was used [5]). The reproducibility and repeatability are expressed in the dimension of measurement. They were calculated in order to determine the feasibility of the RRCs for individual patients as opposed to the reliability and feasibility in the total low-vision population, which was presented as the ICC. The reproducibility and repeatability were calculated from the within-patient standard deviation (SD), i.e., standard error of measurement (SEM), defined as the square root of the sum of the within-patient variance components due to session, chart, and error. The reproducibility ($1.96\sqrt{2}=2.77$ times the SEM) is the within-patient difference due to chance. For example, when the differences between measurements of a subject are within the reproducibility range, there is no improvement or deterioration on this scale. The repeatability is the same as the reproducibility but excluding the session component in the SEM [5]. Statistical analyses were performed with SPSS version 15.0.

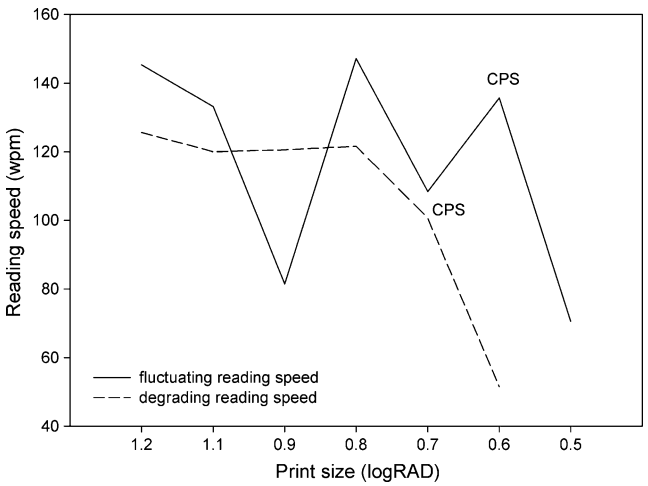

Fig. 1 Reading speed according to print size in two different patients with low vision: the normal graph shows the relation between reading speed and reading acuity, and the other shows fluctuating reading speeds for subsequent print sizes

Results

Response and patient characteristics

A total of 38 patients read the three RRCs in random order to obtain the reliability of the charts. Then about 4 weeks (range 2.0–6.3 weeks) after the initial session the test-retest procedure was performed in 15 patients. Of the 23 patients lost to follow-up, 15 failed to return for the test-retest procedure, four had major changes in distance VA, two did not read the charts with the best refractive correction during the second session, and two were withdrawn for other reasons. Table 1 presents the characteristics of the patient

Table 1 Characteristics of the patient population

Characteristics	Baseline (n=38)	Follow-up (n=15)	Lost to follow-up (n=23)
Mean age in years (SD)	80.5 (8.9)	80.6 (8.8)	80.5 (9.1)
Gender (% woman)	71.1	73.3	69.6
VA (logMAR) of best-corrected eye (SD)	0.5 (0.2)	0.4 (0.2)	0.5 (0.2)
Living situation (% autonomous)	86.8	82.6	93.3
Mean years of education (SD)	8.5 (2.6)	8.7 (2.9)	8.4 (2.1)
Maculopathy (%)	50.0	66.7	39.1
Glaucoma (%)	15.8	6.7	21.7
Cataract (%)	5.3	0.0	8.7
Diabetic retinopathy (%)	5.3	0.0	8.7
Corneal disorders (%)	18.4	20.0	17.3
Other (%)	5.3	6.7	4.3

population. There were no significant differences in baseline characteristics between responders and non-responders to the second testing session. Data from all 38 patients contributed in the mixed-model analysis to estimate the contribution of each source (subject, session, chart, and error) to the total variability.

Inter-chart and test-retest reliability

The mean logRAD VA was 0.57 (SD 0.23), mean logRAD score was 0.59 (SD 0.23), mean logMAR/logRAD ratio was 42.7 (SD 22.9), mean of the average reading speed was 123.6 (SD 30.9) wpm, mean MRS was 154.8 (SD 41.9) wpm, mean MRS calculated according to the method of Maaijwee et al. was 131.7 (SD 42.2) wpm, and mean CPS was 0.77 (SD 0.23).

For the variables logRAD, logRAD score, logRAD/logMAR ratio, average reading speed, MRS, and MRS according to the methods of Maaijwee et al. or Cheung et al. the subject accounted for 85.5–88.5% of the variance; the between-subject component (ICC 0.86–0.89). For the CPS, the subject accounted for 39.5–61.8% of the total variance (ICC 0.39–0.62). The chart and session accounted for 0–0.78% and 0–1.08% of the variability, respectively (Table 2).

Discussion

In the present study conducted among low-vision patients in the Netherlands, the high percentages of variance due to subject and the small percentages due to chart and session, indicate that mainly the patients themselves account for the variability. These results are similar to those reported by Stifter et al. and Maaijwee et al. [5, 16]. However, our percentages due to measurement error are slightly higher

Table 2 Data on the inter-chart and test-retest results

Variable	SD	%subject	%session	%chart	%error	SEM	Reproducibility	SEM without session	Repeatability
VA (logRAD)	0.24	85.52	0.45	0.02	14.00	0.09	0.25	0.09	0.25
LogRAD score	0.24	87.10	0.02	0.01	12.88	0.08	0.24	0.08	0.24
LogRAD/logMAR ratio (%)	24.03	85.52	0.45	0.16	13.87	9.14	25.34	9.00	24.94
Average RS (wpm)	33.15	87.76	1.08	0.12	11.04	11.60	32.15	11.08	30.70
Absolute MRS (wpm)	43.02	88.50	0.18	0.78	10.55	14.59	40.44	14.47	40.12
MRS (Maaijwee's method)	43.47	87.13	0.41	0.35	12.11	15.60	43.23	15.34	42.53
logMRS (Cheung's method)	0.13	88.10	0.03	0.04	11.83	0.04	0.12	0.04	0.12
CPS (logRAD) (Maaijwee's method)	0.26	61.79	0.00	0.00	38.20	0.16	0.44	0.16	0.44
CPS (logRAD) (Cheung's method)	0.15	39.48	4.10	0.00	56.41	0.12	0.32	0.11	0.31

The standard deviation (SD) is the square root of the total variance (sum of subject, chart, session, and error variance); the standard error of measurement (SEM) equals the within-patient SD, defined as the square root of the sum of the within-patient variance components due to session, chart and error; the reproducibility is $1.96\sqrt{2}=2.77$ times the SEM; the repeatability is the same as the reproducibility with exclusion of the session component in the SEM (SEM without session) [5]

for most variables, and our percentages due to subject are somewhat smaller. Nevertheless, the percentages of variance due to chart and session are even smaller in our study compared to those of Maaijwee et al. (chart 0–0.78% vs. 0–2.80% and session 0–1.08% vs. 0.50–4.50%), which confirms the high inter-chart and test-retest reliability of the RRCs, even in a heterogeneous population with different causes of low vision. Therefore, the charts will be feasible to obtain reading performance in our randomized controlled trial, to evaluate the effectiveness of training in the use of closed-circuit televisions in low-vision patients [27].

In the present study, for CPS the subject accounted for only 39.5–61.8% of the variance. It has been reported that the inclusion of patients with low vision will increase the variability of the CPS [28, 29]. Indeed, in our study the ICC of the CPS is considerably smaller (0.39 to 0.62) than that reported by Maaijwee et al. (0.91) [5], but comparable to that of Stifter et al. (inter-chart reliability 0.47–0.79 and test-retest reliability 0.39–0.71) [16]. The interpretation on how to calculate MRS and CPS differs. Subramanian and Pardhan defined MRS as the mean of the reading speeds across a reading plateau and used the logarithm of reading speed to calculate the MRS [23]. However, in patients with severe low vision, reading speed is often not constant over a wide range of print sizes and therefore does not result in a plateau (see Fig. 1). The present study confirms that in low-vision patients the curves of reading speed vs. print size show variability across print size [28, 29]. In replicating the studies on the reliability of the Dutch and German RRCs, the print size at which the line suddenly dropped was defined as the CPS [5, 16]. It proved difficult to exactly identify this point due to the fluctuating reading speeds. Furthermore, since CPS has to be set by the examiners, their subjective decision might make a significant contribution to the large variability [16]. Therefore, we also used the more objective methods of Cheung et al., who found that NLME modeling gave reasonable parameter estimates even when individual fitting yielded unrealistic estimates [22]. However, in the present study, the CPS calculated in this way showed even more variability. The method for determining the CPS directly from plots seems most feasible in clinical practice with low-vision patients. Further studies are needed to establish the clinical value of the CPS and its exact definition [28, 29].

The relatively small differences in reliability (e.g., the smaller percentages due to subject and higher percentages due to error) between our study and that of Stifter et al. and Maaijwee et al. might be explained by the inclusion of low-vision patients only. In low-vision patients, assessment of VA is reported to be difficult and may present fluctuating results [30, 31]. Especially including patients with severe low vision (≥ 0.69 logMAR) will increase variability [28, 29]. Further research might elucidate whether the variability may be a function of the severity of the impairment or that variation is caused by different diseases. In our study, patients with various eye disorders causing low vision were included. It is known that each eye disorder has its own manifestations (e.g., in VA loss, visual field loss, or contrast sensitivity) and these may also differ between patients with similar disorders. Repeating the mixed-model analysis with both baseline and follow-up data from patients with macular disorders alone (as in Stifter et al. and Maaijwee et al.) decreased variability and increased reliability. This confirms that testing reliability in an even more visually heterogeneous group is likely to generate more variability in measurements, resulting in an increased error [28, 29]. However, in the present population, taking into account the variation within and between patients, it can be considered a strength of the charts that they still yielded excellent results. More studies are needed to investigate the reliability among patients with a specific disorder (e.g., patients with diabetic retinopathy, cornea disease, and cataract) since these groups were rather small in the present study. Another reason for a slightly larger measurement error in our study might be that patients were withdrawn from the study only if distance VA had changed with a difference of more than one line above or below the line that was read the first time. In contrast, in the study of Maaijwee et al., patients had to read exactly the same line at both testing sessions. When distance VA differs between sessions, reading performance on the RRCs may also differ. However, in everyday practice, distance VA of low-vision patients often varies between sessions [30, 31]. Our measurements are considered to reflect measurements made in everyday practice.

In the present study, the repeatability and reproducibility were 0.8–2.6 times that of the low-vision group of Maaijwee et al. [5]. For example, in our study, the repeatability and reproducibility of VA were both 0.25 logRAD. Consequently, if a patient reads the RRCs several times, the reading acuity may differ with 0.25 logRAD (or 2–3 lines). The considerable variation in repeated measurements from the same subject indicates moderate reproducibility and repeatability [32], which is also the case for the other variables we investigated and seems to be in conflict with the high inter-chart and test-retest reliability. Therefore, the satisfactory level of reliability depends on how a measure is used. Group research is often concerned with the size of correlations and with differences in means for experimental treatments, for which a reliability of 0.80 is adequate [33]. However, when decisions with respect to specific test scores are being made about individual subjects, a reliability of 0.90 is the minimum that should be tolerated, and a reliability of 0.95 should be considered the desirable standard [33]. This is confirmed by the moderate reproducibility and repeatability in the present

study. However, in our study, 11 patients with severe low vision (21% of the invited patients; mean VA 1.24 logMAR) were unable to read the largest print size on the charts, since in the design of our study a reading distance of 40 cm was chosen. Therefore, this reading distance might have been suboptimal for low-vision patients and might have negatively influenced the reproducibility and repeatability. The repeatability and reproducibility of measurements can be enhanced by letting patients read at their preferred reading distance and with the use of their low-vision aids. Keeping the distance constant at 40 cm can be considered a limitation of our study. In the design of the RRCs it is possible to correct VA for reading at a shorter distance. However, the problem remains that patients who suffer from severe vision loss show large differences in acuity from one measurement to another [34], as well as greater variability in reading speed [28, 29]. If a high reliability of measurements is required in individual low-vision patients, the reproducibility and repeatability of results might be further enhanced by averaging the results (as recommended by the National Research Council Committee on Vision for measuring acuity [31]). To let patients read two or three charts during one session and then average the results, could improve the precision of measurement by a factor of $\sqrt{2}$ and $\sqrt{3}$, respectively. For example, after three measurements, the variance due to chart and error of the variable logRAD can be divided by three, which will increase the ICC from 0.85 to 0.94 and decrease the repeatability from 0.25 to 0.14. The latter is comparable by dividing the repeatability to $\sqrt{3}$. On the other hand, this will be more time-consuming.

In conclusion, the RRCs showed a high inter-chart and test-retest reliability. However, patients with low vision due to various diseases showed an increased variability of the measurements compared to other studies that tested the reliability of the RRCs. Therefore, it is a strength of the charts that even in this heterogeneous population they yielded excellent results (ICC 0.86–0.89), and they appear to be feasible to determine effects in large groups. However, low-vision patients will always show fluctuating results leading to a moderate reproducibility and repeatability of measurements, therefore, it is important to create optimal reading conditions. Furthermore, letting patients read two or three of the RRCs in one session and averaging the results might enhance the reproducibility and repeatability of the measurements even more.

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