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MISCELLANEOUS

English sentence optotypes for measuring reading acuity and speed—the English version of the Radner Reading Charts

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Abstract
Purpose To develop 28 short sentence optotypes for the English version of the Radner Reading Charts that are as comparable as possible in number and length of words, as well as in difficulty and syntactical construction.
Methods Thirty-four English sentences were constructed following the method used for other Radner Reading Charts to obtain "sentence optotypes" with comparable structure and the same lexical and grammatical difficulty. Best comparable sentences were statistically selected and standardized in 50 volunteers. Reading speed and the number of errors were determined. Validity was analyzed with a 124-word long 4th-grade paragraph of the Florida Comprehensive Assessment Test®. Computerized measurements of reading parameters were performed with the RADNER Reading Device (RAD-RD©; in conjunction with a PC and microphone).
Results The mean reading speed obtained with the 28 selected short sentences was 201.53±35.88 words per minute (wpm), as compared to 215.01±30.37 wpm for the long paragraph. The mean reading times were 4.30±0.79 s and 35.26±4.85 s, respectively. The mean number of reading errors was 0.11±0.34. The correlation between the short sentences and the long paragraph was high (r=0.76; p<0.05; n=50). Reliability analyses yielded an overall Cronbach's alpha coefficient of 0.9743.
Conclusion The present study indicates that the 28 selected English sentence optotypes are comparable in terms of both lexical difficulty as well as in reading length, and it demonstrates the validity and reliability of such sentences as test items for determining reading parameters such as reading acuity and speed.

Keywords Visual acuity chart · Visual acuity · Optotypes · Refractive error · Spatial vision

Introduction

In our modern information-based society, the ability to read is essential for everyday life, and, therefore, a reduction in the ability to read has a considerable impact on the quality of life [1–9]. Rehabilitative methods have been developed to limit or reverse visual impairments and resultant reading disability caused by conditions such as cataracts, presbyopia, refractive errors, and age related macular degeneration (AMD) or other vitreoretinal diseases. Thus, it seems to be evident that the evaluation of reading speed and reading acuity, or even better, of reading speed based upon reading acuity, has clinical importance as a functional preoperative or postoperative measure of near visual performance.

However, most of the historic reading charts that are still used (e.g., Jaeger, Nieden, Birkhäuser, and Parinaud) suffer from a lack of standardization of the test items (text paragraphs). Their print sizes (letter heights) are not standardized, are not logarithmically scaled, and mostly remain unknown because of the limitations of earlier printing techniques. While today it is possible to print letter heights with an accuracy of about 0.01–0.03 mm [10, 11], the historic charts have often been printed only with the limited print sizes available for hot-lead typesetting. This could be the explanation for the many different versions of the English Jaeger charts [12], which are

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hardly comparable to each other and are not at all comparable to the German or other language versions of the Jaeger charts. The Jaeger charts were originally developed in Vienna by Professor Eduard Jaeger (1818–1884) in 1854. Since then, the German charts have been slightly modified, first by Fuchs in 1895 and then extensively after the World War II (by unknown persons). In the current version of the German Jaeger charts, there are a number of nonconformities with modern requirements for visual acuity tests [13–15], including the fact that paragraphs J5 and J6 have the same print size (1.95 mm in height) but different font types. J1 is just about comparable to a decimal Visus of 0.6 (Snellen: 6/10) at 32 cm, and between J3 and J4. The print sizes differ by more than 2 log units. Therefore, such reading charts should be considered obsolete for the purposes of research and medical documentation.

In the past three decades, new concepts of reading chart standardization have been developed. Bailey and Lovie [16] used unrelated single words for their logarithmically scaled charts and have shown that it is possible to simultaneously determine reading acuity and reading speed. The MNread Acuity Cards [10, 17] and the Radner Reading Charts [11, 18, 19] also make it possible to measure reading acuity and speed simultaneously. These two charts systems use short sentences as test items but differ in terms of their principles of test item standardization.

In order to equate the reading requirements at each print size, all the sentences on a reading chart can be either matched for length measured as the number of characters [10, 17] or by generating and statistically selecting a series of test sentences which are as comparable as possible in terms of the number of words, word length, position of words, lexical difficulty, and syntactical complexity [11, 18–22].

The sentences of the MNread Cards are characterized by their length, which is defined as 60 characters, including spaces and an implied period at the end of a sentence [10, 17]. Based on a study of Carver et al. [23], this turned out to be convenient for scoring reading errors and speed when a "standard-length word" is defined to have six characters. In this case, a 60-character sentence consists of ten standard-length words. Using standard-length words helps minimize the differences in scoring that would occur due to the different word lengths found in different sentences. For example, some of the sentences have 13 relatively short words, whereas others have just ten words of a longer length [10, 17, 23].

For the Radner Reading Charts (English version: Fig. 1), the concept of sentence optotypes [11, 18, 19] was developed in interdisciplinary cooperation by psychologists, linguists, statisticians, and ophthalmologists in order to minimize the variations between the test items and to keep the geometric proportions as constant as possible at all distances [11, 18, 19]. A series of test sentences was generated and statistically selected, all of which were as comparable as possible in terms of the number of words (14 words), word length, number of syllables, position of words, lexical difficulty, and syntactical complexity. In addition, this allows standardized communication in terms of functional vision (reading performance) that is in accordance with international standards [13–15]. This concept then was applied to a variety of languages (The Radner Reading Charts are commercially available in German, Spanish, English, French, Dutch, Italian, Swedish, Danish and Hungarian; further languages are in progress).

The goal of the present study is to develop short sentence optotypes for the English version of the Radner Reading Charts that are as comparable as possible to each other in terms of the number and length of words, as well as in difficulty and syntactical construction.

The study also investigates the validity and reliability of these sentence optotypes, which have been developed for evaluating reading parameters as, e.g., reading acuity, reading speed, maximum and mean reading speed, logMAR/logRAD difference, and reading speed based upon reading acuity.

Material and methods

Study population

The study population consisted of 50 native English-speaking persons (average age, 30.38±9.44 years; range, 21–55 years); 16 persons were university students, 18 academics, and 16 non-academics. The volunteers estimated that their average daily reading time was 178±124 min per day. Their best corrected visual acuity was examined with the EDTRS Charts (Precision Vision, LaSalle, IL) at 4 m and was at least 0.0 logMAR (Decimal: 1.0; Snellen: 6/6) in each eye, and none of the participants suffered from diseases or received medication that could influence the results of the study. Tests were performed binocularly. If necessary, presbyopia was compensated with a near addition according to age-related individual requirements. Binocular reading acuity at 40 cm was at least logRAD 0.1 (Decimal: 0.8; Snellen: 6/7.5; logRAD = reading equivalent of logMAR). All tests were performed at a constant luminance of 80–90 cd/m^2. Volunteers were asked to participate in the study and all study procedures adhered to the Declaration of Helsinki for research involving human subjects.

Sentence optotypes

The sentence optotypes (Figs. 1 and 2) are 4th-grade complex sentences (main clause and restrictive relative clause), which represent easily readable adult sentences. The 34 sentences were developed to be as comparable as possible in terms of grammatical difficulty as well as in number (n=14), length, and position of words, following the rules that have been

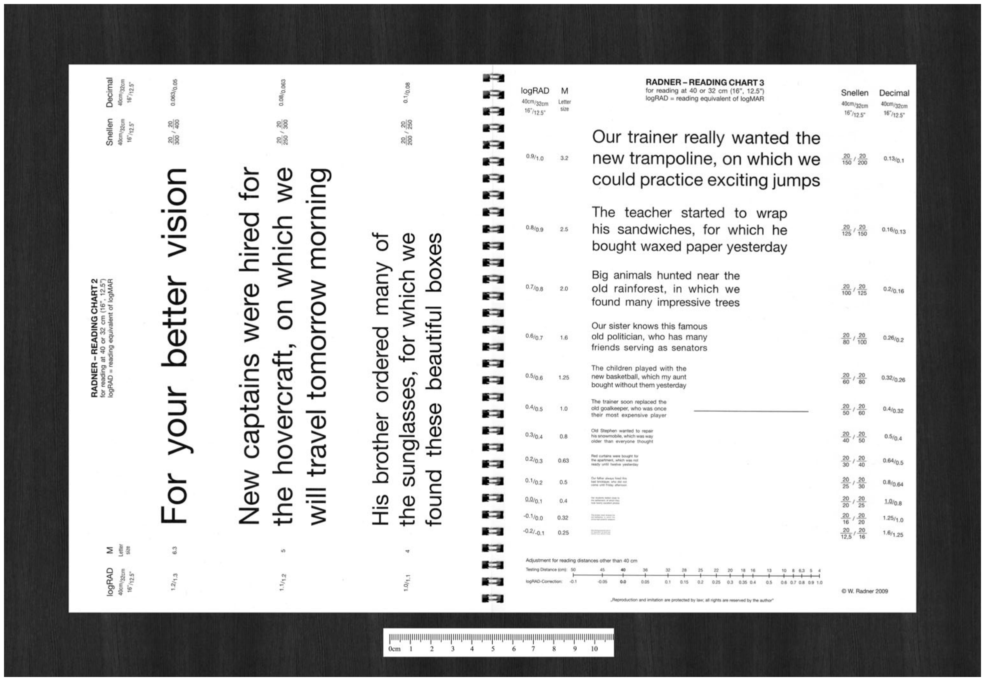

Fig. 1 Photograph of a Radner Reading Chart (front page to the *right* and back page to the *left*). Print sizes are logarithmically scaled as: logRAD which is the reading equivalent of logMAR is given for for 32 cm and 40 cm; M-scaling and Snellen-scaling are also given on the charts). Original size: 229 mm×324 mm (letter format; ruler=10 cm)

generated for sentence optotypes of the Radner Reading Test concept [11, 18] with minor language specific modifications.

Computerized reading performance analyses (RAD-RD©)

Nine or eight sentences were printed on each page. The type size was 12 point (font: Helvetica) for all sentences, and the reading distance was 40 cm. The luminance was 80–90 cd/m^2. Pages were presented on a reading stand, and the reading distance was determined with a 40-cm ruler and constantly verified during the procedure. The sentences were covered with a piece of paper, and the volunteers were asked to uncover sentence after sentence, reading each of the 34 sentences aloud as quickly and accurately as possible. Volunteers were instructed to read the sentences to the end before correcting any reading errors. Measurements were performed with an automated computer-based reading analyses device (RADNER Reading Device; RAD-RD©) [24], a

Our father always hired this
bad bricklayer, who did not
come until Friday afternoon

Our trainer really wanted the
new trampoline, on which we
could practice exciting jumps

His mother never looked for
the sunglasses, which he lost
near these flowers yesterday

Fig. 2 Sample sentences from the 28 sentences selected in the present study

custom-built computer program that is used in combination with a PC and microphone to improve the accuracy of reading speed measurements and facilitate data acquisition [24, 25]. With the RAD-RD©, sentences read aloud are recorded sentence by sentence. The sentences are then displayed as waveforms on the screen of the computer, and the program automatically analyzes the reading length of each sentence in real time, automatically determining the onset and end of reading. The automatically detected reading length results can also be verified manually on the screen before they are copied to a file.

Reading speed in words per minute (wpm) was calculated on the basis of the number of words in a sentence (14 words) and the time needed to read the sentence (14 words×60 s divided by the reading time). Reading errors were noted by marking the wrong words in the sentence on a study form. Errors were counted even when immediately corrected.

To assess the validity of the reading speed results obtained with these short sentences, we also measured reading speed and reading errors under the same conditions for a long 4th-grade paragraph (124 words) of the 4th Grade Reading Florida Comprehensive Assessment Test® (1st paragraph of "Zinnia and Her Babies").

Statistical analyses

Statistical analyses were performed using SPSS for Windows, version 15.0. The data showed a fairly symmetric distribution, and the Kolmogorov-Smirnov test, which indicates whether the distribution of data deviates from a comparable normal distribution, was not significant ($p>0.05$). Under the assumption of a normal distribution, the application of parametric statistical tests as Pearson's correlation was justified. The cut-off level for statistical significance was set at $p<0.05$, two-tailed.

Results

The overall mean reading time measured with the 34 sentences was 4.29±0.80 s (Fig. 3). The overall mean reading speed was 202.48±36.66 wpm. To be selected for the reading charts, the mean time to read a sentence optotype had to be within the reading time interval of 4.09 to 4.49 s (interval=4.29±0.25 × SD) and within the reading speed interval of 193.31 to 211.65 wpm (interval=202.48±0.25 × SD).

Twenty-eight sentences met the inclusion criteria. The mean reading time obtained with these 28 selected sentences was 4.30±0.79 s (standard error=0.021; 95 % confidence interval=4.262 to 4.345), and the mean reading speed was 201.53±35.88 wpm (standard error=0.96; 95 % confidence interval=199.65 to 203.40). Six sentences (numbers 3, 8, 9, 15, 19, and 26) were excluded either because they were outside the prescribed interval (Fig. 3). Two of them exhibited a higher number of errors and an overly long mean reading time (sentences 3 and 8); the other four were removed because their mean reading time was too short (sentences 9, 15, 19, 26; these sentences produced fewer errors).

The mean number of reading errors in all 34 sentences was 0.12±0.37, and in the 28 selected sentence optotypes, it was 0.11±0.34 (Fig. 4).

To assess the validity of the reading speed measurements obtained with the short sentences, we compared these reading speed results to those obtained with a paragraph of the standardized 4th Grade Reading Florida Comprehensive Assessment Test® (Fig. 5). The mean reading speed obtained with the long paragraph was 215.01±30.37 wpm (mean reading time: 35.26±4.85 s). The correlation between the long paragraph and the 28 selected sentences optotypes was high ($r=0.76$; $p<0.05$; $n=50$).

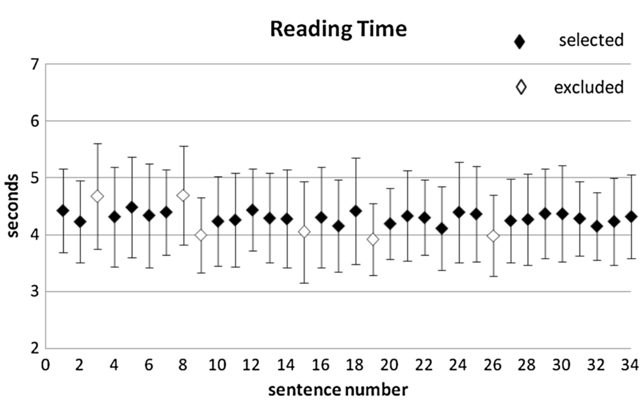

Fig. 3 Mean reading time and standard deviation for the 34 sentences (overall mean reading time: 4.29±0.80 s). *Black diamonds* selected sentences. *White diamonds* excluded sentences

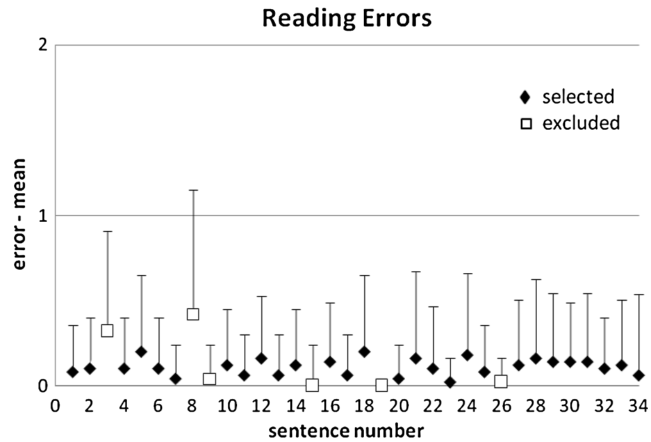

Fig. 4 Mean error number and standard deviation for the 34 sentences. The mean number of reading errors was 0.12±0.37 errors. *Diamonds* selected sentences. *Squares* excluded sentences

The reliability analysis for reading speed measurements made with the short sentence optotypes yielded an overall Cronbach's alpha coefficient of 0.9788 for all 34 sentences and 0.9743 for the 28 selected sentences (Fig. 6a). The "corrected item total correlation" of the 28 sentence optotypes (items) varied from 0.6177 to 0.8864 (Fig. 6b).

Discussion

In the present study we have presented and evaluated 28 short sentence optotypes that were selected for the English version of the Radner Reading Charts in order to be as comparable as possible to each other in terms of the number and length of words, as well as in difficulty and syntactical construction. This study also shows the validity and reliability of these sentence optotypes for measuring reading acuity and speed (Figs. 1 and 2).

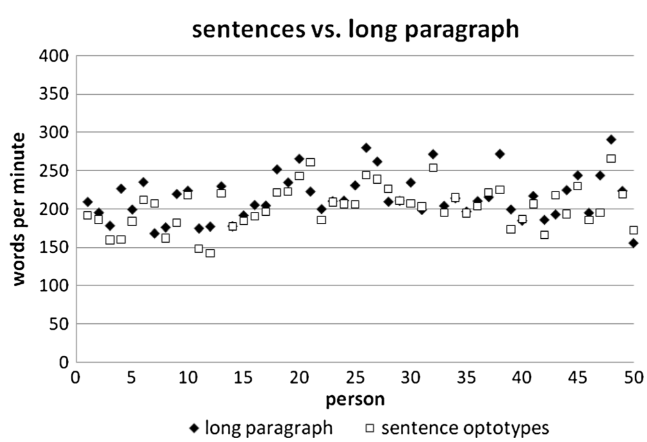

Fig. 5 Reading speed distribution of the 50 readers. Long paragraph (124 words; *diamonds*) vs. sentence optotypes (*squares*)

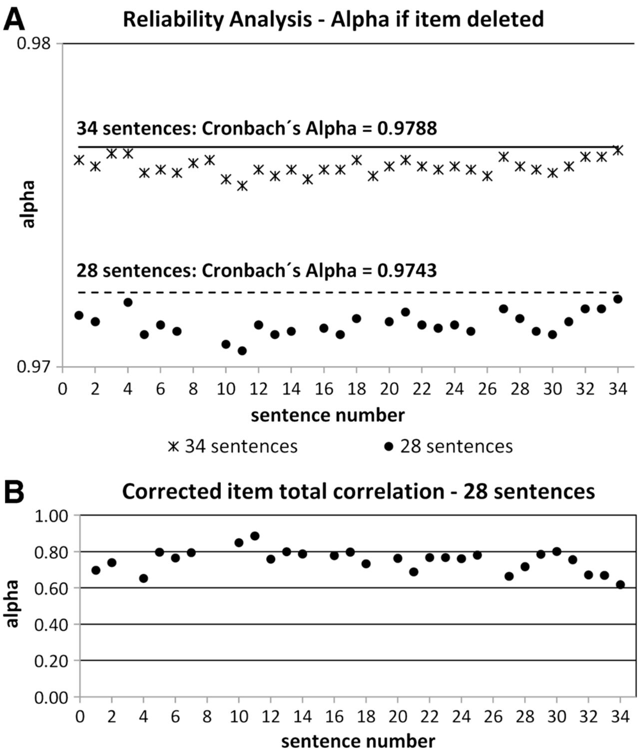

Fig. 6 **a** Reliablity Analysis: "Cronbach's alpha coefficiant" (*line* and *broken line*) and "alpha if item deleted" are given for all 34 sentences (*asterisk*) and for the 28 selected sentences (*dots*). "Alpha if item deleted" never exeeds the Cronbach's alpha coefficiant. **b** "Corrected item total correlations" are shown for the 28 selected sentences and are well above 0.3

Since 1997, the Radner Reading Charts [11, 18, 19] have been developed in a range of languages and used for several clinical studies [9, 26–40]. In the last decade, this standardized multilingual reading test system for clinical practice and research has become an international project because of the increasing need for an internationally comparable reading test that allows for international communication and multicenter research in the field of reading performance. Thus far, the test has been produced in German, Spanish, Dutch, English, French, Italian, Swedish, Danish and Hungarian. Portuguese and Turkish sentence optotypes have already been standardized, and the reading chart versions are currently in the printing process.

The core of the Radner Reading Charts is the concept of sentence optotypes [11, 18, 19], short single sentences that have been standardized in their construction and subsequently statistically selected. Following test item standardization, the reliability and validity of these Radner Reading Charts have been investigated by test-re-test analysis, interchart analysis, and variance component analysis [19, 22]. In addition to their advantage as standardized reading tests for routine clinical use, these Radner Reading Charts not only allow for simultaneous examination of reading acuity and speed but also make it possible to calculate several reading parameters from a single examination, including reading acuity, maximum and mean reading speed, critical print size, and logMAR-logRAD difference [18, 19, 26–40].

The concept that reading speed can be measured with single short sentences presented on a screen had already been introduced by Legge et al. [41]. In 1980, Bailey and Lovie became the first to show that it is possible to determine reading acuity and speed in one simultaneous examination with a reading chart [16]. This concept of simultaneous acuity and speed measurement has also been applied to the MNread acuity cards [10, 17] and to our Radner Reading Charts [11, 18, 19].

The Radner Reading Charts were developed through an interdisciplinary collaboration [11, 18, 19] that generated a statistically selected series of test sentences that are as comparable as possible in terms of number of words (14 words), word length, position of words, lexical difficulty, and syntactical complexity. In addition, the typical word length and word distribution of each language [42] were considered. The length of each line was chosen to be between 27 and 29 characters, including spaces, because this number was found to be used in many newspaper columns, and many visually handicapped patients have expressed a strong desire to read newspapers again. The sentences are complex sentences (main clause and restrictive relative clause), which are simple and common syntactical structures in many languages [11, 18, 19].

In standardizing a series of sentence optotypes for the English version of the Radner Reading Charts, we statistically selected 28 of 34 sentences. Since the reliability analyses for all 34 sentences yielded a high Cronbach's alpha coefficient (0.9788) that was well above the generally agreed lower limit of 0.7 [43–45] and also yielded "corrected item total correlations" that were well above 0.3 [46], none of these sentences would have needed to be excluded from a statistical point of view.

However, one of the main principles of the Radner Reading Chart concept is that the reading length of the sentence optotypes must be as comparable as possible. In order to produce a more restrictive and more comprehensible definition, we introduced a reading time interval (reading length interval) to improve the definition of the sentence optotypes [11, 18, 20–22]. The "reading length interval" is based upon the overall mean and SD: interval = overall mean ±0.25 × SD. All sentences that were read with a mean reading speed between the upper and lower limits of this interval were selected as sentence optotypes. We believe that this strategy optimized the consistency of the test items, a property that is crucial for clinical and research purposes. Reading performance analyses become more reliable and valid under such conditions, and changes in reading speed are most likely related to smaller print size than to sentence characteristics [18, 19].

The present study illustrates the concept of sentences optotypes in English. It further demonstrates that the 28 sentence optotypes selected for the English Radner Reading Charts are well suited for evaluating reading performance in patients with normal to low vision. Thus, the 28 sentences selected for the English version of the Radner Reading Charts constitute valid and reliable test items.

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Conflict of interests The corresponding author receives royalties for the reading charts.

Financial disclosure The RAD-RD© and its reading test setup are patented (AT 504635B1/10-2006). The RAD-RD© is currently used only for research purposes and is not commercially available. For the Radner Reading Charts, one author (W. Radner) receives royalties.

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