Device for Improving Quantification of Reading Acuity and Reading Speed

Alois K. Dexl, MD, MSc; Horst Schlögel, PhD; Michael Wolfbauer; Günther Grabner, MD

ABSTRACT

PURPOSE: To present a new device, the Salzburg Reading Desk (SRD), for the standardized testing of reading acuity and reading speed at a subjectively convenient reading distance (best distance).

METHODS: First, in a systematic experimental setup, testing for validity and reliability was performed at 450 simulated reading distances (90 different test situations, each repeated 5 times) between 16 and 70 cm. The distance read-outs by the SRD software were correlated to the distances measured with a meter ruler. Second, reading distance and reading speed of 27 naturally emmetropic and presbyopic patients were evaluated using the log-scaled Radner Reading Charts implemented in the SRD.

RESULTS: In the experimental setup, an overall mean difference of the SRD distance read-out—compared to a standard distance measurement with a meter ruler—of 0.08±0.13 cm was observed. In the presbyopic patients, overall mean reading distance was 49.74±4.43 cm. Patients were able to read with their own subjectively convenient reading distance. A constant mean reading speed of sentences with bigger typeface (between 152.4±22.6 words/minute [wpm] and 157.3±15.8 wpm) was found, but reading speed gradually diminished over time when reading sentences with smaller typeface.

CONCLUSIONS: The SRD seems to be a valid and reliable device for testing reading acuity at the best reading distance in an experimental setup as well as in clinical use in presbyopic patients. The SRD may be used whenever a detailed comparison of different methods for correcting presbyopia is required. [*J Refract Surg*. 2010;26(9):682-688.]

doi:10.3928/1081597X-20091119-01

The ability to read is essential for everyday life in our modern, information-based society.[1] Losing the ability to read reduces a person's independence and thus has a grave impact on the perceived quality of life.[1-3] The large presbyopic population, which according to current estimates is currently more than 1.3 billion worldwide, is the major driving force for currently available surgical and refractive techniques in this area.[4-17] Therefore, the direction of interest in refractive surgery is rapidly shifting towards presbyopia, considered by many to be its "final frontier."[18]

The determination of reading acuity is an important clinical examination, especially when the potential benefits of presbyopic surgery are discussed.[4-17] For patients who choose to undergo presbyopic surgery, uncorrected reading acuity and reading speed are the most important measures, because the ability to read comfortably without any correction (ie, spectacles or contacts) is their main motivation for undergoing surgery.

Currently available near- and distance-vision tests meet the minimum requirements of international recommendations,[19-26] but standardization of reading conditions is not yet available. Representative of modern log-scaled reading charts, Radner was the first to implement sentence optotypes to minimize variations between the test items and to keep the geometric proportions as constant as possible at all reading distances.[1,24,27-29] Until now, no automatic device for measuring reading distance accurately was available. The Salzburg Reading Desk (SRD) was introduced to further improve the assessment of reading tests by evaluating reading acuity at the best reading distance.

From University Eye Clinic, Paracelsus Medical University, Salzburg, Austria.

The authors have a proprietary interest in the Salzburg Reading Desk (SRD) technology as patent assignees.

This research project was financially supported by the Fuchs-Foundation for the Promotion of Ophthalmology, Salzburg, Austria; and Adele-Rabensteiner-Foundation of the Austrian Ophthalmologic Society, Vienna, Austria.

Correspondence: Alois K. Dexl, MD, MSc, University Eye Clinic, Paracelsus Medical University, Müllner Hauptstraße 48, A-5020 Salzburg, Austria. Tel: 43 662 4482 57288; Fax: 43 662 4482 3703; E-mail: a.dexl@salk.at

Received: July 4, 2008; Accepted: October 14, 2009

Posted online: December 1, 2009

The importance of having such a standardized device to evaluate reading acuity and reading speed—especially when comparing different methods for correcting presbyopia—is increasing because of the growing number of surgical and refractive options for providing acceptable uncorrected vision at both distance and near. Although the design of modern logarithmic-scaled reading charts offers the possibility of testing reading acuity at different reading distances, currently no published method exists that allows automatic evaluation of reading acuity and reading speed at best reading distance.

This article presents a specially designed reading desk, SRD, which enables clinicians and researchers to systematically evaluate reading acuity and reading speed at best reading distance under standardized conditions. With this device, better evaluation of everyday reading abilities seems possible through simulation of the natural reading process.

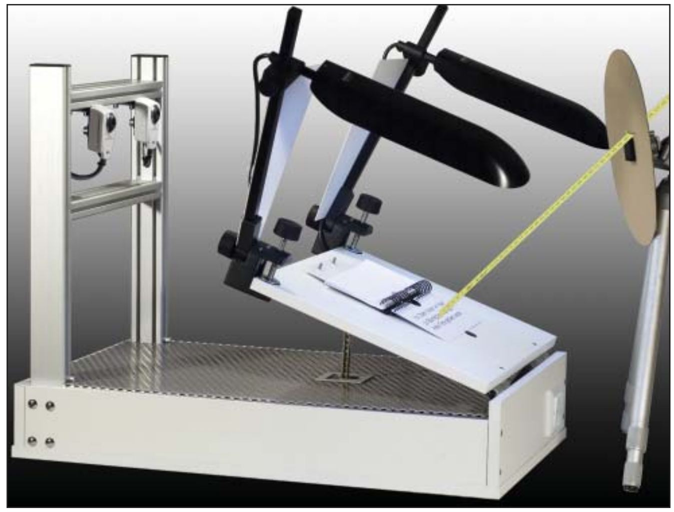

Figure 1. Side view of the Salzburg Reading Desk (SRD). Camera tripod with cardboard and green color-coding dot simulating a test situation in front of the SRD. Yellow meter ruler for reference distance measurement in front of the SRD.

PATIENTS AND METHODS

Radner Reading Charts

Some of the mandatory principles for the standardization of vision tests outlined above[19-22] have been used in the design of new reading charts.[23,24,26] Radner was the first to investigate the test–retest and interchart reliability of his Radner Reading Charts under clinical conditions,[27] which are currently available in German, English, Turkish, Dutch, Swedish, and Spanish, and have been prepared for French and other languages.[1,24,27-29]

The Radner Reading Charts are explained below in detail as an example of the concept of log-scaled reading charts, which make it possible to test reading acuity at different distances.

By implementing sentence optotypes, Radner developed a series of test sentences that are comparable in terms of the number of words, word length, position of words, lexical difficulty, and syntactical complexity, by establishing over 30 definition rules.[1,24,27-29] These sentence optotypes have been shown to provide fully standardized clinical measurements of reading acuity and reading speed.[1,24,27-29] They represent 3rd-grade relative clauses, which are the first complex, but still easily readable, adult sentences.[1,24,27-29] For every language outlined above, three different charts are available.

For the precise documentation of reading acuity, Radner implemented the term "logRAD"[1,24,27-29] (logarithm of the reading acuity determination), which represents the reading equivalent of logMAR. Reading speed can be easily calculated on the basis of the number of words in a sentence (14) and the time needed to read this sentence (14 words×60 sec/reading time).[1,24,27-29]

Salzburg Reading Desk

The SRD system (Fig 1) is a specially designed reading desk. Data acquisition and processing are managed with a USB multi-function DAS module and the SRD software.

Measurement of reading distance is possible with video-stereo-photometry and additional software. For this purpose, the bridge of the patient's nose is marked with a small green color-coding dot. The perpendicular distance between this point and the text line on the corresponding reading chart is continuously monitored, displayed, and processed to indicate the reading acuity in logRAD.

The SRD software has been developed to cover possible reading distances between 16 and 70 cm, at inclinations of the reading surface between 0° and 40°. As an upper limit, a reading distance of 70 cm was chosen; the lower limit depends on the inclination of the reading surface. Between 0° and 10°, reading distance can be measured between 25 and 70 cm. This lower reading distance limit decreases with the increasing inclination of the reading surface to 20 cm between 15° and 20°, and 16 cm between 25° and 40°.

Patients are able to adjust the inclination of the SRD to a subjectively convenient position to offer the most convenient test circumstances.

Each single sentence of the Radner Reading Chart is mounted on the SRD in a specifically designed "textbook." Every textbook has 12 pages, in which the original sentences of Radner (cut out of his commercially available charts) have been glued. In its original version, each chart has 14 sentences—the two largest ones having been omitted, as they are used only to test reading acuity in low vision pa-

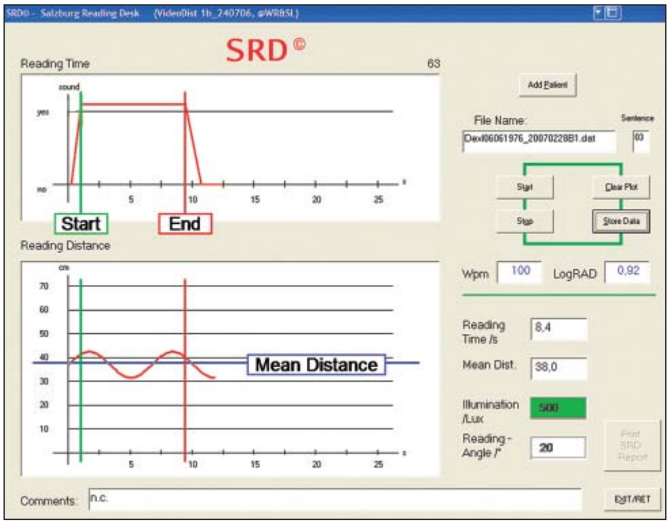

Figure 2. Salzburg Reading Desk (SRD) user interface. The upper white horizontal box represents the reading process (sound yes or no), and the lower horizontal white box represents the distance measurement (simulated sinus curve). The user has to define the reading period by positioning a green vertical line at the beginning and a red vertical line at the end of the reading process.

tients. Hence, within this textbook, the largest sentence is sentence #3, and the smallest is sentence #14. The textbooks are easily exchangeable to prevent a possible recognition and learning/memorizing effect. But, in principle, textbooks of other available log-scaled reading charts could be generated and used with the SRD. Two fluorescent tubes, which emit light similar to daylight (5400 K, 40 kHz), uniformly illuminate the reading surface of the SRD. This preadjusted illumination level was chosen based on the existing normal European illumination of working and reading surfaces, respectively, in offices and libraries.[30] However, the operator is able to set the illumination to a different value, if desired.

Patients read the sentences aloud into a microphone, which sends a signal to the computer, providing visualization of the reading process (Fig 2). At the end of each reading process (ie, a complete sentence has been read aloud by the patient), the examiner defines the beginning and end of the reading process by positioning two vertical lines on the user-interface (see Fig 2). A sentence will be taken into statistical account, when the sentence has been read aloud by the patient, with a minimum reading speed of 80 words per minute (wpm), which represents the lower limit for recreational, sense-capturing reading.[31,32] The software automatically calculates and displays the following parameters: reading acuity at best reading distance (logRAD), reading speed (words/minute), reading distance (cm), reading time (seconds), illumination of the reading surface (preset to 500 lux), and inclination (reading angle) of the SRD (0° to 40°).

Experiment

As the reading distance measurement is the most important parameter in testing reading acuity with the SRD, validity and reliability were tested with 450 single measurements (90 different test situations, each repeated 5 times) in simulated reading distances between 16 and 70 cm and inclinations of the reading surface between 0° and 40°. To check the entire possible test spectrum, validity and reliability have been evaluated by correlating the calculated reading distance from the SRD to the distance as measured with a meter ruler, which served as a reference method of measuring reading distances (see Fig 1). All computations were done using Statistica 6.1 (StatSoft Inc, Tulsa, Oklahoma).

Validity Testing. As a limit of agreement for validity, a possible deviation (95% confidence interval [CI]) to the reference value of ±0.5 cm was set. This value was chosen because a possible measurement error of ±0.5 cm would only create a possible logRAD inconsistency between ±0.013 logRAD at 16 cm and ±0.003 logRAD at 70 cm, which was judged by the authors to be of no clinical relevance.

The formula was as follows:

$$\text{Error(logRAD)} = \log\,(1+\Delta/D)$$

where Δ is the accepted measurement error of 0.5 cm and D is the reference value (between 16 and 70 cm).

Reliability Testing. Each test was repeated five times, assuming it to be reliable when the standard error within these five repeated measurements was within the range of ±0.05 cm, which represents the tenth of the limit for validity.

Experimental Setup. Cardboard was positioned on a camera tripod (to simulate the face of a trial patient) in front of the SRD (see Fig 1). Each simulated reading distance was quantified in advance with a meter ruler. Thereafter, mean values, standard deviations, standard errors, and 95% CIs were calculated.

Clinical Use in Presbyopic Patients

Preoperative data of 27 naturally emmetropic and presbyopic patients aged between 50 and 57 years (mean: 52.8±2.1 years) who presented to the University Eye Clinic, Salzburg, Austria, for possible surgical correction of presbyopia, were used to evaluate whether the SRD could be an additional advantageous clinical tool for the assessment of reading ability (especially reading distance and reading acuity/reading speed at best distance). All patients were naturally emmetropic and had to read binocularly without externally worn correction (with a minimum reading speed of 80 wpm). Mean values, standard deviations, standard errors, and 95% CIs

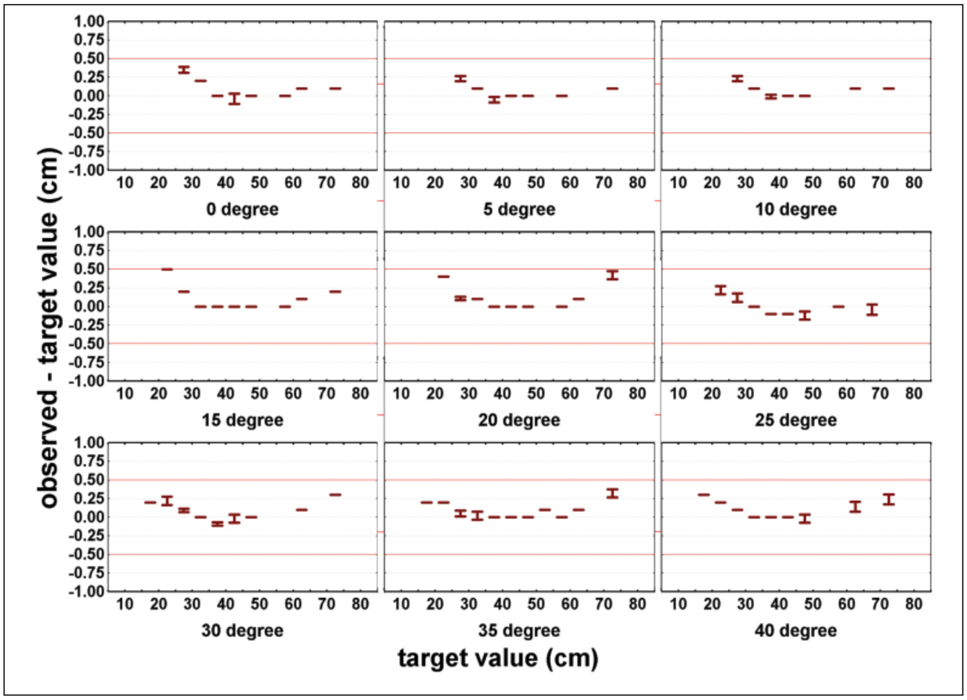

Figure 3. Bland-Altman plot indicating the 95% confidence interval of comparison of the observed value to the target value. The red lines indicate the limits of agreement (±0.5 cm from target value) for validity.

TABLE 1

Difference in Reading Distance in the Experimental Setup as Measured by the Salzburg Reading Desk and Reference Method With a Meter Ruler

Inclination of Reading Surface (°)	No. of Tests	Difference (cm) Mean	SD	SE	−95% CI	+95% CI
0	45	0.11	0.15	0.02	0.07	0.16
5	45	0.06	0.11	0.02	0.03	0.10
10	45	0.08	0.10	0.01	0.05	0.11
15	50	0.11	0.16	0.02	0.07	0.16
20	50	0.12	0.16	0.02	0.07	0.16
25	50	0.00	0.12	0.02	0.03	0.03
30	55	0.07	0.13	0.02	0.04	0.11
35	55	0.09	0.11	0.01	0.06	0.11
40	55	0.10	0.11	0.01	0.07	0.13
Overall	450	0.08	0.13	0.02	0.05	0.13

SD = standard deviation, SE = standard error, CI = confidence interval

of reading distance and reading speed were calculated, as well as mean values and standard deviations of descriptive parameters such as manifest refraction (sphere and cylinder) and reading acuity at best distance.

RESULTS

Experiment Data

The Bland-Altman plot[33] is used to compare two different measuring methods (eg, a new measuring method to a reference method), and is an appropriate statistical method for verifying validity and reliability. The measured distance, using a meter ruler, between the green dot and the Radner Reading Chart served as a reference and was compared to the distance read-out by the SRD software. In the experiment, an overall mean deviation of 0.08±0.13 cm to the reference measurement method was observed, with a mean standard error of 0.02 cm. A deviation to the above-mentioned preset limits of agreement for validity and reliability did not occur in any

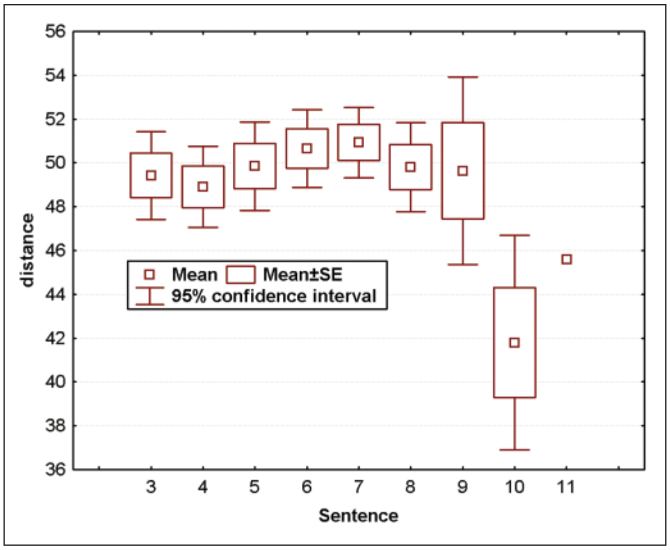

Figure 4. Box plot showing the reading distance (cm) of the presbyopic patient group (SE = standard error).

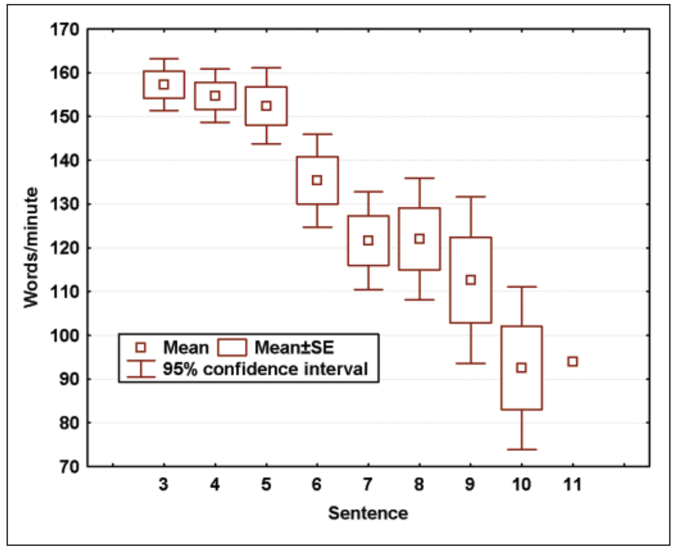

Figure 5. Box plot showing the reading speed (words/minute) of the presbyopic patient group (SE = standard error).

of the test situations. Test situations and outcomes are summarized in Figure 3 and Table 1.

Clinical Data

Reading Distance. Twenty-six patients were able to read through sentence 5, only one patient was able to read through sentence 11, and no patient was able to read sentences with smaller typeface without correction. The reading distance was relatively constant from sentences 3 through 9, with a minimum reading distance of 48.91±4.92 cm (sentence 4) and maximum reading distance of 50.93±3.66 cm (sentence 7). The sample sizes from sentences 10 (n=2) and 11 (n=1) are small, but in these sentences, the reading distance diminished to 41.8±3.54 cm and 45.6 cm, respectively (Fig 4, Table 2). Based on their reading distances, patients had a mean uncorrected binocular reading acuity at a best distance of 0.37±0.14 logRAD (Table 2).

Reading Speed. Whereas patients were able to read the sentences with bigger typeface with a constant reading speed (sentences 3 through 5, mean reading speed was between 152.4±22.6 wpm and 157.3±15.8 wpm), when reading sentences with smaller typeface, the mean reading speed gradually diminished and fewer patients were actually able to read the sentences with a minimum reading speed of 80 wpm (Fig 5, Table 3).

DISCUSSION

Cataract and refractive surgery has developed rapidly over the past decade.[34] The determination of visual acuity is one of the most important clinical examinations when dealing with the potential benefits of procedures to correct presbyopia.[4-17] Refractive surgeons and clinicians often tend to overlook the fact that the visual system is composed of an optical component and an important sensory component that begins at the retinal photoreceptor level and ends at the optical cortex.[35] Hence, when the aim is only to test the "optical system," it seems appropriate to test "pure" near visual acuity at first sight. Yet, reading is much more than just being able to discriminate single optotypes in an almost unlimited time period. Therefore, in all refractive patients, reading acuity, not near visual acuity, should be tested, because that is what the patient, willing to undergo surgery, wants to regain postoperatively.

Reading distance—the most critical parameter in testing reading acuity—seems to vary considerably in every patient tested, especially when he/she is allowed to choose a subjectively convenient reading distance. Subjective reading distance depends on posture, body size, habits, illumination, type of spectacles, and other factors to be evaluated. Therefore, measuring reading acuity with a fixed reading distance does not allow conclusions to be drawn on the everyday reading ability of individual patients. Modern logarithmic-scaled reading charts offer the possibility of testing reading acuity at different reading distances, and the SRD seems to continue to improve reading test assessments by evaluating reading acuity at best reading distance.

In the present study, we evaluated a new method for testing reading acuity at best reading distance. In a standardized setting, the complete test spectrum, regarding reading distance and inclination of the reading surface, was evaluated. In 100% of the test settings, we were able to stay within the previously set limits of agreement. In the first clinical use of the SRD in presbyopic patients, we

TABLE 2

Reading Distance and Reading Acuity of the Presbyopic Patient Group

Sentence	No. of Patients*	Distance (cm)					LogRAD	
		Mean	SD	SE	−95% CI	+95% CI	Mean	SD
3	27	49.43	5.30	1.02	47.43	53.94		
4	27	48.91	4.92	0.95	47.05	53.26		
5	26	49.85	5.24	1.03	47.83	54.34		
6	26	50.66	4.60	0.90	48.89	54.86		
7	20	50.93	3.66	0.82	49.33	54.68		
8	10	49.81	3.26	1.03	47.79	53.35		
9	5	49.64	4.89	2.19	45.35	53.97		
10	2	41.80	3.54	2.50	36.90	45.49		
11	1	45.60	—	—	—	—		
Overall		49.74	4.43	0.37	46.32	52.99	0.37	0.14

SD = standard deviation, SE = standard error, CI = confidence interval, logRAD = logarithm of the reading acuity determination
**8 men, 19 women.*

TABLE 3

Reading Speed and Refraction of the Presbyopic Patient Group

Sentence	No. of Patients*	Words Per Minute					Mean±SD	
		Mean	SD	SE	−95% CI	+95% CI	Sphere (D)	Cylinder (D)
3	27	157.26	15.82	3.04	151.29	163.22		
4	27	154.74	16.09	3.10	148.67	160.81		
5	26	152.38	22.62	4.44	143.69	161.08		
6	26	135.38	27.63	5.42	124.76	146.01		
7	20	121.60	25.55	5.71	110.40	132.80		
8	10	122.00	22.41	7.09	108.11	135.89		
9	5	112.60	21.76	9.73	93.53	131.67		
10	2	92.50	13.44	9.50	73.88	111.12		
11	1	94.00	—	—	—			
Overall		126.94	20.66	1.72	119.29	142.82	0.15±0.22	0.08±0.17

SD = standard deviation, SE = standard error, CI = confidence interval
**8 men, 19 women.*

were able to demonstrate that evaluating reading acuity at best distance seems to be an interesting additional parameter in clinical trials. This group of patients had a mean reading distance of 49.74±4.43 cm, which might be an underestimation in regards to their uncorrected reading acuity when tested at a standard reading distance of 40 cm.

We postulate that the SRD is a valid and reliable method for measuring reading distance and calculating the correlating reading acuity at best reading distance and reading speed, as shown in the experimental setup as well as clinically in this group of presbyopic patients.

Using the SRD, it is possible to evaluate reading acuity at best reading distance on an individual basis with higher accuracy. The SRD seems to be an advantageous tool for future studies comparing the everyday reading abilities of patients, especially after presbyopia correcting surgery.

AUTHOR CONTRIBUTIONS

Study concept and design (A.K.D., H.S., M.W., G.G.); data collection (A.K.D.); analysis and interpretation of data (A.K.D., H.S., M.W., G.G.); drafting of the manuscript (A.K.D., G.G.); critical revision of the manuscript (A.K.D., H.S., M.W., G.G.); statistical expertise (A.K.D.); supervision (H.S., M.W., G.G.)

REFERENCES

1. Radner W, Obermayer W, Richter-Müksch S, Willinger U, Velikay-Parel M, Eisenwort B. The validity and reliability of short German sentences for measuring reading speed. *Graefes Arch Clin Exp Ophthalmol*. 2002;240(6):461-467.
2. Uusitalo RJ, Brans T, Pessi T, Tarkkanen A. Evaluating cataract surgery gains by assessing patients' quality of life using the VF-7. *J Cataract Refract Surg*. 1999;25(7):989-994.
3. Mönestam E, Wachtmeister L. The impact of cataract surgery on low vision patients. A population based study. *Acta Ophthalmol Scand*. 1997;75(5):569-576.
4. Anschütz T. Laser correction of hyperopia and presbyopia. *Int Ophthalmol Clin*. 1994;34(4):107-137.
5. Bauerberg JM. Centered vs. inferior off-center ablation to correct hyperopia and presbyopia. *J Refract Surg*. 1999;15(1):66-69.
6. Fernandez-Suntay JP, Pineda R II, Azar DT. Conductive keratoplasty. *Int Ophthalmol Clin*. 2004;44(1):161-168.
7. McDonald MB, Hersh PS, Manche EE, Maloney RK, Davidorf J, Sabry M; Conductive Keratoplasty United States Investigators Group. Conductive keratoplasty for the correction of low to moderate hyperopia: U.S. clinical trial 1-year results on 355 eyes. *Ophthalmology*. 2002;109(11):1978-1989.
8. Schachar RA. Cause and treatment of presbyopia with a method for increasing the amplitude of accommodation. *Ann Ophthalmol*. 1992;24(12):445-447,452.
9. Qazi MA, Pepose JS, Shuster JJ. Implantation of scleral expansion band segments for the treatment of presbyopia. *Am J Ophthalmol*. 2002;134(6):808-815.
10. Fukasaku H, Marron JA. Anterior ciliary sclerotomy with silicone expansion plug implantation: effect on presbyopia and intraocular pressure. *Int Ophthalmol Clin*. 2001;41(2):133-141.
11. Baïkoff G, Matach G, Fontaine A, Ferraz C, Spera C. Correction of presbyopia with refractive multifocal intraocular lenses. *J Cataract Refract Surg*. 2004;30(7):1454-1460.
12. Holladay JT, van Dijk H, Lang A, Portney V, Willis TR, Sun R, Oksman HC. Optical performance of multifocal intraocular lenses. *J Cataract Refract Surg*. 1990;16(4):413-422.
13. Gimbel HV, Sanders DR, Raanan MG. Visual and refractive results of multifocal intraocular lenses. *Ophthalmology*. 1991;98(6):881-888.
14. Langenbucher A, Seitz B, Huber S, Nguyen NX, Küchle M. Theoretical and measured pseudophakic accommodation after the implantation of a new accommodative posterior chamber intraocular lens. *Arch Ophthalmol*. 2003;121(12):1722-1727.
15. Cumming JS, Slade SG, Chayet A; AT-45 Study Group. Clinical evaluation of the model AT-45 silicone accommodating intraocular lens: results of feasibility and the initial phase of a Food and Drug Administration clinical trial. *Ophthalmology*. 2001;108(11):2005-2009.
16. Findl O, Kriechbaum K, Menapace R, Koeppl C, Sacu S, Wirtitsch M, Buehl W, Drexler W. Laserinterferometric assessment of pilocarpine-induced movement of an accommodating intraocular lens: a randomized trial. *Ophthalmology*. 2004;111(8):1515-1521.
17. Küchle M, Seitz B, Langenbucher A, Gusek-Schneider GC, Martus P, Nguyen NX; Erlangen Accomodative Intraocular Lens Study Group. Comparison of 6-month results of implantation of the 1CU accommodative intraocular lens with conventional intraocular lenses. *Ophthalmology*. 2004;111(2):318-324.
18. Waring GO III. Presbyopia and accommodative intraocular lenses—the next frontier in refractive surgery? *Refract Corneal Surg*. 1992;8(6):421-423.
19. Bach M, Kommerell G. Determining visual acuity using European normal values: scientific principles and possibilities for automatic measurement [German]. *Klin Monbl Augenheilkd*. 1998;212(4):190-195.
20. Ophthalmic optics. Visual acuity testing. Standard optotype and its presentation (ISO 8596:1994). Berlin, Germany: Beuth-Verlag; 1994.
21. Colenbrander A. Visual acuity measurement standard. *Ital J Ophthalmol*. 1988;II/I:5-19.
22. Visual acuity test. Part 3, 5 and 6. DIN 58220. Berlin, Germany: Beuth-Verlag; 1997.
23. Bailey IL, Lovie JE. The design and use of a new near-vision chart. *Am J Optom Physiol Opt*. 1980;57(6):378-387.
24. Radner W, Willinger U, Obermayer W, Mudrich C, Velikay-Parel M, Eisenwort B. A new reading chart for simultaneous determination of reading vision and speed [German]. *Klin Monbl Augenheilkd*. 1998;213(3):174-181.
25. Recommended standard procedures for the clinical measurement and specification of visual acuity. Report of working group 39. Committee on Vision. Assembly of Behavioral and Social Sciences, National Research Council, National Academy of Sciences, Washington, D.C. *Adv Ophthalmol*. 1980;41:103-148.
26. Ferris FL III, Kassoff A, Bresnick GH, Bailey I. New visual acuity charts for clinical research. *Am J Ophthalmol*. 1982;94(1):91-96.
27. Stifter E, König F, Lang T, Bauer P, Richter-Müksch S, Velikay-Parel M, Radner W. Reliability of a standardized reading chart system: variance component analysis, test-retest and inter-chart reliability. *Graefes Arch Clin Exp Ophthalmol*. 2004;242(1):31-39.
28. Richter-Mueksch S, Weghaupt H, Skorpik C, Velikay-Parel M, Radner W. Reading performance with a refractive multifocal and a diffractive bifocal intraocular lens. *J Cataract Refract Surg*. 2002;28(11):1957-1963.
29. Ergun E, Maár N, Radner W, Barbazetto I, Schmidt-Erfurth U, Stur M. Scotoma size and reading speed in patients with subfoveal occult choroidal neovascularization in age-related macular degeneration. *Ophthalmology*. 2003;110(1):65-69.
30. Light and lighting. Lighting of work places. Part 1: indoor work places (German version). DIN EN 12464-1:2003 03. Berlin, Germany: Beuth-Verlag; 2003.
31. Rubin GS, West SK, Muñoz B, Bandeen-Roche K, Zeger S, Schein D, Fried LP. A comprehensive assessment of visual impairment in a population of older Americans. The SEE Study. Salisbury Eye Evaluation Project. *Invest Ophthalmol Vis Sci*. 1997;38(3):557-568.
32. Whittaker SG, Lovie-Kitchin J. Visual requirements for reading. *Optom Vis Sci*. 1993;70(1):54-65.
33. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1(8476):307-310.
34. Bühren J, Terzi E, Bach M, Wesemann W, Kohnen T. Measuring contrast sensitivity under different lighting conditions: comparison of three tests. *Optom Vis Sci*. 2006;83(5):290-298.
35. Holladay JT. Understanding neural adaptation. In: *Quality of Vision: Essential Optics for the Refractive Surgeon*. Thorofare, NJ: SLACK Incorporated; 2007:115-122.