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Lighting Needs and Lighting Comfort During Reading with Age-Related Macular Degeneration

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Abstract: This study investigated the effects of changes in luminance on the oral reading speeds of 13 participants with age-related macular degeneration (AMD) and a control group of six age-matched persons with typical vision. For the AMD participants, self-reports of light preferences were also recorded. In the AMD group, reading rates depended on light levels and were considerably lower than those of the control group. Reading speeds differed substantially among the AMD participants and, to obtain a functional range of luminance levels for reading, a combination of objective measurements and self-reports were required.

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Age-related macular degeneration (AMD) is the most common cause of visual impairment among elderly persons in developed countries (Evans, 2001). The condition results in reduced visual acuity, reduced contrast sensitivity, and central or paracentral scotomas (Fosse, Valberg, & Arnljot, 2001; Marshall, 1991; Van der Schaft, 1993). The resulting functional visual disabilities have a significant impact on the quality of these persons' lives. Persons with AMD may lose their driver's licenses, fail to recognize people they pass on the street, and suffer a significant loss of reading ability. For some, AMD may even result in functional illiteracy in the absence of adequate rehabilitation (Fosse, 2000).

Reading ability may be restored, to a large extent, if a person with AMD is fitted with customized spectacles and/or is provided with a closed-circuit television system (CCTV), along with proper training (Bäckman

& Inde, 1979; Fosse, 1984; Lund & Watson, 1997; Nilsson & Nilsson, 1986). The person's reading speed is, however, drastically lower than that of a person with typical vision (Bullimore & Bailey, 1995; Legge, Rubin, Pelli, & Schleske, 1985). Some persons with AMD may find it difficult to use high lens power because the eyeglasses necessitate a short reading distance, which may be uncomfortable and result in fatigue when reading (Faye, 1984).

The reading performance of persons with AMD is more likely to improve with an increase in luminance than is the reading performance of persons with typical vision (Bowers, Meek, & Stewart, 2001; Bullimore & Bailey, 1995; Eldred, 1992; Lovie-Kitchin, Bowman, & Farmer, 1983; Sloan, Habel, & Feiock, 1973). Appropriate and comfortable lighting is also an essential factor in the benefits obtained from optical aids in reading rehabilitation (Bowers et al., 2001; Cornelissen, Kooijman, van Schoot, Bootsma, & van der Wildt, 1994; Eldred, 1992; LaGrow, 1986). LaGrow demonstrated that the reading rates of 60 visually impaired adults with diverse ocular pathologies increased significantly at optimal levels of illumination compared to standard room illumination. In a group of 18 persons with AMD, Eldred found that all had optimal reading rates for lighting levels above 480 lux and that 11 performed best at lighting levels above 5900 lux. Similarly, Bowers et al . found that the majority of their AMD participants required task illumination of at least 2000 lux to maximize their reading performance. (See Box 1 for an explanation of the technical terms used in this article.) The visual acuities of persons with AMD may be significantly affected by changes in levels of photopic light (Fosse et al., 2001; Sloan, 1969). Some persons with AMD require light intensities above 300 cd/m^2 to obtain maximum acuity (Fosse et al., 2001; Sloan, 1969), whereas others show no change or only minor improvement with light intensities above 4 cd/m^2 (Brown & Kitchin, 1983; Fosse et al., 2001).

The aim of the study presented here was to evaluate the effects of luminance on the individual reading performance of 13 participants with AMD and to compare the objective measurements of reading speed with the participants' self-reports of their comfort with lighting while they were reading. We hypothesized that it is possible to identify the optimal level of light for reading and to determine a larger, acceptable range of luminance. We also wanted to explore the individual relationship between near letter visual acuity and reading speed as a function of luminance, under the assumption that an increase in acuity will also have a positive impact on the reading rate.

Great care was taken to ensure that the participants were pure AMD cases; that is, that they had no other ailment, such as cataract, glaucoma, or diabetes. It was necessary to do so to eliminate the possibility that the variability found could be ascribed to such additional factors. This point has not always been given sufficient attention in the literature.

Method

Participants

Twenty-two persons with binocular AMD, aged 67 or older, were originally referred to the study. Since we wanted to ensure that the results were pertinent to AMD alone, the persons were enrolled only if no other disease relevant to visual function was present. At the time of enrollment, the distance decimal visual acuity for the best eye, given by the referring ophthalmologist, was to be between 0.05 (corresponding to Snellen 20/400) and 0.33 (corresponding to Snellen 20/60), spherical refractive errors were to be no more than ± 6.0 diopters (D), and cylinders were to be ≤ 3D. On the basis of comprehensive ophthalmological and optometric examinations, only 13 participants met the strict selection criteria.

The AMD participants were to have either typical findings of "dry" (nonexudative) macular degeneration, with clear-cut atrophy of the pigment epithelium, or "wet" (neovascular/exudative) macular degeneration, with neovascularization (growth of new blood vessels), hemorrhagic or serous detachment of the pigment epithelium, lipid exudation (the slow escape of lipids from blood vessels through pores or breaks in the cell membranes), and/or fibrotic scars. Persons with central corneal or lens opacities were excluded from the study. To evaluate the size and location of central and paracentral scotomas and to exclude other diagnoses, manual perimetries were performed on all persons using the Haag- Streit Goldman perimeter. Diagnoses were finally established on the basis of clinical findings, including fundus photographs for all patients and fluorescein angiography for some. The participants were then assigned to either a wet (AMD-W) or a dry (AMD-D) subgroup.

Details regarding the participants' ages, genders, and diagnoses are presented in Table 2. Six participants with typical vision, aged 65 years or older (mean age: 74 years), served as the control group. All the participants gave their informed, written consent to participate and passed the verbal part of the Wechsler Adult Intelligence Scale. The same 13 persons with AMD formed the basis of three previously published studies (Fosse & Valberg, 2001; Fosse et al., 2001; Valberg & Fosse, 2002). All the AMD participants were, prior to the onset of AMD, experienced readers, according to their self-reports.

Test facilities and procedures

Vision and Light Laboratory

All experiments were carried out in the Vision and Light Laboratory (VLL) at the Tambartun National Resource Center of the Visually Impaired in Norway.

The VLL contained technical equipment that enabled us to assess a range of visual functions, such as visual field, visual acuity, luminance and color-contrast sensitivity, illumination requirements, light and dark adaptation, and so forth. The technical aids available were ophthalmological, optometric, educational, and physical equipment. Besides the diagnostic tools for medical purposes and the common optical aids required for reading and orientation (for example, spectacles, telescopes, and filter eyeglasses), there were CCTV systems and software- and hardware-enhancement systems for word processors.

During the experiments, lighting requirements for reading and acuity testing were analyzed using fluorescent tubes (color-rendering index, Ra = 85) mounted in low-reflectance luminaries that covered the ceiling. Low luminance values were obtained using halogen spotlights with dimmers, and Luxo table lamps and spotlights were added to the fluorescent tubes to reach a maximum level of 1200 cd/m^2 . We did not compare the different sources of light with one another, nor did we study the individual effects of these sources on the participants' reading performance.

Visual acuity

Near letter acuity (NLA) was obtained using the double-sided logarithmic NLA chart 2000 (Precision Vision, 1998), which measures acuity in the 0.05 (20/400) to 2.0 (40/20) range when testing is performed at 40 cm (about 16 inches). The participants were placed 20 cm or 40 cm (about 8 inches or 16 inches) from the near chart, using a chin and forehead rest to ensure a fixed viewing distance. All were optimally corrected for the relevant distances. The chart was presented with a surround of the same luminance as the chart (± 5%) at all but the highest level of luminance. At 1200 cd/m^2 , the surround luminance was 50% lower than that of the chart, since the available lighting equipment could provide a maximum light level of only 600 cd/m^2 for the background (that is, the wall behind the chart).

All assessments of visual acuity were made using the better eye, starting at 0.4 cd/m^2 after a minimum of six minutes of adaptation to the dark, following preadaptation to a normally lit room of about 200 lux illuminance. The acuity assessments were performed consecutively from low to high light levels. Here, we present data on acuities for levels of luminance from 4 cd/m^2 to 1200 cd/m^2. All acuity scores were based on all correctly identified letters using a scoring scale with increments of 0.02 logMAR (Lovie-Kitchin, 1996). For details on visual acuity at lower levels of luminance, see Fosse et al. (2001).

Both NLA and reading rate were measured at the same nine levels of luminance (4, 14, 40, 80, 140, 300, 400, 600, and 1200 cd/m^2) for all the participants with AMD. Luminance levels were controlled as a matter of routine before each reading session by using a Minolta luminance meter.

Reading rate

All assessments and the reading tasks were performed with the better eye, conventionally defined as the eye with the best letter visual acuity. Reading rates were obtained using the Tambartun Oral Reading Test (hereafter the Tambartun test; Fosse, 2001), a test with 28 different charts, each consisting of 50 words. The test is available in several different print sizes, from 12 to 32 points, all in Times Roman font. Readers with typical vision read one test chart aloud in about 18–25 seconds, corresponding to a reading rate of about 120–165 words per minute (WPM; Fosse, 2001). All the test charts have the same level of difficulty. The 50 words in each chart are randomly selected from the 300 most frequently used two- to six-letter words in a selection of texts from Norway's three largest newspapers (Heggstad, 1971; Hunstad, 1992). All the words in the test charts are unrelated, which means that the participant is not able to base his or her reading on the syntactic and semantic cues available in a meaningful text. Consequently, the participant has to rely exclusively on visual information to recognize the words that are presented.

Magnification

The need for magnification during reading was established by using the Norwegian version of the MNREAD Acuity Chart (Mansfield, Ahn, Legge, & Luebker, 1993), which consists of short sentences with print sizes varying from 1.25M to 8M, equal to about 10- to 64-point text. Each sentence was read aloud as rapidly as possible at a fixed distance (normally at 20, 30, or 40 cm, or about 8, 12, or 16 inches, depending on acuity) with the AMD participants wearing optimal correction. This procedure allowed for the identification of the *critical print size*—the smallest print size that produced the maximum reading rate. The geometric difference between the critical print size and the word acuity threshold is referred to as the *acuity reserve* (AR; Whittaker & Lovie-Kitchin, 1993). In this article, we report the acuity reserve as the ratio between the critical print size and NLA, both measured in minutes of arc. A four-step procedure was used to establish the magnification required for reading:

Step 1. We determined a level of luminance appropriate for optimal reading on the basis of measures of visual acuity and self-reports. We did so by presenting the level of light at which the best acuity was obtained and asking the participants if they felt comfortable with it. If a participant indicated in any way that the chosen level was uncomfortable, we adjusted the light until he or she was satisfied.

Step 2. We then applied the MNREAD Acuity Chart to obtain an estimate of the critical print size. The AMD participants were asked to read each sentence aloud at a fixed distance (as was described earlier), starting with the 8M (about 64-point) text, continuing with the smaller print sizes until their reading speeds decreased significantly. During reading, the participants were optimally corrected for the chosen reading distance.

Step 3. To estimate optimum magnification for reading 16-point Times Roman text, we divided the critical print size using the stroke width of the letter "l," in millimeters, with the corresponding stroke width for 16-point print size, which gave us the magnification factor needed to obtain the optimum retinal print size for reading 16-point text. The distance at which the critical print size was originally read, divided by the magnification factor, gave us the new reading distance for 16-point text. To control the luminance of the text charts, we could not make the reading distance lower than 4–5 cm (about 1.6–2 inches). Most participants could read 16-point text at a distance of 4–5 cm or greater, but for a few, 26- or 32-point text sizes were used. For those who read 26- or 32-point text, magnification and reading distance were determined by the same procedure as was described for 16-point text. All the participants wore monocular spectacles that were appropriate for their reading distance.

Step 4. In Steps 2 and 3, we obtained the retinal print size that was considered optimal by the chosen criteria. Although critical print size defines the *smallest* print size that permits the maximum reading rate, some persons may prefer a smaller or larger retinal image for reading longer texts. We therefore established the *preferred* print size by asking the participants to read some of the Tambartun test charts while lens power was added or subtracted in small step sizes (1.0D to 2.0D). Starting a few diopters below the optimal retinal print size, we gradually increased the magnification while we adjusted the reading distance in accordance with the altered lens power. When we asked which magnification the participants preferred, none preferred a magnification lower than the critical print size. The majority of the AMD participants preferred a magnification that was slightly larger than that determined by the critical print size, as obtained by MNREAD.

The AR, defined earlier, was between 2.3:1 and 18.5:1, with a mean of 6.0:1. The AR values at light levels for which the maximum reading speed was obtained are presented in column 7 of Table 2. To compare the magnification used by different participants, we calculated the magnification needed to read 12-point Times Roman text. Table 2, column 6, presents these data in ADD diopters.

Reading speed and illumination

The participants were asked to read aloud from two to four randomly picked Tambartun test charts at each level of luminance. Before the testing, they were given a short training period during which they read two or three of the test charts other than those used for testing. They were asked to read as fast as they could without skipping any of the words presented in the text and were instructed to continue without a pause, even if they thought that they had misidentified a word. Each participant's reading rate (in WPM) was calculated on the basis of correctly identified words, normally given as the mean result of two tests at each level of luminance. For a few highly motivated participants, we increased the number of tests from two to three or four. Since the participants were reading short texts, we controlled the time spent by using a stopwatch and counted the number of misread words by making continuous notes.

To compare the objective measurements with self-reports, we asked the AMD participants to indicate, on a comfort scale of from 1 (a highly uncomfortable light level) to 5 (a very comfortable light level) what they felt about each light level. The participants were instructed to score each light level independently without comparing light levels.

The AMD participants were tested at luminance levels ranging from 4 to 1200 cd/m^2. In each session, reading tests were performed for three photopic ranges, each covering a different range of luminance levels: 300, 400, 600, and 1200 cd/m^2 (high photopic); 40, 80, and 140 cd/m ^{2} (photopic); and 4 and 14 cd/m^2 (low photopic). Between each range, two minutes of adaptation time was allowed. Approximately one minute was allowed between luminance levels within each photopic range, this being the time needed to control the luminance level and mount a new reading chart in the frame. First, we randomly selected the luminance range (high photopic, photopic, or low photopic) at which the testing should start. We then randomly selected the luminance levels within each range. Then the next luminance range was randomly selected, and so on.

For the participants who read twice at each light level, the reading assessments were performed on the same day. For the three participants who read three or four times at each light level, the assessments sometimes extended over two days. When one reading session was finished, the participants took a break of 30–45 minutes before they started all over again. By using this procedure, with frequent short breaks within each reading session and a longer break at the end of each session, we largely avoided complaints of strain. However, for a few participants (E, G, and J), we had to decrease the number of reading assessments because they indicated fatigue. Therefore, for these participants, we skipped an assessment or made only one assessment at levels of light that they felt were uncomfortable or yielded low reading speeds. Participants K and M were unable to read at all at lower levels of luminance.

For the control group, we introduced a total of eight luminance levels for reading, from 0.4 to 1200 cd/m ^{2}, as is shown in the upper curve of Figure 1. These participants read 16-point text and wore their own reading glasses during the assessments.

Statistics, acuity notations, reliability, and validity

Correlation coefficients for each individual were calculated for the average reading speed in relation to the average comfort score during reading. We used Spearman correlation coefficients, since they are nonparametric and do not require specific distributional assumptions. Two-tailed *p*-values are regarded as significant for values lower than .05. In the text and tables, we present decimal acuity and Snellen equivalents as notations. In the figures, we present only decimal acuity, but Snellen equivalents are given in the caption for Figure 3.

In a previous study (Fosse, 2001), both the reliability and the validity of the Tambartun test were tested. The average correlation between the reading speed for each possible pair of charts in the test was 0.96 (Chronbach's alpha: 0.998) and 0.98 (Chronbach's alpha: 0.999) for 9 sighted and 11 visually impaired participants, respectively. The reading speed for the 11 visually impaired participants varied from an average of 34 WPM for the poorest reader to 156 WPM for the best reader, with a relative standard deviation ranging from 3.4% to 10.3%. The relative standard deviation was defined as (*SD* /MORR)*100, MORR being the mean oral reading rate in WPM and *SD* the standard deviation. The validity of the Tambartun test was assessed by comparing the reading speed obtained from the Tambartun test with the measures of reading speed from a semantically meaningful text. The Pearson correlation coefficients between the reading speeds for the two tests were 0.87 and 0.92 ($p < .001$) for the sighted group and the visually impaired group, respectively. It was also noted that the average reading speed was 1.3 times higher when the participants read a meaningful text than when they read the Tambartun test.

The reliability, or measure of internal consistency from one set of lighting-comfort measurements to another, was calculated for the eight participants who read two times or more at each level of luminance. The mean correlation is $r = .53$ ($n = 8$), but with a large variation, from $r = .00$ for the poorest to $r = .83$ for the highest. Excluding the outlier ($r = .00$) yielded a mean correlation of $r = .60$ ($n = 7$), varying from $r = .38$ to $r = .83$.

Results

The upper curve of Figure 1 depicts the average reading speed for the six participants with typical vision in the control group, with ±1 *SD* across the participants at each level of luminance. In this group, the mean reading speed was relatively stable as a function of photopic luminance for the interval ranging from 4 to 1200 cd/m^2. In comparison, for the group of AMD participants, there was a larger reduction in the mean reading speed with ±1 *SD* than for the participants with typical vision, with a substantial intersubjective difference (see the lower curve of Figure 1). In the AMD group, reading speed usually improved up to about 80 cd/m^2 or higher. The mean reduction in reading speed changed from about 28% of that of the control group at low levels of luminance to 42% at the highest luminances.

Plots of oral reading speed and lighting comfort are shown in Figure 2 for the 13 AMD participants (A–M). The reading rate (the solid lines and filled circles), with error bars showing maximum deviation at each light level, is plotted against the left y-axis and was tested over a 2.5 log unit range (8 octaves) of luminance, from 4 to 1200 cd/m^2. The bottom graph in each panel (dashed lines) is plotted against the right y-axis, giving the AMD participants' subjective rating of comfort at each light level, on a scale of 1 (a highly uncomfortable light level) to 5 (a very comfortable light level).

Seven AMD participants (A, B, C, D, G, I, and L) obtained maximum reading speeds for a luminance value of between 80 and 400 cd/m^2. The same participants also achieved a satisfactory and fairly comfortable reading level for a three-octave luminance range or larger. However, Participants G and I did not indicate a high level of comfort at *any* light level. Five participants (E, F, H, J, and K) had a maximum reading rate for luminances that were equal to or higher than 300 cd/m^2 , but only Participants F, H, and K had light preferences that were restricted to the light levels for which their maximum reading speeds were obtained. Participants E and J accepted a larger range of luminance, including levels for which their reading speeds were best, as well as levels of light for which their reading speeds were severely reduced. However, both participants were easily fatigued by the reading sessions, and the number of assessments was therefore reduced compared with the other participants. The remaining participant, M, differed somewhat from the others. She never achieved functional reading, since her maximum reading speed never exceeded 15–20 WPM. For her, reading was a strain, and she did not believe that she would be able to read in this manner for an extended period.

Table 3 shows the Spearman correlation coefficients between reading speed and comfort with light levels for each AMD participant. Participants B, C, D, E, F, G, J, and K had correlation coefficients ranging from .68 to .93, whereas the remaining six participants had either low or nonsignificant coefficients. The information gathered from the lighting-comfort assessments seems to add supplementary information that will prove useful during rehabilitation. For instance, Participant G read fluently at high levels of light but felt uncomfortable at levels of about 1200 cd/

m^2 (see Figure 2).

There were no systematic luminance-dependent differences between the participants with dry and wet AMD with regard to lighting needs during reading. In both groups, we found participants whose reading rates improved rapidly with increasing luminance (for example, AMD-D Participant E and AMD-W Participant F). For AMD-W Participants A and G, we also found reading profiles that resembled those of the AMD-D Participants B and D, with a similar dependence on luminance.

Figure 3 depicts reading speed and visual acuity as a function of luminance. A solid line with circles refers to acuity (the left axis), while a solid line with no markers, the same as those drawn through the data points in Figure 2, refers to reading speed (the right axis). For some participants, an improvement in visual acuity with increased luminance also had a positive impact on their reading rates. This finding is best illustrated in Figure 3 for Participants E, F, H, J, K, and L. However, there were also clear examples in which the highest reading speed was not achieved at the same level of luminance as was the best acuity. For increases in luminance above 100 cd/m^2, the reading speed dropped while the acuity continued to improve for Participant C, whereas for Participant G, the acuity deteriorated slightly above 140 cd/m^2 but the reading speed remained fairly constant.

Discussion

This study was designed to measure lighting needs during reading for participants with AMD only (with no suspicion of other visual disorders). Our goal was to identify both an optimum level of lighting and a wider range of luminance that were acceptable for each individual. We also wanted to see if self-reports of lighting preferences were in agreement with the objective measurements of reading speed and to explore the relationship between NLA and reading speed as a function of luminance.

For the six age-matched participants in the control group who had typical vision, the mean reading speed was relatively stable (about 130 WPM) across the photopic light levels ranging from 4 to 1200 cd/m^2, but with slightly poorer reading performance (about 110 WPM) for mesopic light levels (0.4 cd/m^2). This finding is in agreement with those of other studies (see, for example, Bullimore & Bailey, 1995; Legge & Rubin, 1986).

Although the number of AMD participants in this study was too low to allow the results to be generalized to all persons with AMD, the findings are nevertheless interesting with regard to reading rehabilitation. It is worth noting that since the 13 participants were pure AMD cases with no additional ailment, such as cataract or glaucoma, variability caused by such additional factors can thus be discounted, and the remaining differences can be ascribed to variations in AMD, along with variations in ages within the AMD group. Although we were not able to find any data on age-related increases in the need for illumination for persons aged 60 and older with typical vision, one may assume that the steep rise in lighting needs from age 40 to age 65, documented by Fortuin (1963), extends to persons aged 65 and older. How this age factor influences elderly persons with AMD is, to our knowledge, not known.

For all the participants, it was possible to identify an optimal level of light for reading. For five participants, the reading speed was the highest for a relatively narrow range of luminance, higher than 300 cd/m^2. Seven of the 13 AMD participants achieved a satisfactory reading speed for a three-octave luminance range or wider. One participant (M) never obtained a satisfactory reading rate even at her estimated optimal light level of 140 cd/m^{2,}, probably because she had a combination of a central scotoma, eccentric fixation, and reduced visual acuity. Although her massive central scotoma was confirmed by Haag-Streit Goldman perimetry, her degree of eccentric fixation was difficult to assess, since the size of the scotoma may vary with changing illuminance (Bullimore & Bailey, 1995). This issue is discussed in greater detail later in this section.

The relatively low reading speed for Participant K can be explained by her reluctance to use high lens powers during reading. As a result, she was unable to read fluently at lower levels of luminance, since the AR was close to 1:1. See our discussion of the effects of AR later in this section.

Since the reliability measures, or internal consistency, of the comfort assessments were low for some participants, the comfort scaling is not necessarily a valid expression of preferences for lighting. However, when we omitted the outlier (Participant I, see Figure 2) in the calculations, we found a mean internal consistency of 0.60. Problems associated with the low reliability of assessments of comfort with lighting were also addressed by LaGrow (1986), who did not find an acceptable level of internal consistency of such assessments. LaGrow suggested that the low reliability may have been due to the lack of variance across levels of light. On the other hand, the inclusion of the comfort variable did prevent unnecessary exposure to uncomfortable lighting conditions and, as such, was an important component in the assessment procedure (LaGrow, 1986). These considerations are also relevant for our study. For instance, Participant G indicated low comfort at the highest level of luminance in spite of fluent reading at this level. However, since Bowers et al. (2001) and Cornelissen et al. (1994) did not report the reliability of the comfort assessments, we do not know the extent to which low reliability in the subjective evaluations of comfort with lighting is a general problem. Nevertheless, caution is required when analyzing the data on comfort, and efforts should be made to ensure that the levels of light that are found suitable for reading are in accordance with the preferences and needs of individuals with AMD.

We believe that the optimal levels of light for each individual—when the maximum reading rate is combined with high visual comfort—cannot be identified by objective measurements of reading rate alone or solely by subjective assessments of visual comfort. The studies by LaGrow (1986), Cornelissen et al. (1994), and Bowers et al. (2001) pointed in the same direction. Bowers et al. concluded that optimal illumination should be determined individually for each person using both objective measures of performance and subjective evaluations of visual comfort. Cornelissen et al. also stated that subjective measures alone do not always suffice for optimizing illumination.

In analyses of individuals' reading performance, variation in near visual acuity as a function of luminance can yield important information on some persons' lighting needs while reading. Although the reading speed did increase monotonically with acuity for some participants (for example, H, J, and L), the association between reading speed and acuity for other participants was less predictable. For example, Participant C's reading speed decreased gradually for luminance values higher than 100 cd/m^2, while his acuity improved up to 600 cd/m^2. For participant G, there was a small improvement in his reading speed, from 4 to 140 cd/m^2, after which his reading speed leveled off. In contrast, his visual acuity deteriorated for luminance values higher than 140 cd/m^2.

Two other examples worth noting are Participants E and F, whose reading speeds improved dramatically as luminance increased. These enhanced reading speeds may be related to increasing acuity and increasing AR, but other factors that were not specifically controlled in our study are also of relevance. One possible explanation is that the scotoma changes with increased levels of light, a phenomenon described by Bullimore and Bailey (1995). Another possible explanation may be that different retinal areas are used for reading at different levels of light. Using a scanning laser ophthalmoscope, Lei and Schuchard (1997) documented that persons with central scotomas have different preferred retinal loci at different illuminances; this may have been a factor in our study as well. Our assessments and instructions were related to reading tasks, and they might well have led the participants to use different retinal or macular areas with changing luminances. The participants were urged to fixate in a way that allowed the easiest identification of letters and words, but we did not have the means to control fixation precisely during reading and must consequently leave questions regarding fixation patterns unanswered.

During the reading test, each participant with AMD used the individual magnification at all levels of luminance. Since we based our calculation of AR on NLA (see the Method section), the graphs in Figure 3 showing changes in acuity also illustrate changes in AR; the higher the NLA, the higher the AR, and vice versa. Thus, the reading scores of the AMD participants were influenced, to some extent, by both changing AR and changing levels of light. Therefore, we may have identified the levels of light that allow satisfactory reading for the chosen magnifications, whereas reading rates at other levels may have been influenced by changes in AR as well as luminance. The fact that, so many of the participants achieved satisfactory reading rates over a wide range of levels of light supports the view that, in most cases, we identified a suitable level of light and magnification.

Watson, Baldasare, and Whittaker (1990) found that the oral reading speeds for a coherent text were, on average, 1.6 times greater than the reading speeds for disconnected words for participants with AMD. Similarly, Fosse (2001) found that the reading speed for a continuous text was, as a mean, 1.3 times faster than the reading speed for unrelated words (using the Tambartun test). This finding means that, for some persons with AMD, one can expect an improved reading performance for continuous and meaningful text. This factor was not controlled in our study.

Finally, Eldred (1992) found that for 4 of 18 persons with AMD, high levels of illumination during reading may have been beneficial only for short-term reading tasks. Our study presented no systematic data on long-term reading, nor can we make claims with regard to reading speeds for silent reading or for comprehending sentences.

Practical implications

Reading rehabilitation includes (1) chart-ing an individual's needs, prior reading abilities, and motivation; (2) assessing a person's visual function and magnification needs, testing different optical and technical equipment, and considering a person's need for a CCTV system; (3) providing counseling to help the person achieve insights into his or her situation; (4) giving the necessary instructions and, if necessary, teaching the person new reading techniques; and (5) making plans for local follow-up. Charting needs, analyzing performance, and providing proper guidance and follow-up for visually impaired persons are time-consuming tasks. Even so, the addition of systematic assessments of lighting needs during reading to the foregoing list seems both cost-effective and rewarding. At the Tambartun National Resource Center, we are in the fortunate position of being able to dedicate considerable time (typically, one or two days) to low vision rehabilitation for each individual. Supplementing current assessments with the measures suggested next may therefore be feasible.

The importance of proper lighting for people who are visually impaired is widely accepted (see, for example, Bowers et al., 2001; Cornelissen et al., 1994; International Commission on Illumination, 1997; LaGrow, 1986; Lovie-Kitchin et al., 1983). We support the idea of starting with preliminary assessments of reading performance at low (5–20 lux), medium (100–300 lux), and high (1500–5000 lux) levels of illuminance (suggested by Lovie-Kitchin et al. and Bowers et al.), which can serve as a basis for further analysis. For persons whose best reading performance is at medium or high levels of light, reading assessments at one and two octaves below and above the initial level should be added to ensure that the best level of light for reading is identified. For instance, a person who initially prefers 100 cd/m^2 (equivalent to about 400 lux) may also be asked to read at 25 cd/m^2 (equivalent to 100 lux), 50 cd/m^2 (200 lux), 200 cd/m^2 (800 lux), and 400 cd/m^2 (1600 lux), covering a 1.2 log (il)luminance range. All these assessments will require that several equivalent reading test charts are available (such as the Tambartun test) to determine reading speeds under different testing conditions. By combining the objective measurements with self-reports of comfort with lighting, it should be possible to identify an optimal level of light or an optimal range of light levels. It is hoped that the lighting and reading assessments will also make individuals aware of the importance of proper adjustments of light.

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