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Reading Speed Does Not Benefit from Increased Line Spacing in AMD Patients

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Abstract

Purpose—Crowding, the adverse spatial interaction due to the proximity of adjacent targets, has been suggested as an explanation for slow reading in peripheral vision. Previously, we showed that increased line spacing, which presumably reduces crowding between adjacent lines of text, improved reading speed in the normal periphery (Chung, Optom Vis Sci 2004;81:525–35). The purpose of this study was to examine whether or not individuals with age-related macular degeneration (AMD) would benefit from increased line spacing for reading.

Methods—*Experiment 1:* Eight subjects with AMD read aloud 100-word passages rendered at five line spacings: the standard single spacing, 1.5×, 2×, 3×, and 4× the standard spacing. Print sizes were 1× and 2× of the critical print size. Reading time and number of reading errors for each passage were measured to compute the reading speed. *Experiment 2:* Four subjects with AMD read aloud sequences of six 4-letter words, presented on a computer monitor using the rapid serial visual presentation (RSVP) paradigm. Target words were presented singly, or flanked above and below by two other words that changed in synchrony with the target word, at various vertical word separations. Print size was 2× the critical print size. Reading speed was calculated based on the RSVP exposure duration that yielded 80% of the words read correctly.

Results—Averaged across subjects, reading speeds for passages were virtually constant for the range of line spacings tested. For sequences of unrelated words, reading speeds were also virtually constant for the range of vertical word separations tested, except at the smallest (standard) separation at which reading speed was lower.

Conclusions—Contrary to the previous finding that reading speed improved in normal peripheral vision, increased line spacing in passages, or increased vertical separation between words in RSVP, did not lead to improved reading speed in people with AMD.

Reading is difficult and slow for many low vision patients, especially those who have lost their central vision, and thus are obligated to use their peripheral retina. The leading cause of visual impairment in developed countries is age-related macular degeneration (AMD),[1,2] which is also the leading cause of central vision loss. Because reading is the most common clinical complaint as well as the primary goal for patients with AMD seeking visual rehabilitation,[2–4] the understanding of why reading is slower in the peripheral visual field is of utmost importance to the visual rehabilitation of these patients.

Previous studies have established that even when print size is not a limiting factor, or when the demand for reading eye movements is minimized using the rapid serial visual presentation (RSVP) paradigm where words of a sentence are presented one at a time in rapid succession, patients with central scotomas due to diseases such as AMD still read slowly.[5–6] Similarly,

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people with normal vision read slower when text is presented in their peripheral vision, even when print size is not a limiting factor and when RSVP is used to present the text.[7–9] What then, accounts for slow peripheral reading?

One factor that has been suggested as a contributor to slow peripheral reading is crowding. Crowding refers to the decreased visibility of a visual target in the presence of nearby objects.[10] Using single letters as targets, earlier studies showed that the extent and magnitude of crowding increase in peripheral vision.[11–15] Given that text or words are made up of letters, it is conceivable that the stronger crowding effect in the periphery may account for slow peripheral reading. If crowding among letters indeed accounts for slow peripheral reading, then by increasing the separation between individual letters, which presumably reduces the magnitude of crowding, reading speed should improve, especially in peripheral vision where crowding is stronger. Contrary to this prediction, Chung[16] found that increased letter spacing did not improve reading speed in normal central or peripheral vision.

In relation to reading, crowding can occur among letters, as well as among words. Even though Chung[16] showed that reading speed does not benefit from increased letter spacing, which presumably reduces crowding among letters, it remains plausible that reading speed may benefit from reduced crowding among individual words. To investigate this possibility, Chung[17] measured reading speed for sequences of unrelated words, with each word flanked above and below by other words of the same word-length, at various vertical word separations. If crowding among words contributes to slow peripheral reading, then reading speed should improve with larger vertical word separation, more so in peripheral than central vision. Her results showed that in the normal fovea, reading speed increased with vertical word separation up to approximately 1.25× the standard line spacing, beyond which reading speed remained constant for larger vertical word separations.[17] In the normal periphery, reading speed increased monotonically with vertical word separation, and reached only approximately 75% of the unflanked reading speed at 2× the standard line spacing.[17] These results clearly suggest that reading speed in normal peripheral vision benefits from increased line spacing. The purpose of the present study was to extend these results to examine whether or not reading speed in AMD patients, who presumably rely on their peripheral vision to read, would similarly benefit from increased vertical spacing between words. Because we were interested in examining if the benefit that we observed using RSVP could be generalized to page-style reading, in experiment 1, we measured reading speed for printed passages of newspaper articles, as a function of line spacing. In a second experiment, we tested a smaller group of AMD subjects using the same stimuli and methodology as used by Chung.[17]

METHODS

Oral reading speed was measured for subjects with AMD using passages of continuous text (experiment 1) or sequences of unrelated four-letter words (experiment 2). The subjects, all native English speakers and aged between 67 and 89 (mean = 77.3 ± 6.4), were recruited from the Center for Sight Enhancement at the University of Houston College of Optometry according to HIPAA regulations. Clinical characteristics of these subjects are given in Table 1. Distance visual acuities, measured using the Bailey-Lovie chart, were scored for each correctly identified letter. Critical print sizes (CPS) in degrees were estimated using the MNREAD Acuity Chart (see below) “by eye.” Characteristics of the central scotoma(s) and subjects’ preferred retinal loci for fixation were assessed using the Amsler grid. Although the Amsler grid does not provide information as to the exact retinal location that a patient uses for fixation, it does provide qualitative information about the fixation locus in relation to scotoma(s). All subjects either already demonstrated eccentric viewing or were undergoing eccentric viewing training. Eight subjects participated in experiment 1 and four participated in experiment 2. They gave their informed consent after the procedures of the experiment were explained, and before the commencement of data collection. The protocol of this study was approved by the Institutional Review Board at the University of Houston.

Experiment 1

The primary purpose of this experiment was to examine if reading speed for passages of continuous text improves with increased line spacing in subjects with AMD. To ensure that our task was representative of an everyday page-style reading task, we chose passages of news articles as our reading materials. Thirty-five passages, each exactly 100 words in length, were obtained from electronic sources that were based outside Texas, so as to minimize the chance that subjects would have read these articles in their local newspapers. We avoided articles that were unpleasant and could cause emotional distress to subjects.

According to our experimental design (see below), each subject was required to read one practice passage and 10 test passages (2 print sizes × 5 line spacings). We selected the 12 most homogeneous (in terms of reading times required to read these passages and reading errors) passages from the entire pool of 35 passages to use in the experiment. To do so, we printed each of the 35 passages individually in 12-point Times New-Roman font, with a column-width of 7 cm, as high-contrast black print on a piece of white paper. All passages contained 13 or 14 lines of text, with an average of 44 character-spaces per line. We then measured the time taken to read each of these 35 passages in 20 normally sighted young adults. Each of these 20 young adults read the 35 passages in a different randomized order. From the distribution of the mean reading time for each passage, we selected the 12 passages with the most similar reading times. None of these passages contained words that were consistently misread by the normally sighted young adults. Although this method of selecting the 12 passages was performed on young adults, there was no a priori reason to believe that the homogeneity of the passages would change for older adults, or in the presence of AMD. The grade level[a] of these passages ranged between 8.4 and 12.0, all below the education level of our AMD subjects.

Each of the 12 selected passages was then printed in Times New-Roman font at a range of print sizes, and at each of the five line spacings: 1× (standard), 1.5×, 2×, 3×, and 4× the standard spacing. The standard line spacing was defined as the standard vertical separation between the baselines of two adjacent lines of text in printed materials. On average, this value was approximately 2.5 times the height of the lowercase letter “x.” We extended the range of line spacing to values larger than those used in Chung[17] because even at 2× the standard spacing, subjects with normal vision were only reading at 75% of their maximum reading speed using their peripheral vision.[17] Given that our AMD subjects all had central vision loss, and presumably had to use their peripheral vision, we expected that AMD subjects might require line spacings >2× the standard spacing in order to read at their maximum reading speed. All passages were printed as high-resolution, high-contrast, black print on sturdy white cardstock, while maintaining the column format. The column width increased proportionally with print size, but the number of lines per passage remained the same regardless of the print size.

To determine the physical print sizes of the reading passages for each AMD subject, we first measured CPS using the MNREAD Acuity Chart.[18] The CPS is defined as the smallest print size at which the subject read at his/her maximum reading speed.[18] Then, we gave each observer a passage to practice. The practice passage was printed at the same print size and line spacing as the first passage on which a subject was going to be tested (but with a different passage content). Because each subject was tested with a different sequence for the combination of print size and spacing, the print size and spacing of the practice passages differed among subjects. All subjects felt comfortable commencing the testing after the practice passage was

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[a] According to the Flesch-Kincaid Grade Level score provided by the Microsoft Word application.

read. For the actual testing, each subject read 10 passages—two print sizes corresponded to 1× or 2× CPS each printed at the five line spacings. None of the subjects read any passage twice. Four subjects were tested with the larger print size (2× CPS) first and the other four subjects were tested with the smaller print size (1× CPS) first. The five line spacings for each print size were tested in randomized sequences that differed among subjects. Reading time was measured for each passage, and reading errors were recorded. Reading speed, in words per minute (wpm), was computed according to the following equation:

$$\text{Reading Speed (wpm)}=\frac{100-\text{number of reading errors}}{\text{reading time (min)}}$$

We instructed the subjects to read as quickly and as accurately as possible and stop when they reached the end of each passage. They were allowed to hold the printed passages at their habitual viewing distance (the same as was used for MNREAD measurement). Subjects wore their own habitual correction if it was appropriate for the viewing distance, or if necessary, trial lenses (either as clip-on attached to subjects' habitual distance glasses or inserted in a trial frame) were used as the refractive correction for the viewing distance.

Experiment 2

The results of experiment 1 (see Results) showed that passage reading speeds for AMD subjects did not depend on line spacing. This was unexpected based on the results from Chung[17] who showed that reading speed benefits from increased vertical word spacing in the normal periphery. There are a number of differences in methodology between our experiment 1 and the study of Chung[17]—AMD vs. normally sighted subjects, passages of continuous text vs. sequences of random words, printed reading materials vs. words presented on computer screen, the use of page reading vs. RSVP paradigm etc. To ascertain that the discrepancy in results was not due to the differences in methodology between the two studies, in experiment 2, we tested four AMD subjects using the same methodology as that of Chung.[17] Three of the four subjects participated in experiment 1. Details of the experimental procedures can be found in Chung.[17] In brief, reading speed was measured for sequences of unrelated four-letter words. Each sequence (trial) consisted of six target words presented using the RSVP paradigm. Words were rendered as high contrast (ca. 90%), black lowercase letters on a white background of 45 cd/m^2. We used the Method of Constant Stimuli to present words at six exposure durations for each testing condition. Reading speed was calculated based on the RSVP word exposure duration that yielded 80% of the words read correctly. In different blocks of trials, the target words were flanked above and below by other four-letter words that changed in synchrony with the target words, at various vertical word separations ranging between 1 and 2× the standard line spacing, as in Chung.[17] Vertical word separation was defined as the baseline-to-baseline vertical separations between adjacent, vertically separated words. The definition of standard line spacing was the same as that used in experiment 1. For comparison, reading speed for sequences of unflanked single words was also measured. Words were rendered in Courier, a fixed-width font. Therefore, the use of flanking words of the same word-length as the target word provided uniform effect of crowding on the target word. Print sizes used were equivalent to 2× CPS so that we could compare the effect of vertical line/word spacing on reading speed for passage and RSVP reading for the same print size. We did not test 1× CPS as we believe that the pattern of our results would be similar to that obtained using 2× CPS, given that similar patterns of results were obtained for 0.8× and 2× CPS when we manipulated letter and word spacings in earlier studies.[16,17] The word stimuli were generated and presented using an SGI O2 workstation (Silicon Graphics Inc.) and a Sony color graphics display monitor (Model# GDM-17E21, refresh rate = 75 Hz).

RESULTS

Reading speeds for 100-word passages are plotted as a function of line spacing, for the two print sizes (1× and 2× CPS) and for each AMD subject in Fig. 1. By definition, CPS represents the smallest print size at which subjects read at their maximum reading speed.[18] Therefore, we expected that reading speeds obtained for 1× and 2× CPS should be very similar. However, six subjects read faster at 2× CPS than at 1× CPS. The difference in reading speed obtained for the two print sizes could be due to errors associated with estimating the CPS "by eye," which might occasionally underestimate the real CPS, leading to lower values. The important point here, however, is that across all observers, and regardless of whether they had the "dry" or the "wet" type of AMD, reading speed did not show any systematic changes with line spacing, at least for the range of line spacing tested in this study (repeated measures analysis of variance: $F_{(df = 4,28)} = 0.63$, Greenhouse-Geisser corrected p-value = 0.62).

Reading speed for sequences of unrelated four-letter words is plotted as a function of vertical word separation in Fig. 2 for the four AMD subjects. For all subjects, reading speed was virtually identical for the range of vertical word spacing tested, except for the smallest (standard) spacing where reading speed was lower. In Fig. 3, we plot the averaged normalized reading speed for the four subjects, as a function of vertical word separation. The normalized reading speed represents the ratio of the reading speed at a given separation to the unflanked reading speed. Averaged across the four subjects, reading speed at the standard (1×) spacing was significantly lower (35% lower) than those at other spacings (repeated measures analysis of variance: $F_{(df = 4,12)} = 8.37$, Greenhouse-Geisser corrected p-value = 0.04); however, reading speeds at other vertical word spacings did not differ from one another. In fact, reading speed at 1.25× the standard spacing already approached the unflanked reading speed, a finding that resembles more closely the pattern observed in the normal fovea (gray circles in Fig. 3) rather than that in the normal periphery (gray triangles and squares).

DISCUSSION

Previously, Chung[17] showed that in normal peripheral vision, reading speed improved with the vertical separation between lines of text (words). This effect occurred along both the vertical or horizontal meridians from fixation. Based on this finding, we predicted that AMD subjects, who presumably have to rely on their peripheral vision to read because of their central vision loss, would benefit from increased line spacing in a passage reading task. Contrary to this prediction, we found that reading speed does not depend on line spacing (for line spacing greater than the standard value) for a passage reading task in a group of eight AMD subjects.

To ascertain that this unexpected finding was not due to the differences in methodology between this study and that of Chung,[17] in a second experiment, we tested four AMD subjects using the same task as that of Chung.[17] Unlike the results obtained in the normal periphery,[17] our AMD subjects did not show any dependence of reading speed on word separation beyond the 1.25× the standard separation. This result confirms and validates the finding of experiment 1, and argues against the differences in the experimental details as the cause of a lack of benefit of line spacing on reading speed.

What accounts for the discrepancy in the benefits of increased line spacing on reading speed in normal periphery and in subjects with AMD? One possibility is that the flanking words above or below the target words fell within the scotoma(s) so that they did not interfere with target words. However, this explanation requires that all our subjects used a retinal locus that was either below or above their scotoma to read, instead of one that was to the right or left of the scotoma. It is clear from Table 1 that some subjects fixated to the right or left of the scotoma.[b] For these subjects, the flanking words above or below the target word did not fall within the scotoma, yet they too, did not benefit from an increased line spacing on reading speed. Therefore, the explanation of the flanking words falling into the scotoma(s) and thus not interfering with the target word could not satisfactorily explain the results of all subjects.

A second possibility is that the absolute distance between lines of text (words) exceeded the crowding zone at the retinal location that a subject used to read. For letter crowding, the extent of the crowding zone is approximately half the eccentricity.[14,15,19] For now, let's assume that the crowding zone for lines of text or words is the same as that for letters. If so, then for subject S3 who read 0.42° print (1× CPS in experiment 1), the baseline-to-baseline separation between adjacent lines of text for the standard line spacing would be 1.1° (the separation was equivalent to ~2.5× the print size, see Methods). He reported a fuzzy area with the edge approximately 5° above and to the right of his fixation on Amsler grid. Given that all our subjects adopted eccentric viewing, we could assume that S3 used an eccentric retinal location that was at least 5° from his anatomical fovea. According to Bouma,[14] the crowding zone is expected to be 2.5° at 5° eccentricity, therefore, for the 1× standard line spacing condition, three lines of text should fit comfortably within the crowding zone. Accordingly, we would expect that S3 should suffer from crowding at the smallest nominal line spacing. When line spacing increased, theoretically the upper and lower lines of flanking text would have fallen out of the crowding zone and his reading speed should have improved. However, S3's reading speed did not improve with increased line spacing. Similar analyses showed that subjects S4 and S7 demonstrated similar reading speed patterns that could not be accounted for by the theoretical size of the crowding zone. Moreover, we have previously shown that the crowding zone for words is larger than that for letters, extended to approximately 5.4° at 5° eccentricity and 12.4° at 10° eccentricity.[17] Applying these values to our subjects, they should all have suffered from word crowding for up to at least 2 to 3× the standard line spacing. However, this was not what we found, suggesting that the size of the word crowding zone was not the determining factor of our results. Clearly, these analyses assume that the properties of the peripheral retina of patients with AMD are the same as those of the normal periphery, an assumption that may well be untrue. On one hand, it is highly likely that because of the disease process, the peripheral retina of AMD patients is not as sensitive as the normal periphery. If so, then the visibility of the flanking words may be reduced thus diminishing the crowding effect. On the other hand, the peripheral retina of AMD patients can be more sensitive than the normal periphery due to adaptation—adaptation to the increased reliance of the peripheral retina to function or adaptation of the peripheral retina to become more fovea-like (see below). This too, would predict a different crowding effect as that observed in the normal periphery.

Another plausible explanation is that the peripheral retina of our AMD subjects might have adapted to becoming more fovea-like. The finding in experiment 2 that reading speed improves with vertical word separation only up to 1.25× the standard separation, and remains virtually constant for larger separations is reminiscent of the finding observed in the normal fovea (Fig. 3). This resemblance hints toward an adaptation process at work, that with time, the characteristics of the peripheral retina used by AMD subjects may take on the characteristics of the normal fovea. In addition to the study of Chung[17] who found that the word-by-word crowding extent was smaller at the normal fovea than in the periphery, other studies using single letters all consistently showed a smaller extent and magnitude of crowding at the normal fovea than in the periphery.[11–15,20,21] Therefore, if the peripheral retinal locus adopted by AMD subjects indeed behaves more like the normal fovea than the normal periphery, then the crowding effect due to neighboring words would be small, which may explain why reading speed is not as affected by neighboring words in AMD subjects than in the normal periphery.

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[b] In this study, we tried to quantify the distance between any scotomas (areas on the Amsler grid where subject reported to be abnormal) and the presumed fixation point. However, the findings of the Amsler grid may not be very accurate and thus should be interpreted with caution.

A comparison between the results of experiments 1 and 2 reveals that reading speeds were similar across all line spacings in experiment 1, but in experiment 2, reading speed was lower at 1× the standard separation than at other separations. Even though different fonts were used in the two experiments, the physical separation between adjacent lines of text or words (in mm), for the same magnitude of line separation remains similar. Therefore, the slower reading speed at 1× spacing in experiment 2 than in experiment 1 cannot be attributed to a difference in how the vertical separation was defined. We speculate that in experiment 2, when sequences of unrelated words were presented at a close separation, subjects might have difficulty isolating the target word from its flanking words, thereby slowing down reading. In experiment 1, subjects were able to use contextual cues to help guide them on the correct line of text, thus minimizing the crowding effect that arises due to the close proximity of adjacent lines of text.

For the three subjects who participated in both experiments, S7 read at approximately the same reading speed in both experiments, S3 read faster for unrelated word sequences presented using RSVP in experiment 2 and S4 read slower in experiment 2. Reading speeds are usually higher for RSVP than for page reading,[7,22] but only when meaningful sentences are used. For unrelated word sequences, RSVP reading speeds are much lower.[9] Rubin and Turano reported that the advantage of RSVP over page reading is much smaller for subjects with central field loss than for visually impaired subjects with intact central fields or subjects with normal vision.[5] Their data also showed that subjects with central field loss demonstrated a great deal of individual variability—some showed the same reading speed for RSVP and page reading, some showed faster while others showed slower RSVP reading speeds.[5]

Our attempt to reduce the crowding effect between adjacent lines of text by using larger line spacing, in the hope of improving reading speed in people with AMD, failed. Although we only tested small number of subjects, given the consistency of our results, we believe that our results would generalize to other patients with AMD. A practical implication of our findings is that as long as the line separation is approximately 1 to 1.25× the standard single line separation, then there is no added benefit of printing text at a larger line separation for AMD patients. This is an important piece of practical information because it is more economical to print text at single spacing (or slightly larger than single spacing) than at a larger spacing. From the rehabilitative point of view, our quest for practical ways to improve reading speed in patients with AMD remains.

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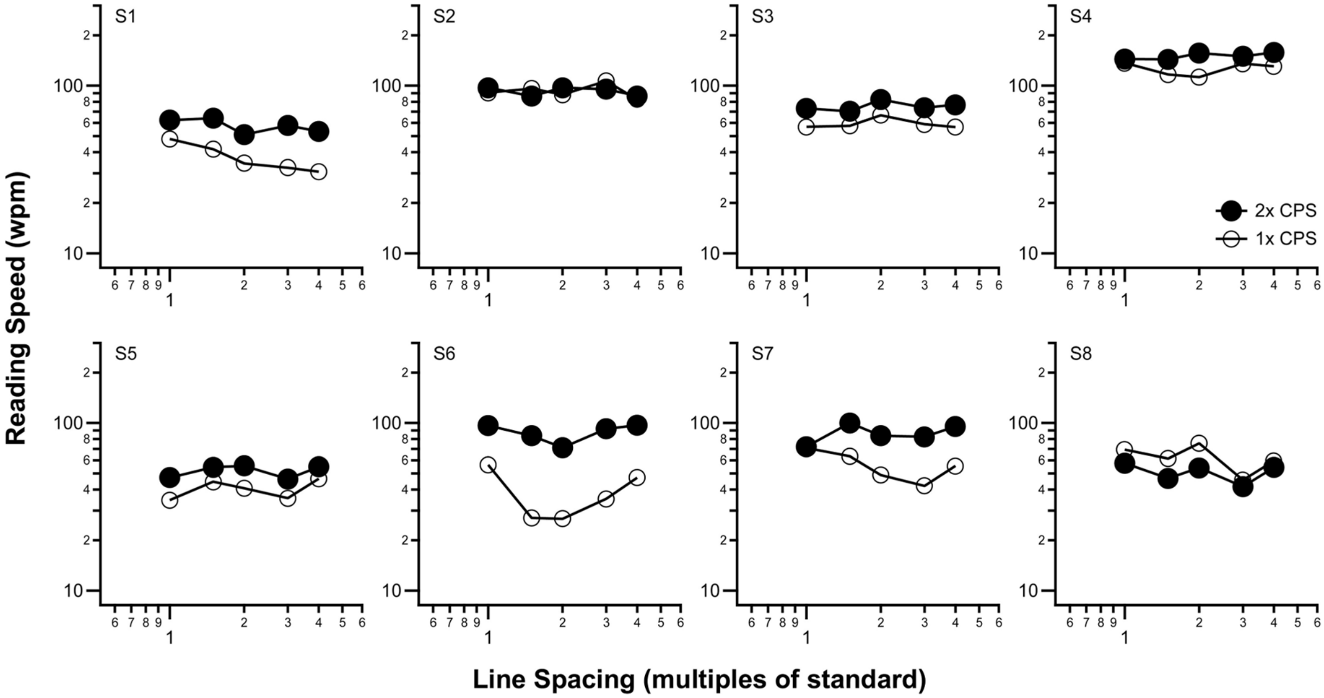

FIGURE 1.

Reading speed (wpm) for passages of news articles is plotted as a function of line spacing (multiples of the standard single-line spacing) for the eight subjects with AMD who participated in experiment 1, and for two print sizes (1× and 2× CPS).

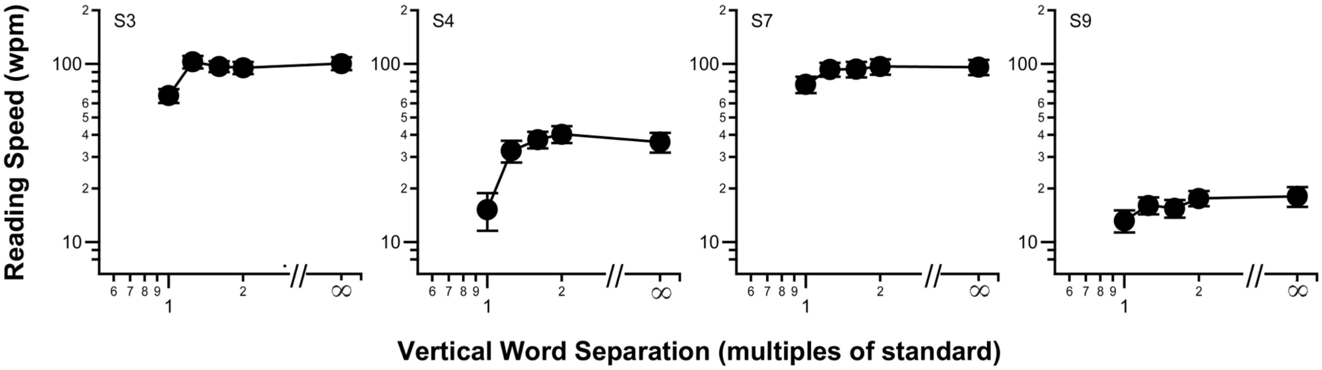

FIGURE 2.

Reading speed (wpm) for sequences of unrelated four-letter words is plotted as a function of the vertical word separation, for the four AMD subjects who participated in experiment 2. The rightmost data-points represent reading speeds for sequences of unflanked words. Error bars represent ±1 SEM.

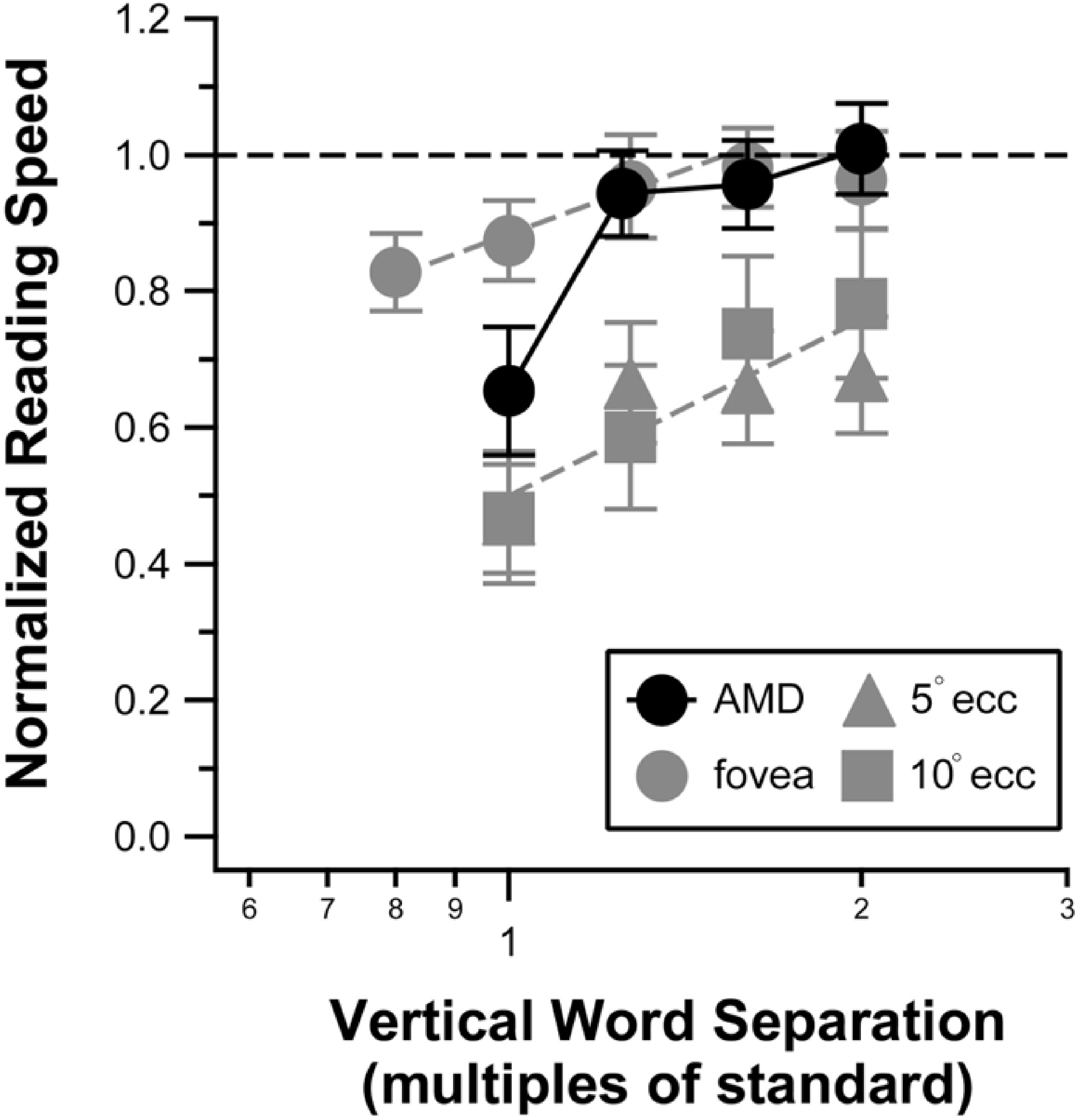

FIGURE 3.

Normalized reading speed (reading speed at a given vertical word separation normalized to the unflanked reading speed) averaged across the four AMD subjects who participated in experiment 2, is plotted as a function of the vertical word separation as black circles. For comparison, averaged data obtained from the fovea, 5° and 10° lower visual fields of a group of normally sighted young adults are included as gray symbols (data are replotted from Fig. 6 of Chung, Optom Vis Sci 2004;81:525–35). Error bars represent ± 1 SEM. The dashed line represents reading speeds that are the same as the unflanked word reading speed.

TABLE 1

Characteristics of the AMD subjects

Subject	**Age**	**Type of AMD**	**Years since onset of AMD**	**Distance acuity testing eye (logMAR)**	**Critical print size (°)**	**Characteristics of central scotoma and subject's preferred retinal locus**
S1[a]	74	Wet	At least 0.5	1.00	1.11	Dense scotoma covering upper part of Amsler grid, edge ~3.5° above fixation
S2[b]	67	Wet	3	1.06	1.68	Scotoma ~15° in diameter centered on Amsler, fixation could be below scotoma
S3[a,b]	72	Dry	0.5	0.80	0.42	Fuzzy area, edge ~5° above and a bit to the right of fixation
S4[a,b]	75	Dry	5	0.40	0.26	Dense scotoma, edge ~5° left of fixation
S5[a]	79	Wet	5	1.00	1.31	A dense scotoma, edge ~10° above, and a small scotoma, edge ~20° lower right of fixation
S6[a]	77	Dry	>10	0.78	0.84	Wavy, distorted areas, edge ~6° above fixation
S7[a,b]	81	Dry	7	0.44	0.47	Wavy, distorted areas, edge ~5.5° left of fixation
S8[a]	82	Dry	5	0.98	0.88	Multiple missing areas, blurry, fuzzy regions around 3.5° of fixation
S9[b]	89	Dry	15	1.00	0.83	Wavy, distorted areas covering right of Amsler grid, edge ~6.5° right of fixation
Subject	Age	Type of AMD	Years since onset of AMD	Distance acuity testing eye (logMAR)	Critical print size (°)	Characteristics of central scotoma and subject's preferred retinal locus
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S3[a,b]	72	Dry	0.5	0.80	0.42	Fuzzy area, edge ~5° above and a bit to the right of fixation
S4[a,b]	75	Dry	5	0.40	0.26	Dense scotoma, edge ~5° left of fixation
S5[a]	79	Wet	5	1.00	1.31	A dense scotoma, edge ~10° above, and a small scotoma, edge ~20° lower right of fixation
S6[a]	77	Dry	>10	0.78	0.84	Wavy, distorted areas, edge ~6° above fixation
S7[a,b]	81	Dry	7	0.44	0.47	Wavy, distorted areas, edge ~5.5° left of fixation
S8[a]	82	Dry	5	0.98	0.88	Multiple missing areas, blurry, fuzzy regions around 3.5° of fixation
S9[b]	89	Dry	15	1.00	0.83	Wavy, distorted areas covering right of Amsler grid, edge ~6.5° right of fixation

[a] Subjects who participated in Experiment 1.

[b] Subjects who participated in Experiment 2.