Investigative Ophthalmology & Visual Science

Beneficial Effects of Spatial Remapping for Reading With Simulated Central Field Loss

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Purpose. People with central field loss (CFL) lose information in the scotomatous region. Remapping is a method to modify images to present the missing information outside the scotoma. This study tested the hypothesis that remapping improves reading performance for subjects with simulated CFL.

Methods. Circular central scotomas, with diameters ranging from 4° to 16°, were simulated in normally sighted subjects using an eye tracker on either a head-mounted display (HMD) (experiments 1, 2) or a traditional monitor (experiment 3). In the three experiments, reading speed was measured for groups of 7, 11, and 13 subjects with and without remapping of text.

Results. Remapping increased reading speed in all three experiments. On the traditional monitor, it increased reading speed by 34% (8°), 38% (12°), and 35% (16°). In the two HMD experiments, remapping increased reading speed only for the largest scotoma size, possibly due to latency of updating of the simulated scotoma.

Conclusions. Remapping significantly increased reading speed in simulated CFL subjects. Additional testing should examine the efficacy of remapping for reading and other visual tasks for patients with advanced CFL.

Keywords: remapping, simulated scotoma, macular degeneration, head mounted display, eye tracking

Age-related macular degeneration (AMD) is a leading cause of central field loss (CFL) in developed countries,[1] often resulting in binocular central scotomas.[2,3] For patients with advanced AMD, scotoma diameters can be large, frequently ranging between 10° and 20°.[4–6] Activities of daily living such as reading and driving are most affected by CFL; in one study, 87.5% of patients gave up reading, 33% driving, and 12.5% watching TV due to vision loss.[7] There is no effective cure for AMD, and current treatments work toward either slowing disease progression or partially restoring vision.[8,9] Hence, there is a clear need for interventions to improve reading and other everyday tasks for people with CFL.

Patients with CFL typically adopt a location in the peripheral retina outside their scotoma for fixation. This area is called the preferred retinal locus (PRL). Training patients with CFL in using an existing PRL, or to use a PRL better suited for reading, has shown some benefit in improving reading rates.[10–12] Other perceptual learning paradigms that focus on specific visual tasks, not necessarily targeted to a PRL, have also shown limited benefit in improving reading speeds.[13,14]

A number of devices have also been developed to assist people with CFL. These can be optical or electronic, and usually involve magnification and/or contrast enhancement.[15] Recent developments in technology are allowing new potential solutions to be developed for CFL rehabilitation. In particular, wearable head-mounted displays (HMDs) with embedded eye trackers are rapidly advancing in quality and dropping in price. Coupled with increases in computer processing power, these portable displays allow for real-time manipulation of images displayed to patients with CFL, with the potential to compensate for visual defects and improve visual performance (Werblin FS, et al. *IOVS* 2015;56:ARVO E-Abstract 2226).

For convenience, investigations of adaptive technologies often begin by testing normally sighted subjects with simulated field loss. CFL can be simulated using a gaze-contingent display, wherein a scotoma-shaped mask is placed over the instantaneous gaze location and updated continuously.[16–20] Scotoma simulations allow for complete control over factors such as the scotoma size and shape, which are highly variable in patients.

Here we explore the concept of "remapping" to aid vision in AMD. We define remapping in general as any method that projects the portion of the image originally lost behind a scotoma onto a functional part of the retina. For reading applications, this can involve shifting portions of text from the scotoma location to a region in the functional periphery. Another method of remapping (not explored here) involves spatial multiplexing, where a region is selectively magnified and superimposed onto the image in the periphery in the case of

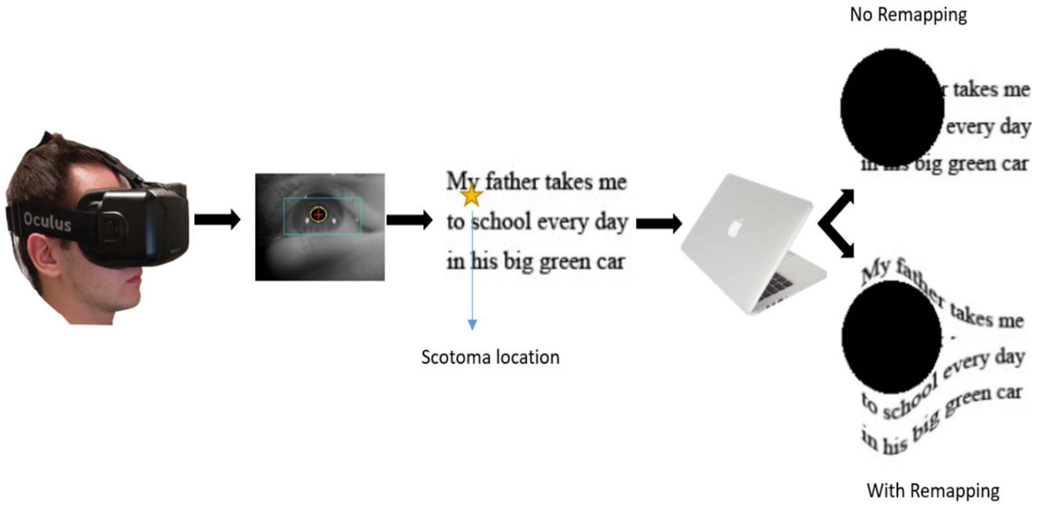


FIGURE 1. HMD device process flow from left to right: A subject wears the HMD fitted with eye trackers. The eye-tracking system locates the gaze position on the screen. The laptop simulates a scotoma and remaps the image based on this gaze location. The remapped image can then be displayed onto the HMD using the same laptop. While white circular scotomas were used in testing, *black* scotomas are shown here for clarity.

CFL, or a minified view of the peripheral field is superimposed onto the functioning central field in the case of peripheral field loss (PFL).[21]

An early study of remapping was conducted in 1995, using a device developed by the National Aeronautics and Space Administration (NASA).[22] Normal observers with simulated central scotomas of 4° and 8° showed small but significant increases in reading rates with remapping. Testing with two AMD subjects showed some benefits, but more testing was needed to assess general efficacy.[23] Testing was ultimately abandoned, in part due to the device's technologic limitations such as limited field of view, inconvenient eye-tracking hardware, and poor resolution. Current advances in display and tracking technology make the time ripe for revisiting remapping as a potential aid for CFL. Using modern hardware, we have developed both desk-mounted and head-mounted setups for remapping of visual stimuli, and here report initial tests of their efficacy for aiding reading.

METHODS

In two experiments, normally sighted subjects viewed computer-generated text through an HMD. A built-in eye tracker provided instantaneous gaze position, a computer simulated a circular scotoma at the center of gaze and remapped images, and the result was displayed in real time on the HMD. Figure 1 shows device process flow. Experiment 1 compared reading rates for sentences viewed with and without remapping for a range of sizes of the simulated scotoma. Experiment 2 replicated experiment 1 with improved hardware that had become available.

In simulated scotoma systems, hardware latency can manifest as a delay in the scotoma movement following an eye movement, which can result in "peeking," wherein the subject can briefly foveate on the visual stimulus until the scotoma catches up. HMD eye-tracking systems such as those in experiments 1 and 2 typically have relatively high latencies because of the hardware constraints from having to fit in the HMD assembly. To assess the effects of remapping in a low-latency system, a third experiment was conducted using a desk-mounted setup not subject to such constraints. In this third experiment, the HMD and eye tracker assembly were replaced with a desk-mounted monitor and a low-latency eye tracker with higher sampling frequency.

Remapping

A column Gaussian bump algorithm was used to remap the text based on gaze position.[24] The equation used to compute remapped text locations was as follows:

$$u = x \tag{1}$$

$$v = y + b * e^{\frac{-x^2}{a^2}} * sign(y) \tag{2}$$

Here, output image pixels are represented by $[u, v]$, and input image pixels are represented by $[x, y]$. The parameters a and b correspond to the semimajor and semiminor elliptical axes, respectively, and are chosen to encapsulate the scotoma. The effect of the remapping can be seen in Figure 1. The algorithm changes only the vertical location of the text. The horizontal position is unchanged.

The column Gaussian bump algorithm was chosen because it preserves local area and thereby size of the letters at the expense of local letter shape.[24] By not causing magnifications of variable magnitude across the remapped text, as would a local shape-preserving remapping like the radial eccentric remapping used by Wensveen et al.,[22] this remapping provided subjectively better readability of remapped text.

Subjects

Normally sighted subjects participated—10 in experiment 1, 12 different subjects in experiment 2, and 13 others in experiment 3. Three subjects were excluded from experiment 1 and one subject from experiment 2 because of poor eye-tracker calibration. This research was approved by the Institutional Review Board at the University of Minnesota and conformed to the tenets of the Declaration of Helsinki. Informed consent was obtained from all subjects.

Apparatus and Software

The hardware used in each of the three experiments is detailed in Table 1. Eye trackers in the head-mounted setups were mounted within the HMD assembly.

Table 1. Technical Specifications for Hardware Used in Experiments 1, 2, and 3

Parameter	Experiment 1	Experiment 2	Experiment 3
Device type	Head mounted	Head mounted	Desk mounted
Display			
Model	Sensics zSight HMD (Columbia, MD, USA)	Oculus DK2 HMD (Menlo Park, CA, USA)	ASUS 23" Monitor (Taipei, Taiwan)
Resolution	1280 × 1024	1920 × 1080	1920 × 1080
Refresh rate	60 Hz	75 Hz	120 Hz
Field of view	60° diagonal	100° diagonal	45° horizontal at a 60-cm viewing distance
Eye tracker			
Model	Arrington Research ViewPoint Eye Tracker (Scottsdale, AZ, USA)	SMI DK2 Upgrade (Teltow, Germany)	Tobii TX 300 (Danderyd, Sweden)
Frequency	60 Hz	60 Hz	300 Hz
Type	Monocular—right eye	Binocular	Binocular
Accuracy	0.25°–1°	<1°	0.4°
System latency	76–93 ms, estimate	53–87 ms, estimate	18.04 ± 6.9 ms, measured

System latency for the head-mounted setups is an estimate based on software frame rates, quoted eye tracker and display latencies, and refresh rates. System latency for the desk-mounted setup was determined by measuring frames between eye movement and corresponding scotoma update from high-speed camera footage (240 Hz). Opportunity for "peeking" was further reduced in experiment 3 by blanking the screen for the duration of a saccade, when one was detected. A saccade was classified as a movement of greater than 1.1° between two frames, a velocity threshold of 132°/s, based on pilot testing. This experiment met Saunders and Woods'[25] suggestion of an average system latency of less than 25 ms for central vision masking experiments.

The C++ programming language was used along with the OpenCV 2.4.9 image processing library[26] to create the software and test environment for the first two experiments. For the third experiment, the software and test environment was created using MATLAB (MathWorks, Natick, MA, USA) and the Psychophysics Toolbox extensions.[27–29]

In experiments 1 and 2, the eye trackers were calibrated prior to testing with 16- and 3-point calibration sequences, respectively, using proprietary software provided by the manufacturer. Calibration was repeated until deemed acceptable by the software. In experiment 3, a 9-point calibration sequence was displayed using the Tobii SDK and the Psychophysics Toolbox for stimulus presentation. Calibration was considered acceptable when the error at each of the nine calibration points was under 1°.

Stimuli and Testing Procedure

Stimuli were MNREAD[30] sentences displayed in black on a white background in Times New Roman with a 1.5-line spacing. MNREAD sentences are standardized short sentences of 60 characters (i.e., approximately 10 words), equally spaced over three lines, and designed to measure visual reading performance. White circular scotomas of varying diameter were simulated at the gaze position. Scotomas were matched in luminance to the background so as not to be visible against it. The character height, scotoma sizes, and number of characters masked for each experiment are shown in Table 2. Scotoma sizes relative to a stimulus sentence for experiments 1 and 2 can be seen in Figure 2.

Prior to testing, subjects were told they could use peripheral vision to read, as central vision would be blocked, but they were not instructed in any strategy. They were given a summary of the experiment, but no further training. In experiments 1 and 2, subjects were shown a sample MNREAD sentence with the 4° and 8° scotomas, respectively, and no remapping. There were no practice trials before data collection.

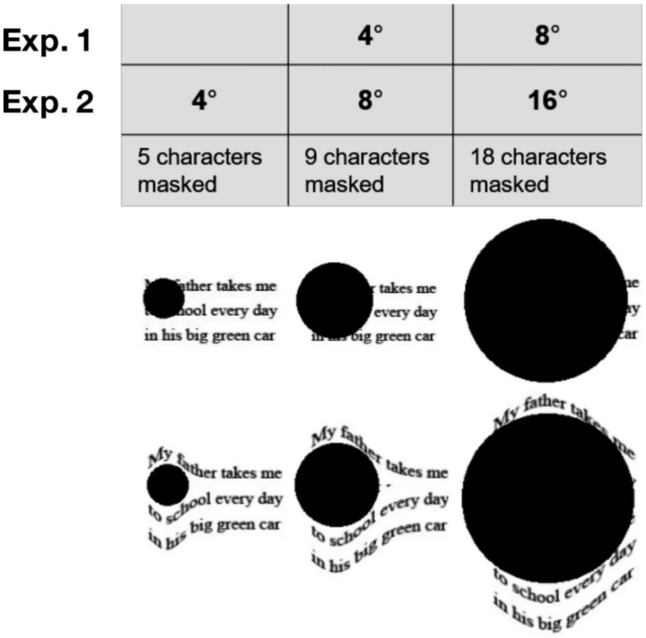
For each scotoma size, reading speeds were measured with and without remapping. Baseline reading speeds without a simulated scotoma were also recorded. The combination of scotoma size and remapping status (on/ off) will be referred to as a "condition"—for example, 8° scotoma with remapping is one condition. We instructed subjects to avoid actively trying to peek behind the scotoma using strategic eye movements we had observed in pilot tests, for example, rapidly moving from the text displayed near the screen center to the border of the screen and back to escape the scotoma. Some subjects in the first two experiments indicated that at least marginal "peeking" nevertheless occurred from time to time. Subjects in experiment 3 reported that they rarely if ever received glimpses of masked text.

In experiment 1, seven unique MNREAD sentences were presented for each condition. Condition order was randomized. Subjects were asked to read each sentence silently and to

Table 2. Visual Stimuli and Scotomas Used in Experiments 1, 2, and 3

Parameter	Experiment 1		Experiment 2			Experiment 3		
Character "x" height, degrees	0.42°		0.8°			0.8°		
Character "x" height, Snellen	20/100		20/200			20/200		
Simulated scotoma diameter	4°	8°	4°	8°	16°	8°	12°	16°
Critical print size at periphery*	0.39°	0.62°	0.39°	0.62°	1.08°	0.62°	0.85°	1.08°
Characters masked by scotoma along a line of text	9	18	5	9	18	9	14	18

* Critical print size at periphery refers to the critical print size at the eccentricity corresponding to the radius of the scotoma. Quoted values are obtained from Chung et al.[31] assuming $T_0 = 0.16°$ and $E_2 = 1.39$.



Exp. 1		**4°**	**8°**
Exp. 2	**4°**	**8°**	**16°**
	5 characters masked	9 characters masked	18 characters masked

FIGURE 2. From *left* to *right*: The relative sizes of some scotomas in relation to the MNREAD sentences used for the unremapped condition (*top*) and remapped condition (*bottom*), for experiments 1 and 2. For experiment 1, the 4° and 8° scotomas used would mask the same number of characters along a line as the 8° and 16° scotomas in experiment 2 and 3 because the character height used was 0.42°—approximately half of the 0.8° character height used in the second and third experiments. While white circular scotomas were used in testing, black scotomas are shown here for clarity. The 8° and 16° scotomas in experiment 3 would look identical in relation to the MNREAD sentences to those pictured for experiment 2.

press a response key after finishing. The keypress was used to record reading time. After each sentence, a blank screen was presented, and subjects were asked to repeat the sentence out loud, which allowed errors to be scored. If the subjects could not read a sentence within a 20-second time limit, the sentence was marked as "not completed." Calibration was checked after every sentence. If a calibration error was detected, calibration was repeated and the prior sentence was excluded from data analysis.

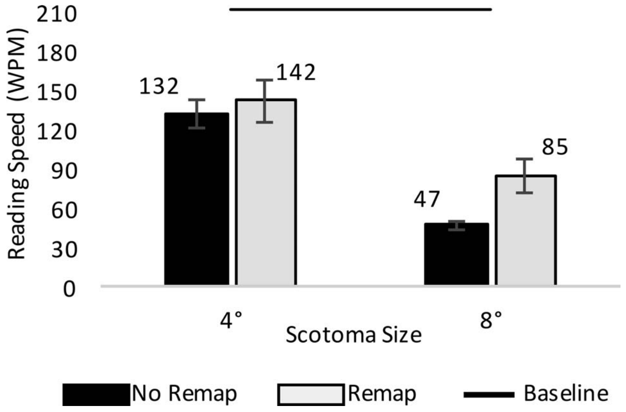


FIGURE 3. Experiment 1: average reading speeds in words per minute (WPM) for all subjects, for the two scotoma sizes with and without remapping of the stimulus. Individual subject reading speeds were averaged to calculate an average for the tested population (*numbers above the bars*). The *line above the bars* displays average baseline reading speeds without a scotoma for the tested population.

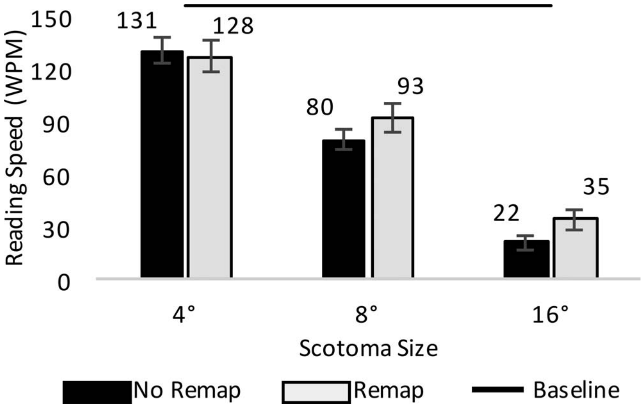


FIGURE 4. Experiment 2: average reading speeds in words per minute (WPM) for all subjects, for the three scotoma sizes with and without remapping of the stimulus. Individual subject reading speeds were averaged to calculate an average for the tested population (*numbers above the bars*). The *line above the bars* displays average baseline reading speeds without a scotoma for the tested population.

In experiment 2, three testing blocks, each consisting of all six conditions in a randomized order, were conducted consecutively. Within a block, for each condition, subjects read aloud five unique MNREAD sentences consecutively, and reading time was recorded by the researcher. Thus, subjects read a total of 15 sentences per condition. Errors were recorded and included in the reading speed calculation. If subjects could not read a sentence within a 20-second time limit, they were asked to report the words they were able to identify, which were then used to calculate reading speed. Baseline speed was measured once before the first block. Calibration was checked using fixation targets at the end of each condition.

In experiment 3, the same design as in experiment 2 was used, with five sentences per condition per block. Four such blocks were conducted consecutively, yielding a total of 20 sentences per condition. Before moving to a new condition, an untimed practice trial with the upcoming scotoma and remapping condition (on/off) was presented to familiarize the subjects with the condition. Baseline reading speed was measured with five unique MNREAD sentences once prior to the first block and once halfway through the experiment. Calibration was checked after every 25 sentences and was repeated as needed, whenever the measurement error for any of the nine calibration points exceeded 1°.

RESULTS

Experiments 1 and 2

As expected, simulated scotomas significantly reduced reading speed from baseline, with a larger reduction for larger scotomas. The mean reading speeds averaged over all subjects for the different conditions are shown in Figures 3 and 4. Individual reading speeds, in order of increasing baseline reading speed, are shown in Figures 5 and 6.

Remapping increased reading speed for the larger scotomas. In experiment 1, for the largest 8° scotoma that masked 18 characters, average reading speed increased significantly with remapping, from 46.8 to 84.7 words per minute (WPM), an 81% increase ($P < 0.05$ uncorrected 1-tailed Student's *t*-test; P value = 0.07 when the conservative Bonferroni correction for multiple comparisons is applied). Similar results were obtained for the largest 16° scotoma in experiment 2, which also masked

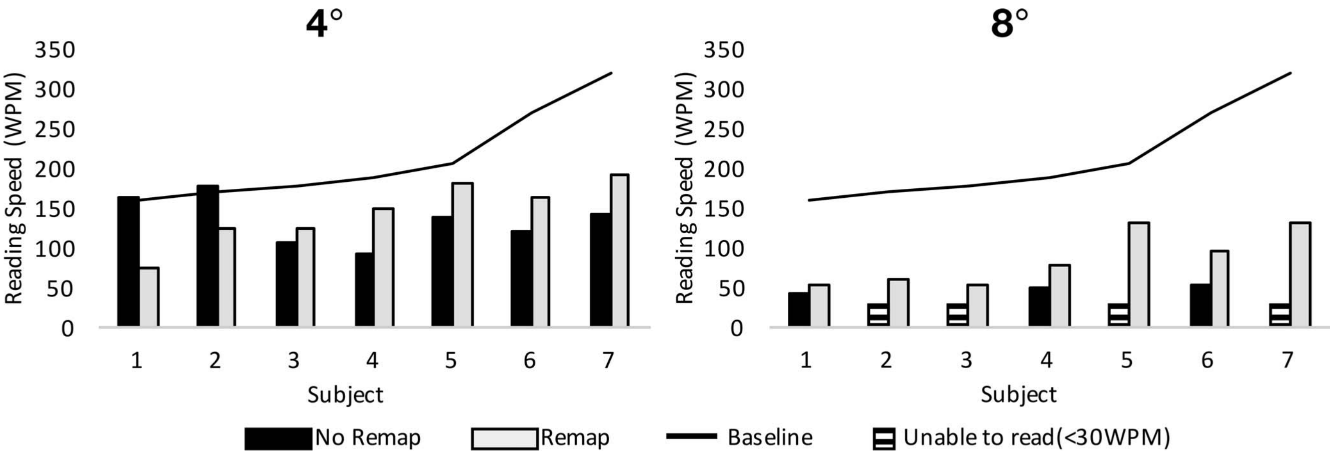


Figure 5. Experiment 1: subjects read seven sentences for each of the four conditions (two scotoma sizes with and without remapping), and their average reading speed for each condition was calculated based on the sentences they read completely within the 20-second time limit. Individual subject reading speeds ordered by increasing baseline reading speed are shown here for the 4° and 8° scotomas. The *curve above the bars* displays baseline reading speeds without a scotoma for each subject. *Bars with horizontal lines* show subjects that could not complete any of the assigned sentences within the 20-second time limit for that given condition, indicating a reading speed less than 30 WPM.

18 characters due to an increase in font size. Remapping increased reading speed significantly, from 21.6 to 34.8 WPM, a 61% increase ($P < 0.01$ uncorrected 1-tailed Student's *t*-test; $P < 0.05$ with Bonferroni correction).

In experiment 2, for the 8° scotoma that masked nine characters, there was a trend for remapping to increase reading speed, from 80.2 to 92.7 WPM ($0.05 < P < 0.06$ uncorrected 1-tailed Student's *t*-test). Remapping did not significantly affect reading speed for the smallest scotomas in experiments 1 and 2 ($P > 0.1$ uncorrected 1-tailed Student's *t*-test).

In experiment 1, we also examined the number of sentences completed within the 20-second time limit. Across the seven subjects for the 4° scotoma, all 49 sentences (7 sentences per subject) were completed both with and without remapping. For the 8° scotoma, only 13/42 sentences were completed without remapping (7 discarded due to poor calibration), while 46/49 were completed with remapping. For this scotoma size, four subjects were unable to complete any of the seven sentences without remapping. Sentences that were not completed were excluded from overall reading speed calculations. Since there were more incompletes for the unremapped versus the remapped condition, and incompletes represent very slow reading speeds (<30 WPM), the increase in average speed for the 8° scotoma shown in Figure 3 is a conservative value. In the other experiments, subjects reported the words they read even if they could not complete the entire sentence within the 20-second time limit, allowing reading speed to be calculated for all sentences and eliminating the need for the sentences completed metric.

Experiment 3

Experiment 3 tested the efficacy of remapping with low-latency updating of the simulated scotomas. Again, as expected, simulated scotomas reduced reading speed, with a greater reduction for larger scotomas. Mean reading speeds averaged over all subjects for the different conditions are shown in Figure 7. Individual reading speeds for the 8°, 12°, and 16° scotomas are shown in Figure 8.

In experiment 3, remapping significantly increased reading speed for all three scotoma sizes. For the 8° scotoma, reading speeds increased by 34% from 84.8 to 113.9 WPM ($P < 0.00005$ uncorrected 1-tailed Student's *t*-test, $P < 0.0001$ with Bonferroni correction). For the 12° scotoma, reading speeds

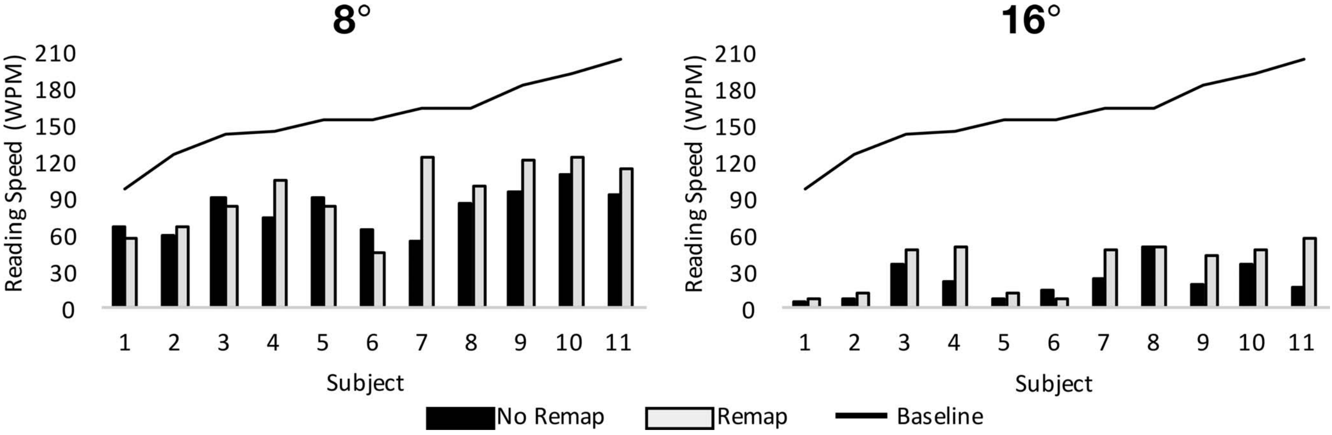


Figure 6. Experiment 2: subjects read 15 sentences for each of the six conditions (three scotoma sizes with and without remapping), and their average reading speed for each condition was calculated. Individual subject reading speeds ordered by increasing baseline reading speed are shown here for the two larger scotoma sizes: the 8° scotoma and the 16° scotoma. The *curve above the bars* displays baseline reading speeds without a scotoma for each subject.

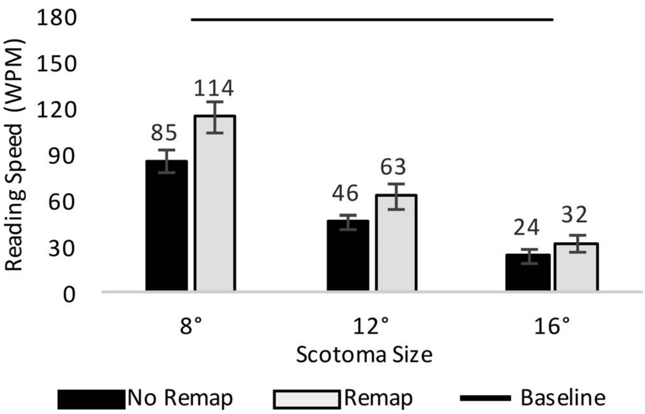


Figure 7. Experiment 3: average reading speeds in WPM for all subjects, for the three scotoma sizes with and without remapping of the stimulus. Individual subject reading speeds were averaged to calculate an average for the tested population (*numbers above the bars*). The *line above the bars* displays average baseline reading speeds without a scotoma for the tested population.

increased by 38% from 45.5 to 62.7 WPM ($P < 0.005$ uncorrected 1-tailed Student's *t*-test; $P < 0.01$ with the Bonferroni correction). For the 16° scotoma, reading speeds increased by 35% from 23.5 to 31.7 WPM ($P < 0.01$ uncorrected 1-tailed Student's *t*-test; $P < 0.05$ with the Bonferroni correction).

DISCUSSION

Our objective was to determine if remapping text to preserve visual information obscured by a simulated scotoma can improve reading speeds. In our experiments, the simulated scotomas reduced reading speeds from baseline, consistent with other studies.[17,19] There was a greater reduction for larger scotomas, as found for patients with CFL.[32,33] In all of our experiments, remapping significantly increased reading speed, suggesting that remapping holds promise for use with patients with CFL.

In the low-latency apparatus of experiment 3, remapping was relatively equally beneficial for all three scotoma sizes. In contrast, in the high-latency setup of experiments 1 and 2, remapping provided significant benefit only for the larger scotomas. A likely reason for this apparent lack of benefit of remapping for the other scotoma sizes is the high system latency, which allows for possible foveal "peeking" as the scotoma lags the actual gaze position. Foveal viewing likely increased reading speeds in the unremapped condition, making the potential benefit of remapping smaller. Peeking is much easier for small scotomas, since the eye has to travel a smaller distance to view clear text. Hence, peeking likely reduced the effects of remapping primarily for those smaller scotomas. This reasoning predicts that lower-latency systems will show increased benefits for smaller scotoma sizes, which was indeed the case in experiment 3.

The column Gaussian bump remapping was chosen over other remapping algorithms to better preserve readability of remapped text. A practical concern with this remapping is that

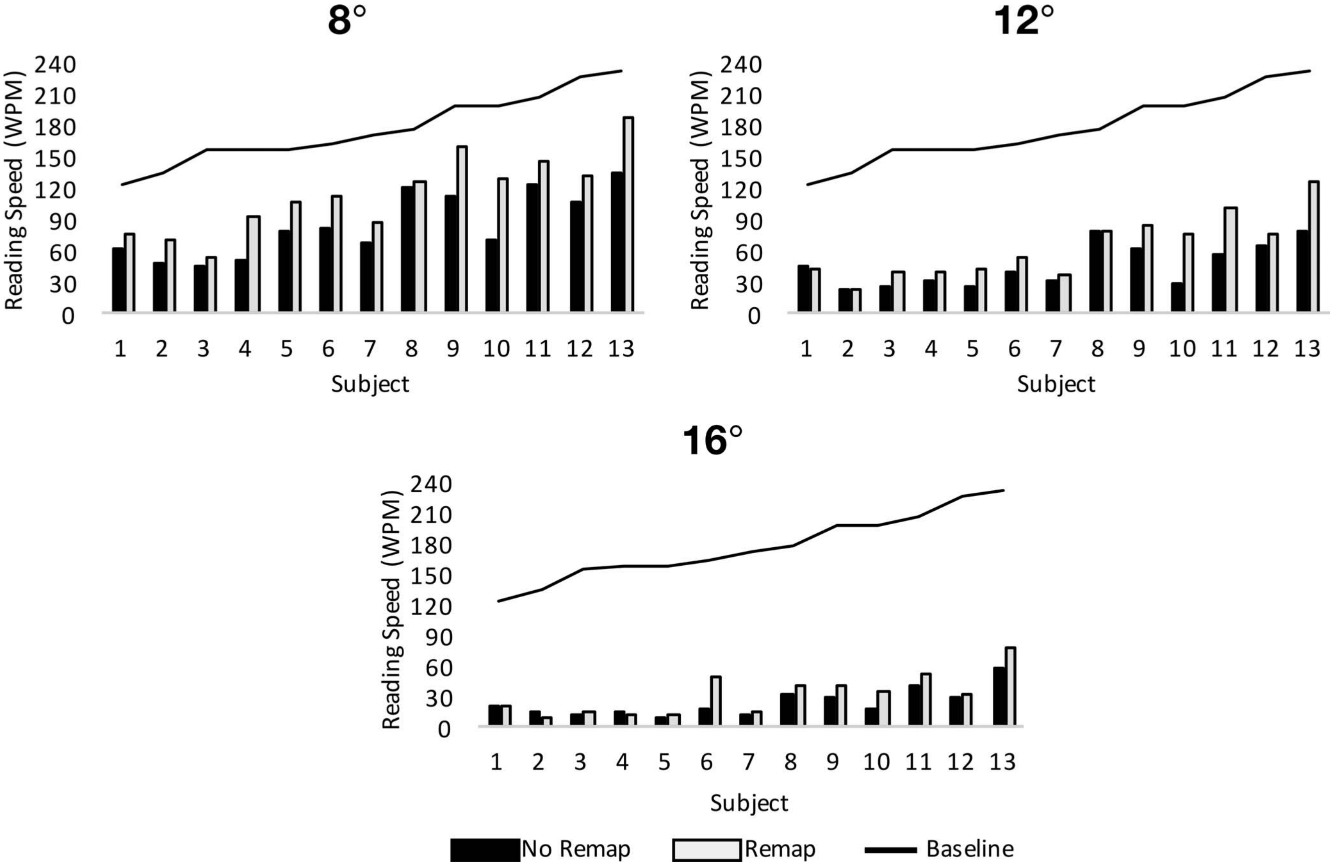


Figure 8. Experiment 3: subjects read 20 sentences for each of the six conditions (three scotoma sizes with and without remapping), and their average reading speed for each condition was calculated. Individual subject reading speeds ordered by increasing baseline reading speed are shown here for the 8°, 12°, and 16° scotomas. The *curve above the bars* displays baseline reading speeds without a scotoma for each subject.

inexperienced observers may, voluntarily or involuntarily, be tempted to continuously attempt to foveate on target words, which results in a constant change in word location. When a subject foveates on a particular word (blocked by the scotoma), it is remapped either upward or downward. The subject's natural tendency is to then shift gaze to foveate at this new word position. When the gaze shifts, this results in the word being remapped in the opposite direction, producing a constant change in remapping location when trying to read. Aguilar and Castet[34] reported similar findings with remapping, although their remapping algorithm is not reported. It is likely that training subjects in using this remapping paradigm over multiple sessions will help reduce this issue and provide even greater benefits with remapping. This possibility is currently being explored in our laboratory.

For patients with CFL, the efficacy of remapping may depend on PRL location. If a patient's PRL is to the left of the scotoma, for example, a remapping such as ours would prove very beneficial as it would uncover upcoming text that would otherwise be lost to the scotoma. It should be possible to tailor remapping algorithms to the location of the patient's PRL. It is also likely that the optimal remapping would also depend on the visual task. A visual search task might benefit more from a local shape preserving remapping, for example.

Real-time spatial remapping allows subjects to maintain foveal reference of the text, that is, base eye movements on foveal coordinates as would a normally sighted reader, but read the remapped text with peripheral vision. This may be particularly beneficial for patients in early stages of AMD, who still maintain a foveal reference. In experiment 3, subjects reported that being able to maintain foveal reference was a noticeable benefit for the smaller scotomas.

Our experiments differed from the 1995 study using NASA's device[22] in several key ways: Instead of using linestep reading that eliminates the need for saccadic eye movements,[22,35] we used a more naturalistic reading experience allowing subjects to maintain control over the timing and extent of saccades. We used an area preserving remapping that exposed all of the hidden text in the vertical directions—above and below the scotoma—while the radial eccentric remapping used in the prior study only partially exposed text and in the horizontal directions. to the left and right (40% and 80% of text exposed for the two variations used). The remapping used in the prior study also caused magnification and distortions in the text not present in our method. Furthermore, a larger letter size of 1.5° was used in the other study as compared to the 0.42° and 0.8° letter sizes used in our experiments. This made the ratio of character height to critical print size at the retinal eccentricity corresponding to scotoma margins much higher than what we tested for corresponding scotoma sizes across both experiments. At the 1.5° letter size, the 2°, 4°, and 8° scotomas used masked approximately one, two, and five letters, respectively, considerably less than the range of characters masked in our experiments. Finally, our white scotomas blended in with the background, and provided a more naturalistic simulated CFL experience than the black ones used in the past work. For the 4° scotoma, with the 40% exposure remapping, Wensveen et al.[22] observed a statistically significant increase in reading speed of 5 WPM (8%) over the nonremapping average of 63 WPM. No increase was observed with the 80% remapping. For the 8° scotoma, they observed an increase of 10 WPM (29%) for both the 40% and 80% remappings, from an average of approximately 35 WPM without remapping to 45 WPM with remapping. While the difference in absolute improvement due to remapping between our study and the previous study can be attributed to the methodological differences listed above as well as differences in technology, we saw similar trends of increasing reading speed with remapping.

Adapting the system for use with patients with CFL will require calibrating the eye tracker, which remains a technical challenge in patients. Eye trackers are usually calibrated for normally sighted subjects by requiring them to fixate on known screen locations with their fovea. This would be difficult in patients with CFL but without a functioning fovea. While patients with CFL with stable PRLs could use their PRLs for calibration, fixation stability with a PRL is generally worse than with the fovea, so the calibration errors would be greater. There has been some success in calibration of eye trackers for patients with CFL using radial grating stimuli.[36,37] A "calibration-free" system that uses stereo tracking cameras has also been developed.[38] The efficacy of this system for patients with CFL may be high but has yet to be demonstrated. Another challenge is the high latency of our HMD systems, which would inhibit naturalistic viewing by causing brief discrepancies between expected and actual remapping location. While this would be an issue with the head-mounted hardware we used, given the pace of technologic advances, head-mounted setups with improved hardware and lower latencies are fast becoming reality.

We have created a paradigm that successfully remaps visual information around scotomas and provides a naturalistic viewing experience. Three experiments with simulated scotomas demonstrated that remapping increases reading speeds, making remapping a promising possibility for improving reading speeds in patients with CFL.

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