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Skilled Deaf Readers Have an Enhanced Perceptual Span in Reading

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Abstract

Recent evidence suggests that, compared with hearing people, deaf people have enhanced visual attention to simple stimuli viewed in the parafovea and periphery. Although a large part of reading involves processing the fixated words in foveal vision, readers also utilize information in parafoveal vision to preprocess upcoming words and decide where to look next. In the study reported here, we investigated whether auditory deprivation affects low-level visual processing during reading by comparing the perceptual span of deaf signers who were skilled and less-skilled readers with the perceptual span of skilled hearing readers. Compared with hearing readers, the two groups of deaf readers had a larger perceptual span than would be expected given their reading ability. These results provide the first evidence that deaf readers' enhanced attentional allocation to the parafovea is used during complex cognitive tasks, such as reading.

Keywords

deaf readers, eye movements, reading skill, perceptual span, visual processing in the parafovea, reading, individual differences, literacy

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Illiteracy is a serious problem in the deaf population. The median reading level of young deaf adults graduating from high school is 8 years below the average of their hearing peers (Kelly & Barac-Cikoja, 2007). Although the reasons for this problem are unclear (Bélanger, Baum, & Mayberry, 2012; Mayberry, del Giudice, & Lieberman, 2011), one intriguing hypothesis is that enhancements in visual cognition engendered by deafness may cause reading difficulties. Recent research has found that individuals who experience early severe to profound deafness are more efficient at processing information in extrafoveal (i.e., parafoveal and peripheral) vision than hearing individuals are. This has been shown in studies investigating low-level visual perception of motion, orientation and brightness discrimination, and detection of stimuli in tasks performed under attentionally demanding conditions. These effects are thought to arise from increased allocation of attention to stimuli in extrafoveal vision as a consequence of early deafness (Bavelier, Dye, & Hauser, 2006; Dye & Bavelier, 2010). On the basis of such results, Dye, Hauser, and Bavelier (2008) speculated that "greater availability of parafoveal information may slow down foveal processing, resulting in longer fixations and slowing down the reading process" (p. 77). It is crucial to investigate how this unique aspect of visual cognition may influence reading in the deaf population.

Although there has been considerable research conducted with deaf people on various cognitive processing tasks related to reading (Kelly & Barac-Cikoja, 2007; Musselman, 2000), little research has examined reading per se in this population. Studies that examine written language processing often use a self-paced moving-window paradigm. In this paradigm, participants are presented with sentences in which the words are masked. Participants push a button at their own pace to reveal the text one word at a time, with the previously read word being replaced again by a mask. This gives the impression that as they read, a window of text is moving across the screen. Studies using such a paradigm have shown that skilled deaf readers spend less time viewing each word than less-skilled deaf readers do (Kelly, 1995, 2003). This result is consistent with findings reported in the literature on skilled and less-skilled hearing readers (Rayner, 1998, 2009). Showing only one word at a time, however, is not very diagnostic of normal reading because it does not allow the reader to access parafoveal information that is clearly used during normal reading (see Rayner, 1998).

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Prior research with hearing readers of alphabetic languages has demonstrated that, in addition to the words processed in the fovea, information up to 14 or 15 characters to the right of fixation is used during reading (McConkie & Rayner, 1975; Rayner & Bertera, 1979). This region of effective vision, the *perceptual span*, is asymmetric because only information from 3 to 4 letters to the left of fixation is used (Rayner, Well, & Pollatsek, 1980). Evidence regarding the size of the perceptual span comes from studies using the gaze-contingent moving-window paradigm (McConkie & Rayner, 1975), in which text is displayed normally in a window around the fixation point but replaced by a mask on either side of the window (see Fig. 1). However, contrary to the procedure in self-paced tasks, in the gaze-contingent paradigm, the window follows the reader's eyes as they move along in the sentence, and the size of the window is manipulated between conditions to provide increasing levels of information in the parafovea. The assumption is that if the window is wide enough, reading will not be disrupted compared with a condition in which all the text is visible. Crucially, the size of the perceptual span is not simply a function of decreased visual acuity in the parafovea. This was demonstrated by the results of one recent study that used a parafoveal magnification technique with a moving window, in which the size of parafoveal text increased gradually on each fixation to compensate for the loss of visual acuity beyond the fovea (Miellet, O'Donnell, & Sereno, 2009). This study found that, despite this manipulation, the perceptual span was 14 to 15 character spaces to the right of fixation, which confirms that the span is under cognitive and attentional control.

The size and asymmetry of the perceptual span does however vary with on-line processing constraints. The directionality of reading (e.g., right to left, as in Hebrew, or left to right, as in English) influences the asymmetry of the span (Pollatsek, Bolozky, Well, & Rayner, 1981). Research has also shown that the size of the perceptual span is sensitive to reading level (Häikiö, Bertram, Hyönä, & Neimi, 2009; Rayner, 1986), reading speed (Rayner, Slattery, & Bélanger, 2010), and the properties of the writing system (Inhoff & Liu, 1998). In fact, eye movement measures in general are very sensitive to reading level: Compared with skilled readers, less-skilled and dyslexic readers are slower readers, have a smaller perceptual span, make shorter saccades, and make more regressive fixations (see Rayner, 1998). These measures can also distinguish highly skilled from average college-level readers (Ashby, Rayner, & Clifton, 2005).

The goal of the present experiment was to examine whether the perceptual span varied as a function of hearing status (i.e., in deaf vs. hearing readers), as well as how skilled deaf readers, less-skilled deaf readers, and skilled hearing readers compared on reading speed (measured in words per minute, or wpm), mean length of forward saccades, and mean fixation durations. As previously mentioned, in skilled hearing readers, when 14 to 15 characters to the right of fixation are visible, and the text beyond the moving window is masked, reading proceeds at the same rate as when text is presented without a window. The enhanced extrafoveal distribution of visual attention reported for deaf individuals would predict a larger perceptual span in deaf readers than in hearing readers when both groups are matched on reading level. Additionally, given that saccades are planned with information gleaned from parafoveal vision and are intimately connected with the distribution of visual attention, longer forward saccades would be predicted for deaf individuals (unless reading level also modulates this effect) compared with hearing controls. Recall, however, that Dye et al. (2008) suggested that increased availability of parafoveal information (a larger perceptual span) could slow foveal processing in deaf readers. This would result in longer fixation durations in deaf readers than in hearing readers. Finally, less-skilled deaf readers would be expected to have a smaller perceptual span than skilled deaf readers because their reading level is much lower. We also expected that less-skilled deaf readers would

```
The little girl was happy to win the race last weekend.        Normal Text
                      *
---------------------------------------------------------------------------

xxe little girl xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx        Moving Window
      *                                                        on Three
xxxxxxxxle girl was hapxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx        Consecutive
            *                                                  Fixations
xxxxxxxxxxxxxxxxxxs happy to win xxxxxxxxxxxxxxxxxxxxxx
                      *
```

Fig. 1. Example of the moving-window paradigm, in which characters are displayed in a window around the position of the eyes within the text but replaced by a mask on either side of the window, on three consecutive fixations. The window follows the participants' eyes as they read along. The asterisk represents the position of the eyes within the sentence. In this example, the window is asymmetrical and shows 4 character positions to the left of fixation and 10 character positions to the right of fixation.

have longer fixation durations and regress back into the text (reread) more than would skilled deaf and skilled hearing readers (see Rayner, 2009). An additional question of interest is whether less-skilled deaf readers have a significantly smaller perceptual span than skilled hearing readers do. Such a difference would be predicted from the reading ability of these two groups.

Method

Participants

Forty adults from San Diego's Deaf community participated in the experiment. They were aged 20 to 45 years (M = 30 years), severely to profoundly deaf (hearing loss > 71 dB in the better ear), born deaf or became deaf before the age of 2 (though 3 participants became deaf at age 3, 4, and 10, respectively), and used American Sign Language (ASL) as their main communication mode for more than 10 years. Twenty skilled hearing readers who were native speakers of English aged 21 to 43 years (M = 29 years) served as a control group. All participants had normal or corrected-to-normal vision and received financial compensation for their participation.

Background measures

All participants completed the Peabody Individual Achievement Test-Revised (PIAT-R; Markwardt, 1989), which provided an assessment of their reading level. This assessment was crucial because reading level has been shown to influence the size of the perceptual span during reading. The deaf readers were split into two groups based on their PIAT-R score: skilled deaf readers (n = 18), who were well matched on reading level with the skilled hearing readers (n = 20), and less-skilled deaf readers (n = 22).[1] A one-way analysis of variance (ANOVA) comparing the reading level of skilled hearing readers (M = 85, SD = 6.8), skilled deaf readers (M = 82, SD = 5.5), and less-skilled deaf readers (M = 68, SD = 4.1) showed a significant effect of group, $F(2, 57) = 52.13$, $p < .0001$, $\eta_p^2 = .65$. Skilled hearing readers and skilled deaf readers did not differ significantly in reading level ($p = .21$), but less-skilled deaf readers differed significantly from both skilled hearing readers ($p < .0001$) and skilled deaf readers ($p < .0001$).[2]

Nonverbal IQ was also assessed for all participants with three subtests of the performance scale of the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981): Picture Completion, Picture Arrangement, and Block Design. Performance of the skilled hearing readers (M = 11.4, SD = 1.7), skilled deaf readers (M = 11.3, SD = 1.4), and less-skilled deaf readers (M = 10.5, SD = 1.5) was not significantly different on this measure, $F(2, 57) = 2.4$, $p > .10$, $\eta_p^2 = .08$. Finally, although skilled deaf readers and less-skilled deaf readers did not significantly differ in age of English acquisition (M = 1.3 years and 2.7 years, respectively), $F(1, 38) = 2.7$, $p = .11$, $\eta_p^2 = .07$, skilled deaf readers acquired ASL at a younger age than less-skilled deaf readers did (M = 4.5 years and 8.2 years, respectively), $F(1, 38) = 5.9$, $p = .02$, $\eta_p^2 = .14$. The skilled deaf readers and less-skilled deaf readers did not differ on degree of deafness in their better ear ($p = .48$) or on age of deafness onset ($p = .17$). On average, deaf participants had used ASL for 25 years (skilled deaf readers) and for 22 years (less-skilled deaf readers). The two groups did not differ on this measure ($p > .20$).

Stimuli

We created 165 sentences containing 10 to 17 words and presented them using the gaze-contingent moving-window paradigm. Each sentence was presented on a single line and had a maximum of 78 characters (letters and spaces). All sentences had simple syntactic structures so that we could avoid potential reading difficulties for the less-skilled deaf readers (see Kelly & Barac-Cikoja, 2007).

Apparatus

Eye movements were monitored via an EyeLink 1000 eye tracker (SR Research, Kanata, Ontario, Canada; spatial resolution > 0.04°). Eye position was sampled every half millisecond. Participants were seated 60 cm from a 22-in. NEC MultiSync FP1370 monitor (refresh rate = 150 Hz). Head movements were minimized with the use of a chin and headrest. Eye movements from the right eye were recorded, but viewing was binocular.

Design and procedure

There were four different window sizes. In each window, 4 character spaces were visible to the left of fixation and 6, 10, 14, or 18 character spaces (the WS6, WS10, WS14, and WS18 conditions, respectively) were visible to the right of fixation. In the moving-window conditions, each character outside the window (including the spaces between words) was replaced by a lowercase "x." As the window of visible text followed the movement of the eyes across a sentence, upcoming characters were revealed, and previous characters were again replaced with an "x" (see Fig. 1). There was also a baseline no-window condition, in which the entire sentence was visible.

Sentences were presented in black 14-pt Courier New font on a light gray background. One degree of visual angle comprised 3.4 letters. Each sentence was presented in only one condition. Sentences were counterbalanced across participants and conditions. Order of presentation was randomized for each participant.

The testing session started with the completion of the reading and nonverbal IQ tests, which were then followed by the experimental task. Participants were instructed to read silently for comprehension and to press a keypad when they finished reading. These instructions were followed by a three-point calibration procedure on the eye tracker for each participant. Then, after reading 15 practice sentences to familiarize themselves with the moving-window paradigm, participants read all the test sentences one at a time.

Comprehension questions were asked after 22% of the trials. Skilled hearing, skilled deaf, and less-skilled deaf readers scored 93%, 91%, and 88%, respectively. An ANOVA revealed a significant difference between these three groups, $F(2, 57) = 6.15$, $p < .004$, $\eta_p^2 = .18$, with significant differences between less-skilled deaf and skilled hearing readers ($p < .01$), and between less-skilled deaf and skilled deaf readers ($p < .01$).

Analysis

To determine whether deaf readers have a larger perceptual span than hearing readers do, we calculated their reading rate (in wpm) in each condition. Reading rate is a composite measure that incorporates the number and duration of fixations across the sentence and is typically used to assess reading performance in moving-window experiments. Forward saccades were also analyzed given that they are tightly linked with the distribution of visual attention in the parafovea. Finally, we analyzed average fixation duration to determine whether deaf readers' foveal processing of words is slower (relative to skilled hearing readers).

Fixations shorter than 80 ms and within one letter of another fixation were combined with that fixation (0.3% of fixations for each group), but other fixations shorter than 80 ms were excluded (3.4%, 2.4%, and 2.4% of fixations for skilled hearing, skilled deaf, and less-skilled deaf readers, respectively). Trials with two or more blinks were excluded (1.8%, 3%, and 2.4% of trials for skilled hearing, skilled deaf, and less-skilled deaf readers, respectively) along with trials in which there were fewer than five fixations for the whole sentence (1.4%, 1.9%, and 1.3% of trials for skilled hearing, skilled deaf, and less-skilled deaf readers, respectively).

Data were analyzed with linear mixed-effects models, using the lme4 package (Bates, Maechler, & Dai, 2009) available in the R programming environment (R Development Core Team, 2008). Participants and items were specified as crossed random effects (Baayen, 2008), and *p* values were computed with Markov chain Monte Carlo sampling (using the pvals.fcn function from the languageR package). To compare the effect of increasing window size for each measure, we set up four contrasts (WS18 vs. no window, WS14 vs. WS18, WS10 vs. WS14, and WS6 vs. WS10) using successive difference contrasts (Venables & Ripley, 2002).[3]

Results

Reading rate

As in prior moving-window experiments, our goal was to ascertain when the reading rate for each group reached asymptote (see Fig. 2). For skilled hearing readers, reading rate significantly increased from the WS6 to the WS10 conditions ($b = -40.21$, $SE = 3.56$, $p < .0001$) and from the WS10 to the WS14 conditions ($b = -14.52$, $SE = 3.56$, $p < .0001$), but there were no further increases in reading rate with larger window sizes ($p = .18$).[4] Thus, the reading rate for skilled hearing readers reached asymptote with a window of 14 characters to the right of fixation, a finding that replicates much prior research (see Rayner, 2009, for a review).

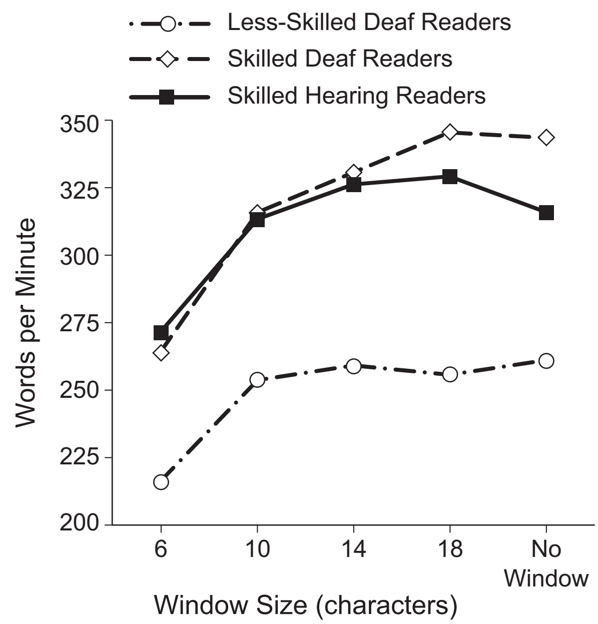

Fig. 2. Mean reading rate as a function of window size for the skilled hearing readers, skilled deaf readers, and less-skilled deaf readers. Window size was defined by the number of characters visible to the right of fixation.

For less-skilled deaf readers, we found a similar pattern despite their significantly lower reading level. Reading rate increased from the WS6 to the WS10 conditions ($b = -38.73$, $SE = 3.94$, $p < .0001$) and from the WS10 to the WS14 conditions ($b = -8.20$, $SE = 3.94$, $p < .04$). As with skilled hearing readers, there were no further increases in reading rate with larger window sizes (all *p*s > .48).

Most interesting, the reading rate for skilled deaf readers did not reach asymptote until there were 18 characters available to the right of fixation. For these readers, reading rate increased not only from the WS6 to the WS10 conditions ($b = -50.86$, $SE = 4.53$, $p < .0001$) and from the WS10 to the WS14 conditions ($b = -16.58$, $SE = 4.53$, $p = .0003$), but also from the WS14 to the WS18 conditions ($b = -13.86$, $SE = 4.55$, $p = .002$), with no additional increase from the WS18 to the no-window conditions ($p = .70$). Thus, skilled deaf readers were faster in the WS18 condition than in the WS14 condition (344 wpm vs. 329 wpm), whereas the other groups did not show this increase in reading speed (skilled hearing readers: 329 wpm vs. 326 wpm; less-skilled deaf readers: 268 wpm vs. 266 wpm).

Overall reading rate did not significantly differ between skilled hearing readers and skilled deaf readers, ($b = 5.55$,

SE = 24.09, p = .82). Not surprisingly, less-skilled deaf readers read slower than skilled hearing readers (b = −51.63, SE = 22.91, p < .05), and skilled deaf readers did (b = −57.14, SE = 23.37, p < .01). Additionally, the increase in reading rate from the WS6 to WS10 condition was significantly greater for skilled deaf than for less-skilled deaf readers (b = 12.67, SE = 5.94, p < .03) and marginally greater for skilled deaf readers relative to skilled hearing readers (b = −10.05, SE = 5.73, p = .08). Similarly, skilled deaf readers' change in reading rate from the WS14 to the WS18 conditions was significantly greater than less-skilled deaf readers' change in reading rate between these two conditions (b = 14.44, SE = 5.96, p < .02) and marginally greater than skilled hearing readers' change in reading rate between these two conditions (b = −9.75, SE = 5.76, p = .09). These interactions indicate that skilled deaf readers were more negatively affected by the loss of parafoveal information (between 6 and 10 characters to the right of fixation) than less-skilled deaf and skilled hearing readers were, and that they were better able to extract information from farther down the line of text.

Forward-saccade length

Mean forward-saccade length reliably increased from one window-size condition to the next for skilled hearing readers (WS6 to WS10: b = −0.98, SE = 0.07, p < .0001; WS10 to WS14: b = −0.63, SE = 0.07, p < .0001; WS14 to WS18: b = −0.19, SE = 0.07, p < .01), for less-skilled deaf readers (WS6 to WS10: b = −0.98, SE = 0.06, p < .0001; WS10 to WS14: b = −0.76, SE = 0.06, p < .0001; WS14 to WS18: b = −0.25, SE = 0.06, p < .0001), and for skilled deaf readers (WS6 to WS10: b = −1.24, SE = 0.07, p < .0001; WS10 to WS14: b = −0.84, SE = 0.07, p < .0001; WS14 to WS18: b = −0.53, SE = 0.07, p < .0001), except from the WS18 to the no-window conditions, in which all groups showed a slight decrease in the length of forward saccades (skilled hearing readers: b = 0.20, SE = 0.07, p < .01; less-skilled deaf readers: b = 0.18, SE = 0.06, p < .01; skilled deaf readers: b = 0.19, SE = 0.07, p = .01). Thus, the overall length of forward saccades was similar for all three groups (all ps > .19).

It is important to note that the increases in forward-saccade length that accompanied increases in window size were significantly larger for skilled deaf than for skilled hearing readers (WS6 to WS10: b = −0.28, SE = 0.10, p < .01; WS10 to WS14: b = −0.19, SE = 0.10, p = .05; WS14 to WS18: b = −0.33, SE = 0.10, p < .001; see Fig. 3a). Skilled deaf readers also made longer forward saccades than less-skilled deaf readers did from the WS6 to the WS10 conditions (b = 0.26, SE = 0.07, p < .01) and from the WS14 to the WS18 conditions (b = 0.28, SE = 0.09, p < .01). There were no significant differences in forward-saccade lengths between the less-skilled deaf and the skilled hearing readers (all ps > .19). As noted earlier, saccade planning is assumed to make use of attentional resources for the purpose of targeting areas of text that have yet to be adequately encoded. The fact that skilled deaf readers planned and executed longer forward saccades than did skilled hearing and less-skilled deaf readers strongly suggests that they were better able to encode more of the intervening text.

Fixation duration

Mean fixation durations for all three groups were longer in the WS6 condition than in the WS10 condition (skilled hearing readers: b = 5.42, SE = 1.45, p < .001; skilled deaf readers: b = 5.54, SE = 1.83, p < .01; less-skilled deaf readers: b = 5.48, SE = 1.63, p < .001) and longer in the WS18 condition than in the no-window condition (skilled hearing readers: b = 6.50, SE = 1.47, p < .0001; skilled deaf readers: b = 8.44, SE = 1.86, p < .0001; less-skilled deaf readers: b = 7.48, SE = 1.64, p < .0001; see Fig. 3b). None of the other successive contrasts for window size were significant (ps > .06). Across all window sizes, mean fixation duration was 215 ms for skilled hearing readers, 217 ms for skilled deaf readers, and 227 ms for less-skilled deaf readers. Crucially, skilled deaf readers and skilled hearing readers did not differ on this measure (p = .85). Less-skilled deaf readers, in contrast, made longer fixations than skilled hearing readers did (b = 16.74, SE = 8.53, p = .05) and skilled deaf readers did, but this latter difference did not quite reach significance (p = .07).

The pattern for mean fixation duration over the window-size conditions was very similar for the three groups of readers. None of the interactions were significant (all ps > .18). This indicates that, relative to hearing readers' ability, skilled deaf readers' ability to effectively utilize parafoveal information, as evidenced by their reading rate, did not slow foveal processing and lead to longer eye fixations, as was suggested by Dye et al. (2008).

Although not discussed here, the mean number of forward fixations per sentence and the mean number of regressive fixations are presented in Figures 3c and 3d, respectively, for the sake of completeness.

Discussion

In the experiment reported here, we investigated the perceptual span of readers who are severely to profoundly deaf and communicate mainly via ASL. We were particularly interested in determining whether differential distribution of attentional resources across the visual field found in individuals with early onset deafness (Bavelier et al., 2006) would translate into a larger perceptual span during reading. Our primary finding was that skilled deaf readers did have an enhanced perceptual span in comparison with the matched hearing control group: The reading rate for the skilled deaf readers reached asymptote with a larger window of visible text (18 characters to the right of fixation) than the reading rate for skilled hearing readers did. We indeed replicated the general pattern of results found in the literature for hearing readers, who have been shown to process useful information up to 14 letter spaces to the right of fixation (McConkie & Rayner, 1975).

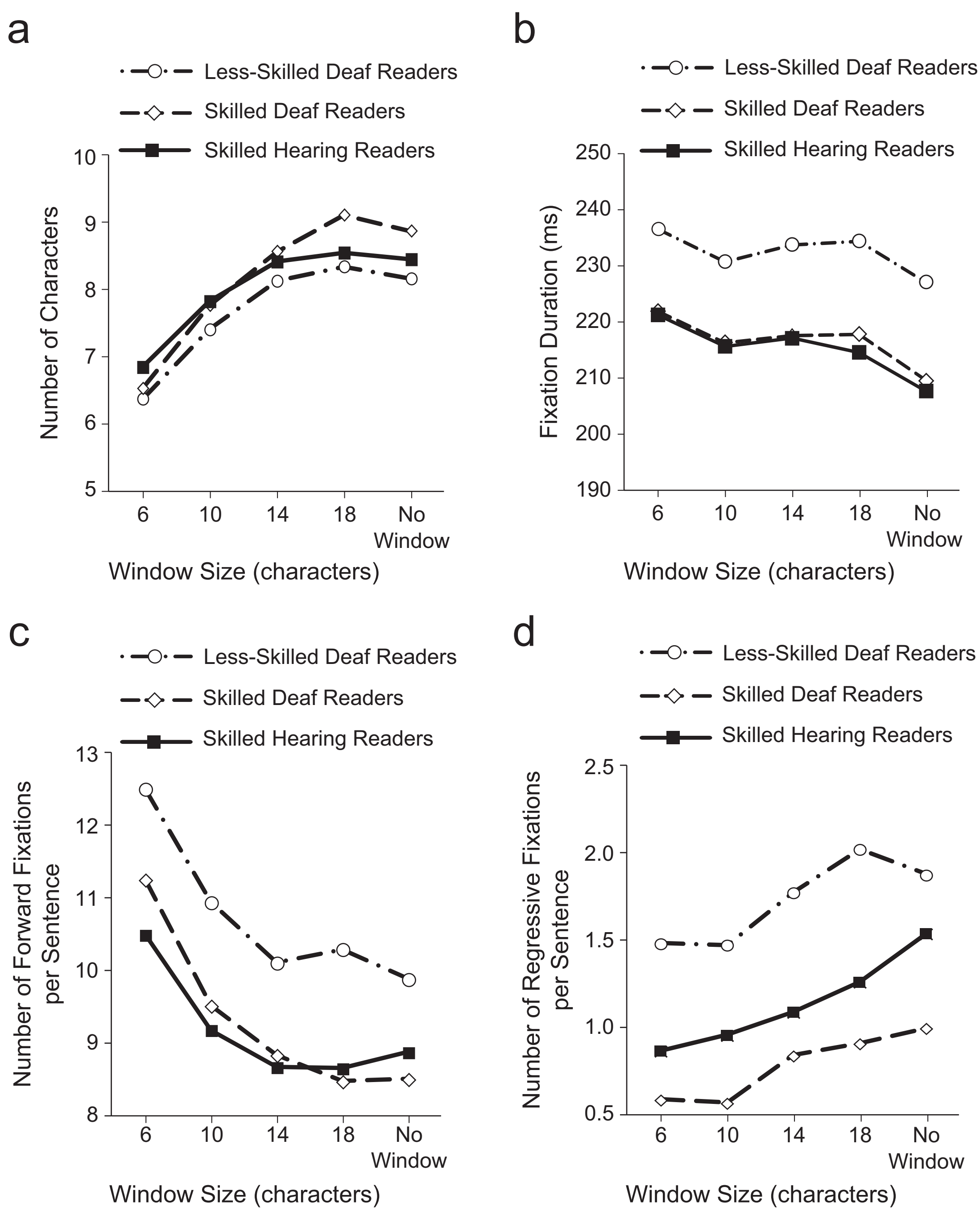

Fig. 3. Mean forward-saccade length (a), mean fixation duration (b), mean number of forward fixations per sentence (c), and mean number of regressive fixations per sentence (d) as a function of window size and participant group (skilled hearing readers, skilled deaf readers, and less-skilled deaf readers). Window size was defined by the number of characters visible to the right of fixation.

Dye et al. (2008) suggested that an extended perceptual span for deaf readers might detract from foveal processing of words and result in slower reading. This was not the pattern of results found here. Skilled deaf readers' mean fixation durations at all window sizes matched those of skilled hearing readers almost perfectly. Furthermore, not only did skilled deaf readers read as fast as skilled hearing readers did, but they also made fewer regressive fixations into prior text (see Fig. 3d), which suggests that they are very efficient readers. Unsurprisingly, the less-skilled deaf readers read at a slower pace than the other two groups did. They also made more fixations (forward and regressive) than the skilled readers did, in line with findings showing that eye movements are highly sensitive to reading level (Ashby et al., 2005; Rayner, 1986).

Is the larger perceptual span in skilled deaf readers a function of their deafness and associated with a wider distribution of visual attention extrafoveally? The tight match on multiple characteristics (reading level, age, nonverbal IQ, and accuracy on the experimental tasks' comprehension questions) between the skilled deaf and the skilled hearing readers suggests that this is the case. Skilled deaf readers read at a slightly lower grade level than skilled hearing readers did (10th grade vs. 11th grade, respectively); thus, it could be expected that the perceptual span of skilled deaf readers might be, if anything, smaller. This was not the case. Additionally, forward-saccade lengths were longer for skilled deaf readers than they were for skilled hearing readers. Much research has shown that attention shifts to the parafovea prior to a saccade being targeted to a specific location (see Rayner, 2009), thus supporting our claim that skilled deaf readers have a wider distribution of attention than skilled hearing readers do.

Finally, we replicated the effects of reading skill on the size of the perceptual span; the skilled deaf readers had a larger span than the less-skilled deaf readers did. These two groups were formed not only on the basis of PIAT-R scores, but they also did not differ on age, nonverbal IQ, degree of hearing loss, age of onset of deafness, and age of acquisition of English. However, they differed in age of ASL acquisition. This factor is tightly linked to reading skills in the deaf population (Chamberlain & Mayberry, 2008; Mayberry, Lock, & Kazmi, 2002), so it is unsurprising that it was predictive of reading level in the current study. Additionally, despite significantly lower reading proficiency (6th-grade equivalence) and a significantly slower reading rate (factors known to reduce the perceptual span; see Rayner, 1986, 2009), less-skilled deaf readers' perceptual span was the same size as skilled hearing readers' perceptual span. This lack of difference suggests that, relative to their reading level, less-skilled deaf readers have a wider perceptual span than hearing readers do.

Overall, our results have at least three major implications. First, they show that enhanced attention to the parafovea in deaf readers is not restricted to low-level visual perception but can also be recruited for a complex cognitive process, such as reading. Second, these results indicate that enhanced attention to the parafovea is not accompanied by reduced foveal processing, as has been previously suggested. Third, our findings show that deaf individuals can be highly proficient readers and that the way in which they process written language varies somewhat from that of hearing readers; they take in more visual information within a fixation than do hearing readers matched on reading level. These results are especially noteworthy against the backdrop of illiteracy that is prevalent in the deaf population.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Notes

1. It would be highly unlikely to find a group of nondyslexic hearing readers matched on age, reading level, and nonverbal IQ with less-skilled deaf readers.
2. On average, skilled hearing readers read at an 11th-grade level, skilled deaf readers read at a 10th-grade level, and less-skilled deaf readers read at a 6th-grade level.
3. The successive-difference contrasts for window size were set up such that the measures for the smaller windows were subtracted from those for the larger windows.
4. Reading rate decreased from the WS18 to the no-window condition for the skilled hearing readers—this was due to an increase in regressive fixations in the no-window condition (see Fig. 3d). This increase could be due to these readers being more willing to reread prior text in the less demanding no-window condition.

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