AMERICAN PSYCHOLOGICAL ASSOCIATION

Journal of Experimental Psychology: General

© 2023 American Psychological Association
ISSN: 0096-3445

2023, Vol. 152, No. 7, 1995–2007
https://doi.org/10.1037/xge0001362

Examining Speech-Based Phonological Recoding During Reading for Adolescent Deaf Signers

Frances G. Cooley[1, 2] and David Quinto-Pozos[1]
[1] Department of Linguistics, University of Texas at Austin
[2] Department of Psychology, University of South Florida

Much of the debate regarding literacy development in deaf and hard-of-hearing readers surrounds whether there is dependence on phonological decoding of print to speech for such readers, and the literature is mixed. While some reports of deaf children and adults demonstrate the influence of speech-based processing during reading, others find little to no evidence of speech-sound activation. In order to examine the role of speech-based phonological codes when reading, we utilized eye-tracking to examine eye-gaze behaviors employed by deaf children and a control group of hearing primary-school children when encountering target words in sentences. The target words were of three types: correct, homophonic errors, and nonhomophonic errors. We examined eye-gaze fixations when first encountering target words and, if applicable, when rereading those words. The results revealed that deaf and hearing readers differed in their eye-movement behaviors when rereading the words, but they did not demonstrate differences for first encounters with the words. Hearing readers treated homophonic and nonhomophonic error words differently during their second encounter with the target while deaf readers did not, suggesting that deaf signers did not engage in phonological decoding to the same degree as hearing readers did. Further, deaf signers performed fewer overall regressions to target words than hearing readers, suggesting that they depended less on regressions to resolve errors in the text.

Keywords: deaf, ASL, eye-tracking, reading, phonological recoding

Supplemental materials: https://doi.org/10.1037/xge0001362.supp

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Researchers have long debated the role of spoken language phonological knowledge and phonological awareness on reading development in deaf children without access to speech sounds (Alegria, 1998; Allen et al., 2009; P. Paul, 2001; P. V. Paul & Lee, 2010; Wang et al., 2008). Phonological awareness, which is the metalinguistic awareness of how the meaningless units of language comprise meaningful words and sentences and the ability to consciously manipulate these units within words and sentences (Castles & Coltheart, 2004; I. Y. Lieberman et al., 1989; Wagner & Torgesen, 1987), has been shown to be a strong predictor of reading skill in typically-developing hearing children (Goswami & Bryant, 1990). However, our understanding of the processes by which deaf and hard-of-hearing (hereafter, we use “deaf” to refer to all readers without auditory access to speech sounds) children learn to read is vague at best. Though some investigations have shown a positive association between reading and spoken language phonological awareness in deaf children (Campbell & Wright, 1988; Dyer et al., 2003), others have failed to find such a correlation (Izzo, 2002; Leybaert & Alegria, 1993; Miller, 1997). Here we present a small-scale, exploratory eye-tracking study targeting activation of speech-based codes during reading in deaf children whose first language is a signed language. To our knowledge, this is one of only a handful of studies to date that leverages eye-tracking to investigate reading patterns in deaf children who use a signed language for daily communication and are developing literacy in the ambient spoken language.

Phonological Decoding as an Early Reading Strategy

Various writings have addressed the phonological decoding of print to speech for hearing readers of alphabetic scripts. Two well-known theoretical accounts are the Developmental Bypass Theory (Pennington et al., 1987) and the Dual-Route access model (Glushko, 1979). According to these models, languages with alphabetic orthographies or writing systems that contain phonetic information require phonological decoding, in which graphemes are recoded into corresponding speech sounds. For shallow orthographies such as Spanish or Italian, grapheme-to-phoneme correspondences are notably consistent. However, the general profile differs for languages with deeper orthographies such as English or French in which a single grapheme or letter can correspond to multiple sounds (e.g., *c*, which can be pronounced in English as [k], [s], and, when part of the -ch- grapheme, as part of [t͡s]). Phonological decoding is believed to be the most prominent strategy employed during early, novice reading, as well as when encountering unfamiliar words as fluent readers progress. The phonological

---

This article was published Online First April 13, 2023.

Frances G. Cooley https://orcid.org/0000-0001-5074-177X

We have no conflicts of interest to disclose.

Frances G. Cooley served as lead for conceptualization, data curation, methodology, writing–original draft, and writing–review and editing. David Quinto-Pozos served in a supporting role for conceptualization, formal analysis, writing–original draft, and writing–review and editing.

Correspondence concerning this article should be addressed to Frances G. Cooley, Eye-Movements and Cognition Lab, Department of Psychology, United of South Florida, 4202 E. Fowler Ave. PCD 4118G, Tampa, FL 33620, United States. Email: cooleyf@usf.edu

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

representation, in turn, activates word meaning. As reading ability progresses, readers begin to engage in sight-word reading for familiar and high frequency words, depending less on phonological decoding (Castles & Coltheart, 2004; Pennington et al., 1987; Share, 2008).

Phonological awareness emerges early in the language learning process prior to the introduction of print, as children as young as four typically demonstrate syllable and rhyme awareness of their spoken language (De Loureiro et al., 2004; Stainthorp & Hughes, 1998; Ziegler & Goswami, 2005). However, it isn't until reading is introduced in school and phonological skills are required that these skills become concrete and testable (Duncan et al., 1993; Lonigan et al., 2000; Martin et al., 2003; Stainthorp & Hughes, 1998), suggesting that the relationship between phonological awareness and reading ability is reciprocal (Carrillo, 1994; Nithart et al., 2011; Perfetti et al., 1987; Share, 2008). While early phonological awareness is highly predictive of later reading outcomes for young hearing readers, the strength of this relationship quickly weakens as reading skill is attained and sight-word reading comes online.

The Homophone Foil Paradigm

The homophone foil paradigm has been used in several applications to target phonological decoding of print to speech. The original task was developed as a sentence verification task to address how phonology is involved in reading. In Doctor and Coltheart's (1980) study, participants were asked to judge sentences and phrases (e.g., *She blew out the candles*) in which certain target words had been replaced by either real homophone target words (e.g., *blue*), real control errors (e.g., *know*), nonword pseudo-homophones (e.g., *bloo*), or nonhomophonic nonwords (e.g., *moe*). Results indicated that children ages 6–10 were more likely to accept homophonic and pseudo-homophonic error words than control errors. Several studies subsequently sought to build off this established work, sparking a series of investigations and methodological improvements on the homophone foil paradigm (Coltheart, Laxon, Keating, et al., 1986; Coltheart, Laxon, Rickard, et al., 1988; Doctor & Coltheart, 1980; Jared et al., 2016; Johnston et al., 1995).

As part of the body of work that utilizes the homophone foil paradigm, Jared et al. (2016) used eye-tracking to investigate the role of phonology in the activation of word meanings in Grade 5 readers. In their multi-experiment article, they investigate phonological activation during reading within the framework of the developmental bypass theory. For their studies, sentence lists were developed, each containing a target word. Target words are either high frequency (HFT) or low frequency (LFT). Nontarget words are also controlled for high frequency (HFD) and low frequency (LFD). Each target word was paired with a homophone and a spelling control.

Consider the following sentence:

> Barbara peered out the window to **see** if you were home.

Following Developmental Bypass Theory, if an individual is reading via the indirect route, replacing the correct target "see" with its homophonic pair "sea" might not disrupt meaning. Both homophones "see" and "sea" activate the phonological representation, /si/, which can activate the correct word meaning in sentence context. One prediction for indirect route readers is that homophone foils would not disrupt reading in the proper context. This would indicate phonological activation resulting in the reader missing the error. Direct route readers who engage in sight-word reading should demonstrate no differences between error conditions, because both "sea" and the nonhomophonic error "set" would be immediately recognized as the incorrect word for that position. Analysis of readers' eye-movements in Jared and colleagues' study (Jared et al., 2016) demonstrated that homophonic errors resulted in fewer regressions and shorter fixation durations than nonhomophonic errors for Grade 5 readers. Further, hearing readers did not demonstrate a frequency effect in this task, and readers were not more or less likely to engage in phonological decoding based on correct, homophone error, or nonhomophonic error word frequency. The authors concluded that this reflected evidence of the indirect route of meaning activation in these Grade 5 readers as they did not notice some of the homophonic errors.

Phonological Decoding in Deaf Signers

One theory regarding the acquisition of print literacy by deaf readers is the Qualitative Similarity Hypothesis (QSH; P. Paul, 2001; P. V. Paul & Lee, 2010; Wang et al., 2008). According to this theory, the processes by which deaf children acquire print literacy are the same as hearing children and are highly dependent on knowledge of speech sounds and the ability to engage in phonological decoding. Following this premise, deaf children require additional support for the acquisition of speech-based codes through alternative routes such as speechreading, residual hearing and hearing devices, visual instruction of phonics, and sign-supported-speech (e.g., Signed English in English-speaking regions) systems. However, this theory holds that while the acquisition of print literacy is thus qualitatively similar across deaf and hearing children, deaf children will be quantitatively delayed due to a lack of auditory access to speech-based codes. Various experimental studies provide evidence in support of active use of speech-based phonological codes in deaf children and adults when reading text (Li & Lin, 2020; M. Yan et al., 2015), during single-word reading (Gutierrez-Sigut et al., 2017; Sehyr et al., 2017), and while engaging in speech-based phonological awareness tasks (Charlier & Leybaert, 2000; MacSweeney et al., 2013). Most of these studies do not report whether the deaf children or adults are fluent users of a signed language, which could be an important factor to consider since signed language knowledge has been shown to play a role in processing during reading in studies of deaf signers (Morford et al., 2011; Villwock et al., 2021).

It should be noted that many profoundly deaf children and adults have little or no experience with speech training and do not use amplification devices or sign-supported speech, yet they become successful readers, and some achieve advanced degrees. This suggests that there are likely alternate approaches to achieve print literacy without speech-based phonology. Recent studies have demonstrated that deaf signers rely on orthographic representations and visual word processing skills more so than speech-based phonological codes when reading (Bélanger et al., 2018; Costello et al., 2021; Emmorey & Lee, 2021; Glezer et al., 2018; Gutierrez-Sigut et al., 2017; Meade et al., 2019; Villwock et al., 2021). Further, evidence from lexical decision tasks and single-word reading studies have suggested that deaf child signers are more sensitive to orthographic manipulations than phonological ones (Beech & Harris, 2002).

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Eye-Tracking and Deaf Signing Children

A small set of studies have leveraged eye-tracking to investigate language use in deaf signers, including investigations of sign language narrative viewing (Bosworth & Stone, 2021), visual world paradigms targeting comprehension of sign, speech, and sign-supported speech (A. M. Lieberman & Borovsky, 2020; A. M. Lieberman et al., 2018; Mastrantuono et al., 2017; Szarkowska et al., 2011; Thompson et al., 2006), and comprehension of subtitles during TV viewing (Cambra et al., 2014). Currently, only a handful of publications exist that employ eye-tracking to investigate reading in deaf child signers, and most of these studies focus on questions about the extent to which readers extract visual and linguistic information from areas outside their point of gaze.

Bélanger et al. (2018) used a moving window paradigm with more- and less-skilled deaf signers (ages 7–15; $M = 10.9$) to test the visual perceptual span of deaf child signers when reading. In moving window paradigms, a gaze-contingent window controls the amount of information available to readers on either side of their fixation point. By changing the size of the window, the number of characters available outside the fixation point can be manipulated to test how much information readers can process outside of their fixation point. Adult deaf signers who are skilled readers have been shown to take advantage of information in the periphery as window size increases more so than hearing peers, resulting in faster reading and longer, fewer saccades (Bélanger & Rayner, 2015; M. J. Traxler et al., 2021). Results of Bélanger and colleagues' study showed similar findings for deaf children: more skilled child deaf readers read faster and performed longer saccades than hearing readers as window size increased. This suggests that young deaf readers took greater advantage of upcoming information in the sentence than hearing readers resulting in increased reading speeds. Furthermore, deaf and hearing readers had similar overall comprehension scores, suggesting that signers were not negatively impacted by not returning to words in the text as often as their hearing peers did (Bélanger et al., 2018). Despite these robust and consistent findings, the broad-brush nature of the moving window manipulation does not allow us to pinpoint the source of these reading differences and whether they are attributed to visual, orthographic, phonological, or semantic processing.

To more specifically pinpoint the source of reading differences, another study employed an invisible boundary paradigm to compare the degree to which high-school age deaf signers of Chinese Sign Language ($M = 18.6$, $SD = 1.8$) and reading-age matched hearing readers take advantage of phonological and semantic information in upcoming text (M. Yan et al., 2015). In invisible boundary paradigms, sentences are first displayed in one condition and change to another after the eyes pass an invisible boundary to test the use of information processed in the parafovea during sentence reading. For this study, sentences were first presented with a target character in one of five preview types before switching to the correct target post boundary: identical, orthographically similar, phonologically similar, semantically similar, and unrelated. Results revealed that hearing readers received stronger phonological preview benefit than semantic preview benefit resulting in shorter fixation durations following phonological preview conditions. However, deaf readers received stronger semantic preview benefit than hearing readers, and only more-skilled deaf readers were found to receive a phonological preview benefit. Interestingly, deaf and hearing readers demonstrated a different timing of phonological activation resulting in different patterns of early- and late-measures of eye-movements. Skilled deaf readers reliably demonstrated a phonological preview benefit with shorter first-pass gaze durations. In contrast, hearing readers presented a phonological preview benefit during their second encounter with the target word, resulting in shorter second-pass gaze durations. Deaf readers reflected no impact of preview benefit during their second pass. These results demonstrate differences in phonological activation by deaf and hearing readers during first- and second-pass reading, as well as differences in the use of parafoveal information during sentence reading.

In a methodology similar to what is employed in the current article, G. Yan et al. (2021) used a version of a homophone foil paradigm to compare speech-based codes in deaf signers of Chinese Sign Language and hearing monolingual speakers of Mandarin Chinese when reading. Chinese has a deep orthography with inconsistent orthography-phonology mapping (X. Zhou & Marslen-Wilson, 2000) but hearing readers have been shown to be sensitive to speech-based phonological features when encountering homophonic errors in text (Feng et al., 2001; W. Zhou et al., 2018). In a sentence verification homophone foil task, deaf and hearing participants ages 13.7–20 ($M = 17.37$) read sentences with target characters in one of three conditions: correct target character, incorrect homophone foil, or unrelated character and indicated whether the sentence contained an error or not. Deaf readers had overall lower sentence verification scores compared to both reading-age and chronological-age matched hearing readers. First-pass measurements did not suggest early phonological activation by either group. However, second-pass behaviors did reflect meaningful differences in how deaf and hearing readers engaged with speech-based codes. Hearing readers spent less time rereading homophonic errors than nonhomophonic errors suggesting activation of spoken Chinese when reading. Overall, deaf readers identified both error types equally, which suggested an activation of word meaning by orthography, but not phonology. In addition to these analyses, the authors performed a median split to categorize signers as more- and less-skilled readers to assess the effect of reading skill on speech-based phonological activation. More-skilled deaf readers had shorter gaze durations on target words following a phonological preview, suggesting that they gained a homophonic preview benefit and do leverage phonological information as reading fluency is attained. Hearing readers demonstrated the opposite effect, as less-skilled readers continued to engage in phonological decoding while more-skilled readers did not. The authors concluded that hearing readers overall did activate speech-based phonology during reading, but that only skilled deaf readers activate speech sounds when reading and were impacted by speech-based phonology.

In summary, results from the few studies of eye-gaze behaviors during reading for middle- and high-school-age deaf readers showed that they differed in parafoveal word processing compared to hearing readers (Bélanger et al., 2018; M. Yan et al., 2015). Additionally, deaf signers in these studies did not primarily depend on speech-based reading strategies when resolving errors in text, while hearing readers did (G. Yan et al., 2021). However, more highly skilled deaf readers had some degree of speech-based code activation when reading, reflected by phonological parafoveal preview benefit (M. Yan et al., 2015) and differences in resolving homophonic and nonhomophonic errors in text (G. G. Yan et al., 2021). All three studies

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

also demonstrated that deaf and hearing readers engage in first- and second-pass reading behaviors differently, resulting in different patterns of phonological and semantic activation across groups (Bélanger et al., 2018; G. Yan et al., 2021).

Currently lacking in the literature is an investigation of the eye-movement patterns and reading strategies of young deaf signers when encountering homophonic and nonhomophonic errors in an alphabetic orthography such as English. To address this gap, we leverage an eye-tracking approach and a version of the homophone foil paradigm (Doctor & Coltheart, 1980; Jared et al., 2016; G. Yan et al., 2021) to examine the impact of speech-based homophony on error detection for deaf readers ages 10–13. This approach allows us to provide additional data for evaluating the claim of activation of speech-based phonology during online reading in deaf child signers.

Research Question

Do deaf and hearing children ages 10–13 demonstrate evidence of different reading strategies when encountering homophonic and nonhomophonic errors in text?

Our hypotheses for the hearing children come from previous studies on monolingual speakers of English. We expect to see an impact of homophonic error words on reading patterns in hearing readers (Ehri, 2014; Jared et al., 2016), as demonstrated by longer fixation durations on nonhomophonic error words as well as increased probability to fixate on or deploy a regression back to nonhomophonic error words as compared to homophonic error words. Further, while nonhomophonic error words are expected to be more disruptive to hearing readers than homophonic error words, these readers would likely demonstrate increased fixation durations and regression deployment to homophonic errors than correct target words. This would suggest that some homophonic errors are not noticed when read in context and that hearing children of this age are still engaging in some degree of phonological decoding when reading.

Deaf signers might not demonstrate the same impact of speech-based phonology on reading as hearing readers since they have less access to ambient speech sounds compared to their hearing peers. We do expect to see increased fixation durations and fixation probability when encountering errors, compared to correct targets. We do not, however, predict differences for this group when encountering both homophonic and nonhomophonic error words. This would indicate that the deaf signers treat homophonic and nonhomophonic error words the same way. This pattern might suggest that deaf readers are more sensitive to target word spelling and meaning than its spoken phonological representation (Bélanger & Rayner, 2015; Costello et al., 2021; Emmorey & Lee, 2021; Glezer et al., 2018; Gutierrez-Sigut et al., 2017). In addition, we predict fewer instances of regression deployment and decreased fixation durations in deaf signers as compared to hearing nonsigners. Previous studies have demonstrated that reading strategies employed by skilled deaf readers involve fewer regressions and lower fixation durations, without a negative impact on comprehension (Bélanger et al., 2018).

Alternatively, the eye-movement patterns of deaf and hearing readers may be similar, indicating that the two groups employ similar strategies of resolving errors in text. This finding would support claims that deaf and hearing children read in qualitatively similar ways, even though there may be quantitative differences (e.g., time delays for deaf readers compared to hearing readers) between the two groups of young readers (P. Paul, 2001; P. V. Paul & Lee, 2010; Wang et al., 2008).

Materials and Method

Participants

This project was approved by our university's governing IRB (Study #2017080044). Deaf participants were recruited by flyers and emails sent to the parents of deaf children at a local ASL-English bilingual school, as well as via snowball recruitment methods leveraging networks of the parents of the participants. Criteria for deaf participants included that they acquired ASL from deaf parents and report using ASL as a primary language, at home with family, and at school. The primary reason for requiring that deaf participants be daily users of ASL is that we wanted to rule out delayed exposure to language and any possible effects on literacy development. Deaf children who do not receive early and robust access to language may experience language deprivation resulting in life-long difficulties with all modalities of communication (Hall et al., 2017). We did not exclude participants based on the use of hearing aids or cochlear implants.

Hearing participants were recruited by flyer and email distribution to local schools and university calendar lists as well as snowball recruitment. Criteria required hearing participants to be monolingual English speakers with no reported hearing loss and normal or corrected-to-normal vision.

We report data from 14 hearing children (three female; ages 9.8–13, $M = 11.5$, $SD = 1$) and nine[1] deaf children (seven female; ages 10–13.6, $M = 11.2$, $SD = 1$) considering that most readers transition from phonological decoding as a primary reading strategy to sight-word reading during this time. Participants were all typically developing with no report of learning delay or disability. None of the participants in the study were home-schooled. Deaf participants all attended a bimodal bilingual residential school for the deaf at the time of data collection and throughout early childhood. All deaf participants were reported by their parents as being exposed to ASL from birth and using ASL as their primary mode of communication at home and at school. Two participants were reported as also using some speech, and all deaf participants were raised in families with at least one deaf-signing parent. According to parent reports, six participants had a dB loss $>$ 70 and three had a dB loss of 40–55; all children had normal or corrected-to-normal vision. No participants in the deaf group reported amplification via hearing aids or the use of cochlear implants. Due to challenges with recruitment, we were unable to balance our groups (in terms of total number per group), which resulted in fewer deaf signers in our sample than hearing readers. While groups are age-matched by mean age and age range, individual participants are not age-matched between groups.

Prior to conducting data collection, informed consent from parents was obtained. An investigator explained the entire consent form to the parents in the family's preferred language (i.e., spoken English or ASL). Both parent and investigator signed two copies, one kept by the family, and one kept in storage by the

---

[1] A 10th deaf participant was enrolled but was ultimately removed due to a failure to properly track their eyes.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

investigator. In addition to parental consent, child participants provided signed assent before completing data collection procedures.

Independent Measure of Reading

All participants completed the Woodcock–Johnson Test of Silent Reading Fluency (WCJ-SRF; Woodcock et al., 2001). This task is a comprehension and fluency measure in which participants are presented with valid (“Fire is hot”) and invalid sentences (“Milk is always blue”) and are asked to read and evaluate validity (“yes,” “no”) for as many sentences as possible in 3 mins. Scores reflect the number of correctly evaluated sentences. Deaf signers performed at age expectations with an average chronological age of 11.7 (range = 9.8–13), but their average reading age equivalence based on raw scores according to the WCJ-III was 12.6 (range = 9.25–18+). Hearing readers, however, performed above the expected reading level for their age. While the average chronological age of the hearing sample was 11.4 (range = 10–13.58, their average reading age equivalence on the WCJ-SRF was 17.7 (range = 8.58–18+).

Previous studies have indicated a strong, positive correlation between family socioeconomic status (SES) and literacy development in children (Reardon et al., 2012) as well as phonological sensitivity (Bowey, 1995). We report three measures of SES: education level of mother and father (if applicable),[2] employment status of mother and father (if applicable), and yearly household income in Table 1. Hearing families reported more parental bachelors and advanced degrees than deaf families, though two of nine deaf participants had mothers with an advanced degree (MA, PhD, MD, or JD). Only one of nine deaf families reported yearly household income above $100,000, while 13 of 14 hearing families indicated annual income at or above $100,000. No families in the study reported income below $20,000 per year

Every increment for each measure was assigned a score from 0 to 5 for the highest degree, 0 to 6 for yearly income, and 0 or 1 for employment status following the Hollingshead Four-Factor Index of Socio-Economic status (Hollingshead, 1975). Scores for each measure were added up to create a composite SES score for each participant. For example, a participant whose unemployed mother (0) has a master’s degree (5), employed father (1) has a college degree (4), and an annual income of 100,000–149,999 (5) has a composite SES score of 15.

Deaf and hearing participants differed significantly on SES aggregate scores (deaf: $M = 10.55$, range = 6–16; hearing: $M = 14.79$, range = 8–17; $t[12.4] = -2.95$, $p = .012$*; $R^2 = -0.58$, 95% CI [−0.95, −0.21]). To test the impact of SES on reading outcomes, regression models were built to test the interaction between group and aggregate SES score on two reading measures used in the study (i.e., WCJ-III Test of Silent Reading Fluency and the homophone foil comprehension questions, which are described as part of the experimental paradigm below):

$$\textit{WCJ-SS} \sim \textit{SES aggregate score} * \textit{group}$$
$$\textit{Homophone foil comprehension scores} \sim \textit{SES aggregate score} * \textit{group}$$

Neither of these models was significant, indicating that the SES of participants did not contribute to the reading ability for either group in this sample based on this estimation and these two reading measurements (see the online supplemental documents for model output).

Experimental Paradigm

Participants completed a version of the homophone foil paradigm (described in the first section of the introduction) using an eye-tracker. All eye-tracking data were collected via EyeLink 1000 at 1,000 Hz sampling rate. Viewing of the sentences was binocular, but only data from the right eye were analyzed and reported. Prior to the calibration process, participants were instructed to read each sentence naturally and for meaning and to place their heads on a chin and forehead rest such that their eyes were approximately 60 cm from the center of the display monitor. The text was presented in 12-point Courier New (0°, 100′, 275″). A horizontal three-point calibration was continually checked and repeated to ensure accurate data capture. Anytime a participant moved their head substantially, calibration was completed again.

Trials were initiated by the participant’s fixation on a gaze-contingent trigger, prompting a sentence to appear. Stimuli were presented such that the first character of the sentence appeared in the exact spot as the trigger to ensure the reader began reading the sentence at the first word of the sentence. Sentences contained target words in one of three experimental conditions: correct, homophonic error, and nonhomophonic error (from Experiment 3 of Jared et al. (2016); see Table 2). Correct targets and both homophonic and nonhomophonic errors were controlled for high frequency (HF) versus low frequency (LF) such that all pairs were equally distributed between: (a) HF correct target versus HF error foils; (b) HF correct target versus LF foils; (c) LF correct targets versus HF error foils; and (d) LF correct targets versus LF error foils. Participants read the same sentence frames, with three possible conditions of target words for each sentence. Each child read up to a total of 108 experimental sentences, broken down into three blocks of 36 sentences, randomized to each condition with filler nonexperimental sentences throughout. Likely due to the degree of fatigue associated with the task, four deaf participants and nine hearing participants only completed two scripts, and an additional two deaf participants only completed one of the three possible blocks. Participants were randomly assigned to start with one of the three possible blocks to ensure counterbalancing of stimuli. In addition, following approximately every fourth sentence, YES/NO comprehension questions were asked about the previous sentence to encourage participants to read sentences for meaning. Comprehension questions followed both test items and filler items.

Eye-Movement Measurements Analyzed

We analyze four specific eye-movement measurements: two measurements that represent the reader’s first encounter with the word (first-pass measures), and two measurements that represent the reader’s second encounter with the word (second-pass measures) if rereading occurred. These measurements were chosen to target differences in error detection when encountering both types of errors. Previous studies have shown that hearing readers demonstrate less evidence of error detection when encountering homophonic errors as the activation of the correct phonology activates the target word meaning (G. Yan et al., 2021; Jared et al., 2016; Rayner et al., 2006).

---

[2] None of the participants had same-sex parents. We report the highest degrees obtained by the mother of each participant (Korat, 2009). Some children may have come from single-parent households as no information was provided about the father.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Table 1

Socioeconomic Status of Groups

SES Factor	Assigned score*	Description of Factor Score	Deaf number of parents	Hearing number of parents
Mother highest degree				
	5	Advanced degree: MA, PhD, MD, or JD	2	6
	4	College degree, BA or BS	2	6
	3	Some college, AA or tech degree	5	2
	2	High school or GED	0	0
	1	Less than high school education	0	0
	0	NA	0	0
Mother employment status				
	1	Employed (part- or full-time)	7	9
	0	Unemployed	2	5
Father highest degree				
	5	Advanced degree: MA, PhD, MD, or JD	0	2
	4	College degree, BA or BS	2	8
	3	Some college, AA or tech degree	4	3
	2	High school or GED	0	0
	1	Less than high school education	0	0
	0	NA	3	1
Father employment status				
	1	Employed (part or full time)	5	12
	0	Unemployed	4	2
Yearly income (in U.S. dollars)				
	6	>150,000	0	6
	5	100,000–149,999	1	7
	4	50,000–99,999	2	0
	3	20,000–49,999	6	1
	2	10,000–19,999	0	0
	1	>10,000	0	0
	0	NA	0	0

Note. *Assigned scores based on the operationalization of SES categories in Hollingshead (1975).

We report an analysis of two first-pass measures: the likelihood that a reader fixates on the target word (first fixation probability) and the duration of the first fixation (first single fixation duration) if it occurs. Readers do not fixate on all words when reading, but perform saccadic jumps from word to word, skipping expected, high frequency, and function words. Increased fixation probability indicates that the reader requires attention to that word due to an error or longer word length (M. J. Traxler et al., 2021; Rayner, 1997; Rayner et al., 2006). The first single fixation duration typically provides a metric of how much time the reader requires to activate the word meaning before

Table 2

Example Homophone Foil Paradigm Sentences (From Jared et al., 2016)

Frequency conditions	Correct target	Homophonic error	Nonhomophonic error
HF correct, HF error	Sandra asked to **hear** her favorite song.	Sandra asked to **here** her favorite song.	Sandra asked to **hair** her favorite song.
	The crowd wanted to **hear** the president speak.	The crowd wanted to **here** the president speak.	The crowd wanted to **hair** the president speak.
	It is hard to **hear** the words of the song.	It is hard to **here** the words of the song.	It is hard to **hair** the words of the song.
HF correct, LF error	The team captains decided **which** players they wanted.	The team captains decided **witch** players they wanted.	The team captains decided **whirl** players they wanted.
	David didn't know **which** chocolate bar he wanted.	David didn't know **witch** chocolate bar he wanted.	David didn't know **whirl** chocolate bar he wanted.
	The janitor showed us **which** recycling box is for paper.	The janitor showed us **witch** recycling box is for paper.	The janitor showed us **whirl** recycling box is for paper.
LF correct, HF error	Diana likes to go around in **bare** feet at home.	Diana likes to go around in **bear** feet at home.	Diana likes to go around in **barn** feet at home.
	Josh formed a snowball with his **bare** hands today.	Josh formed a snowball with his **bear** hands today.	Josh formed a snowball with his **barn** hands today.
	The room looked **bare** when all the furniture was gone.	The room looked **bear** when all the furniture was gone.	The room looked **barn** when all the furniture was gone.
LF correct, LF error	Mrs. Baker warned us not to **waste** the art supplies.	Mrs. Baker warned us not to **waist** the art supplies.	Mrs. Baker warned us not to **worst** the art supplies.
	If you leave the lights on you will **waste** electricity.	If you leave the lights on you will **waist** electricity.	If you leave the lights on you will **worst** electricity.
	The class decided to prevent **waste** at their school.	The class decided to prevent **waist** at their school.	The class decided to prevent **worst** at their school.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

moving on from the word. Increased time spent reading a word can indicate phonological decoding (Costello et al., 2021) or the need to resolve an error (Rayner, 1997; Rayner et al., 2006). We expect increased fixation probability and fixation durations on error words for all readers. We further expect to see evidence of phonological decoding resulting in increased fixation probability and duration on nonhomophonic error words compared with homophonic error words for hearing readers.

We also report two measurements of readers' second encounter with the target word including the likelihood of a reader to regress back to the target word (regression probability) and the amount of time the reader spends fixating on the target during the triggered regression (rereading time). Readers often need to move back in the text during normal reading if saccadic jumps are too long, if important words are skipped, and to resolve issues when an error is encountered (G. Yan et al., 2021; Rayner, 1997; Rayner et al., 2006). If a regression is deployed, the amount of time spent rereading the word can indicate phonological decoding and error resolution (Costello et al., 2021; Rayner, 1997; Rayner et al., 2006). Hearing readers are likely to demonstrate less evidence of error detection when encountering homophonic errors than deaf readers due to phonological decoding. We hypothesize that deaf readers will treat both types of errors similarly.

Data Processing

Eye-movement behaviors were recorded, cleaned, and analyzed via the eye-tracking software suite from the University of Massachusetts, Amherst Eye-Tracking Lab. Eye-movements are recorded by EyeTrack and exported as EyeLink data files (EDFs). EDFs, which contain raw vector data for eye-movement positions, were cleaned and compiled for analysis using Robodoc. EyeDry was employed to extract reports regarding specific measurements for analysis, providing four separate datasets for each analysis.

To begin, all within-subject outliers (i.e., data points that fall beyond ± 3 SD from each participant's mean) for single fixation duration and rereading time measurements were filtered out, resulting in 3.44% of single fixation duration data points being removed and 5.43% of rereading time data points being removed. We report the raw means and *SD* of each measurement by the group.

Statistical Analysis

All data were analyzed via "lmer" for continuous outcome and "glmer" for categorical outcome mixed-effects models from the lme4 package in R (Bates et al., 2015) with a Tukey *p*-value adjustment to account for the issue of multiple analyses conducted. To test fixed effects, we employed mixed-effect models to understand the degree to which deaf and hearing readers were impacted by sentence conditions in the probability of fixating on the target (i.e., "FIX"; categorial variable), first single fixation duration (i.e., "SFD," continuous variable), rereading time (i.e., "RRD," continuous variable), and probability of regressing back to target (i.e., "REG," categorial variable). Considering the issue of multiple samples per participant and the violation of the assumption of independence, the random effect of the subject is included in all models. We report significant fixed effects as well as significant effects with Helmert contrasts. Fixed effects models for each group were created and model equations were as follows:

$$\begin{aligned}\text{outcome} \sim \text{sentence type (reference level} =' \text{correct}')\\ +(1|\text{subject ID}) + (1|\text{trial})\end{aligned}$$

In addition to fixed effects, we employed Helmert contrasts, a sum-to-zero contrast that compares the mean of each level to the mean of the subsequent level (Sundstrom, 2010). Sentence condition factors were ordered (a) homophonic error, (b) nonhomophonic error, and (c) correct target. As such, *contrast 1* in our sentence condition model reports the impact of error conditions compared to the correct condition target words (factor one compared with two and three) and indicates whether error conditions are noticed by the readers, while *contrast 2* reports the difference between homophonic and nonhomophonic error words and indicates the impact of homophony on noticing errors (factor two compared with factor three). Helmert model equations were as follows:

$$\text{outcome} \sim \text{group}^{*}\text{contrasts } 1 \quad 2 + (1|\text{subject ID}) + (1|\text{trial})$$

Results

Homophone Foil Passive Reading Paradigm Results

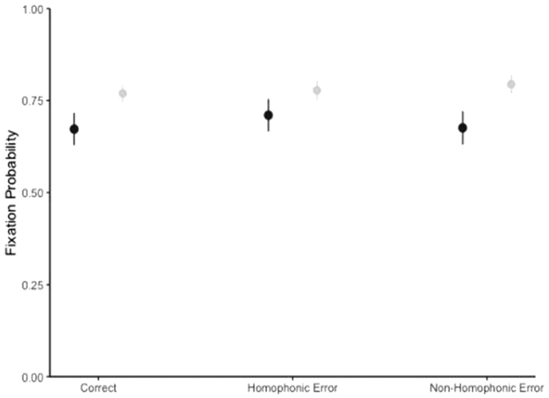
Analysis of comprehension question responses varied between groups. Considering both groups together, participants' responses were 84.92% correct, with deaf signers' responses 75.80% ($SD = 0.44$) correct and hearing participants' responses 88.94% ($SD = 0.31$) correct. Hearing readers responded to comprehension questions correctly more often than deaf readers did, $t(404.91) = -5.2198$, $p < .0001$ (see Appendix for means [and *SD*s] for reported measurements by group and word condition).

Probability of Fixating on Target During First-Pass

Groups did not differ overall when first fixating on target words. Neither deaf nor hearing readers demonstrated any significant fixed effects of sentence condition on their first fixation probability.

Figure 1

Probability of Fixating on Target Word



This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

No significant contrasts emerged when Helmert contrasts were employed. See Figure 1.

First Single Fixation Duration

No fixed effects emerged for deaf or hearing readers in the model predicting the first single fixation duration. Models with Helmert contrasts did not yield significant results and groups did not differ. See Figure 2.

Probability of Regressing Back to Target

Deaf signers were more likely to regress back to homophonic errors compared with correct targets ($z = 2.95$, $p < .01$; $R^2 = 1.12$, 95% CI [0.37, 1.86]), but not nonhomophonic targets. Hearing nonsigners were more likely to regress back to homophonic ($z = 2.64$, $p < .01$; $R^2 = 0.58$, 95% CI [0.15, 1.02]) and nonhomophonic errors compared with correct targets ($z = 5.93$, $p < .0001$; $R^2 = 1.29$, 95% CI [0.86, 1.71]).

Groups differed overall regarding the deployment of regressions ($z = -3.19$, $p < .001$; $R^2 = -0.36$, 95% CI [−0.57, −0.14]). Both contrasts of sentence type emerged as significant regarding the probability of performing a regression back to target for hearing readers (Contrast 1: $z = -4.86$, $p < .0001$; $R^2 = -94$; 95% CI [−1.31, −0.56]; correct vs. error targets: $z = 3.36$, $p < .05$; $R^2 = 0.7$, 95% CI [0.29, 1.11]). Contrast 1 (homophonic vs. nonhomophonic errors) emerged as significant for deaf readers ($z = -2.97$, $p < .01$; $R^2 = -0.93$, 95% CI [−0.97, 0.25]), but contrast 2 (correct vs. error targets) did not. See Figure 3.

Target Word Rereading Time

Deaf readers did not demonstrate any significant effect of sentence condition on rereading time. Hearing readers did demonstrate significant differences in rereading time when encountering nonhomophonic error targets compared with correct targets, $t(290.65) = 3.09$, $p < .01$; $R^2 = 0.43$, 95% CI [0.16, 0.71], but not homophonic error targets.

Groups did not differ overall regarding rereading time. Deaf readers did not differ across sentence conditions on re-reading time following the analysis of Helmet contrasts. Hearing readers demonstrated a significant effect of error type with homophonic versus nonhomophonic errors (Contrast 1: $t[288.85] = -2.12$, $p < .05$; $R^2 = -0.28$, 95% CI = [−0.53, −0.03]) as well as correct versus error targets (Contrast 2: $t[294.03] = 2.37$, $p < .05$; $R^2 = 0.31$, 95% CI: [0.05, 0.57]). See Figure 4.[3]

Discussion

This study examined whether deaf adolescent signers of ASL leverage spoken English phonology during silent reading. We report data from nine deaf signers who attend an ASL-English school, as well as 14 hearing monolinguals, ages 10–13. An eye-tracking protocol was adopted along with a homophone foil paradigm to test the degree to which the participants activate speech-based phonological codes when reading. The homophone foil paradigm we used is a silent reading task that manipulates target words in sentences to examine the phonological decoding of text. Previous studies have shown that young hearing readers are less disrupted in reading by homophonic errors than by nonhomophonic errors (Doctor & Coltheart, 1980; Jared et al., 2016; Johnston et al., 1995). Skilled adult readers, however, do not demonstrate differences in reading patterns between homophonic and nonhomophonic errors, suggesting that hearing readers begin reading by engaging in phonological decoding of print to speech, which is later replaced by faster, sight-word reading (Ehri, 2014; Jared et al., 2016; Pennington et al., 1987; Share, 2008).

In our data, there were ways in which deaf and hearing readers performed similarly and ways that they differed. Neither group demonstrated an effect of homophony nor evidence of error detection during their first encounter with a word. Further, the groups did not differ overall for first-pass measures as there was no significant effect of group in first fixation duration and probability of first fixation (see Figures 1 and 2). Results do suggest that both groups were sensitive to errors in the text during their second encounter with target words, including measures for rereading time and regression deployment (see Figure 3). Finally, deaf readers performed fewer regressions overall compared with hearing readers (see Figure 4).

Young deaf and hearing readers have been reported to engage in first- (M. Yan et al., 2015) and second-pass (G. Yan et al., 2021) reading behaviors differently, particularly regarding the activation of speech-based phonology. The current data add to the existing literature that suggests that the two groups treat error words differently in second-pass measures. Deaf readers in this sample treated homophonic and nonhomophonic error words similarly, indicating minimal activation of speech-based codes, if any[4]. In contrast, hearing readers demonstrated differences in reading behaviors across error conditions suggesting that some homophonic errors were missed (i.e., considered to be correct during processing) while reading. These results suggest that hearing readers engaged in some degree of speech-based phonological decoding but the same cannot be said for deaf readers. Though previous studies have shown some degree of speech-based phonological activation by deaf readers (Bélanger et al., 2018; G. Yan et al., 2021; M. Yan et al., 2015), that finding has only been reported for studies that compared more- and less-skilled deaf readers. Due to a low number of deaf participants (and, as a consequence, lower statistical power) in the current study, we did not separate the deaf group by skill level. Further investigation incrito the impact of reading skill and speech-based phonological activation is warranted to understand the development of speech-based codes in deaf signing readers.

In addition to eye-tracking measures, we report lower comprehension scores overall for the deaf group, however, the effect size was relatively low ($R^2 = -0.15$). This result deviates from Bélanger et al. (2018), as their data did not reflect comprehension differences between deaf and hearing groups. It is important to note that Bélanger's work involved testing parafoveal processing using a moving window paradigm while the current study leverages a homophone foil paradigm to test error detection and homophony without a moving window. In the homophone foil paradigm,

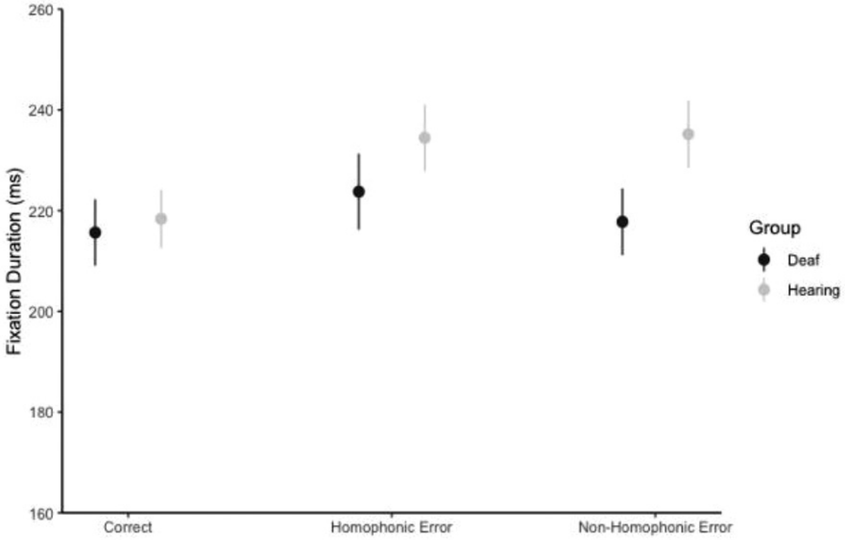
---

[3] A post-hoc analysis of rereading time on nonhomophonic errors was performed and demonstrated a significant difference between deaf and hearing readers ($p < .05$). We do not report this finding in these results due to the exploratory nature of this analysis.

[4] Though a significant main effect of correct target versus error words did emerge for deaf readers' regression probability, importantly no significant difference was found between homophonic and nonhomophonic errors.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

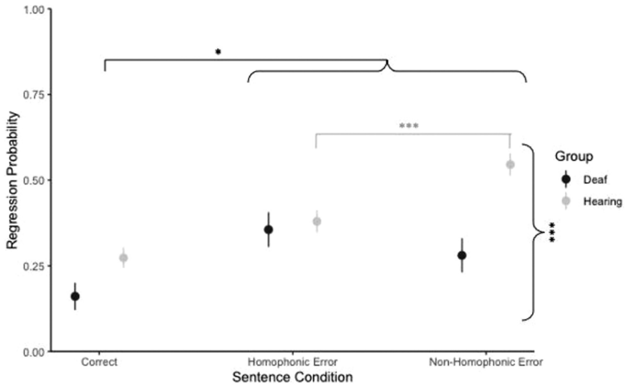
Figure 2
First Single Fixation Duration



measurements of target words that are correct or incorrect are the focus, whereas in the moving window paradigm, no error words were introduced. Indeed results from a sentence verification homophone foil task, G. Yan et al. (2021) report overall lower reading scores for deaf readers compared with chronological- and reading-age-matched hearing readers. Considered together, we wonder whether the difference in comprehension question performance across the two studies may be due, at least in part, to the existence of error words in sentences and their effect on comprehension question responses. Perhaps deaf readers are not resolving errors in text in the same way that hearing readers do. This warrants further investigation.

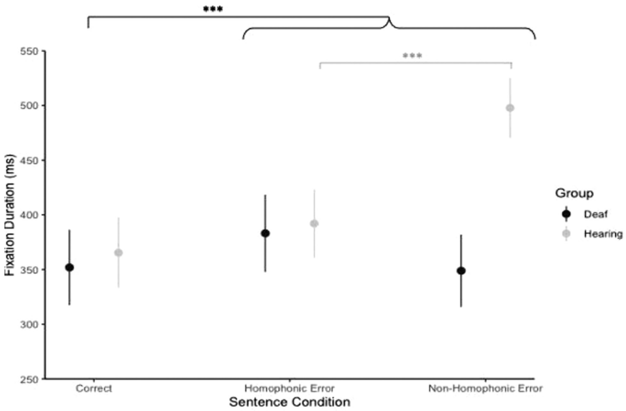
Another factor to consider is differences in SES metrics across the group. The overall SES of the families of hearing readers was greater than that of deaf signers as it relates to the highest degrees attained by parent(s), parental employment status, and household income. Children who come from higher SES backgrounds are often stronger readers than lower SES peers, especially regarding maternal education level (Korat, 2009; Reardon et al., 2012), and children from higher SES families have stronger phonological sensitivity (Bowey, 1995). The aggregate SES scores for hearing families were significantly higher than those for deaf families. However, a composite SES score did not predict outcomes on either the independent measure of reading or the comprehension questions for the homophone foil paradigm. The results of these models (see the online supplementary files for details) suggest that the SES of participants did not have a significant impact on reading outcomes for this sample. Notwithstanding this result, we suggest that future studies would benefit from balancing SES across groups. Importantly, however, despite hearing readers having overall higher SES than deaf readers, hearing readers still demonstrated evidence of phonological decoding at this age while deaf readers did not.

Figure 3
Probability of Performing a Regression Back to Target



* $p < .05$. ** $p < .01$. *** $p < .001$.

Figure 4
Target Word Rereading Time



* $p < .05$. ** $p < .01$. *** $p < .0001$.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Overall, the results from the current study do not provide strong evidence for phonological decoding of print to speech by young deaf readers. In particular, the two groups demonstrated differences in reading strategies when resolving errors in text, particularly considering regression deployment. The hearing readers showed an effect of phonological decoding, since homophonic and nonhomophonic errors differed in the probability of regression and fixation duration measures. The same was not true for deaf readers, who treated both types of error words similarly. Further, the deaf children were not delayed in their reading, following a standardized measure of reading. We suggest that these findings do not provide evidence in support of the QSH (P. Paul, 2001; P. V. Paul & Lee, 2010; Wang et al., 2008) and the claim of similar reading strategies employed by deaf and hearing readers While the QSH argues that phonological decoding is necessary to acquire proficient reading skill, the findings from the present study combined with studies that examine more- and less-skilled deaf readers (Bélanger et al., 2018; G. Yan et al., 2021) suggests that skilled reading *precedes* phonological awareness for these young readers.

The results from the standardized measure of reading are worth commenting on in slightly more detail. A notable result is that the deaf readers in this study, who were all primary users of sign language and who grew up in signing households, were not age-delayed in reading fluency. Despite previous reports suggesting that deaf signing children are likely to be age-delayed in reading acquisition and achieve overall lower reading success (Easterbrooks & Beal-Alvarez, 2012; P. Paul, 2001), many scholars and educators suggest that early and robust exposure to a signed language for young deaf children is optimal for literacy development (Allen et al., 2009; Hrastinski & Wilbur, 2016; McQuarrie & Parilla, 2014; Petitto et al., 2016; Stone et al., 2015). Though we do not directly test language ability in this study, we speculate that age-appropriate reading levels in this group are due, at least in part, to the fact that deaf participants are first-language users of ASL, having acquired the language during infancy and early childhood in signing households and at ASL-English schools and programs. The development of a foundational L1, we suggest, supports the successful learning of an L2, in this case via print. Clearly, the suggested relationship between sign language ability and reading proficiency requires additional investigation. Finally, we emphasize that despite the finding that hearing readers performed above both their expected age range and above the performance of deaf signers, they still demonstrated evidence of phonological decoding while the deaf readers did not.

Limitations

There are various limitations of this study that we would like to highlight, which could help to contextualize our results and provide important information to colleagues who wish to replicate this work. First, we acknowledge that statistical power is low due to a small number of participants and that this study has an exploratory quality to it. This is an unfortunate but common trend in behavioral studies with deaf populations due to recruitment difficulties. Future studies with greater resources should include a larger sample size. We were unfortunately unable to individually match our deaf and hearing readers for chronological age, reading level, or SES. We did not control for the degree of hearing loss, only the everyday language of participants. This is an important covariate that should be considered in future studies. A larger sample size of hearing and deaf families might allow for more matching of groups. Finally, we did not control for the variability in the number of items completed per participant. Several participants were unable to complete all eye-tracking stimuli, and it remains unclear whether deaf readers engaged with the sentences differently than hearing readers considering the overall poorer performance on the comprehension questions. The task may have been overall too fatiguing for this group and a shorter paradigm may have resulted in more participants completing all items for all tasks.

Conclusion

There still exists a debate regarding the use of speech-based codes during reading by deaf readers. The current study is one of a handful that describes eye-tracking and reading in deaf-signing children. We leveraged a homophone foil paradigm to examine the degree to which deaf and hearing readers ages 10–13 engage in phonological decoding of print to speech. All deaf participants were exposed to ASL from birth, grew up in signing households, and attended an ASL-English bilingual school. Signers in this group were not age-delayed in their expected reading levels. While sample sizes are small, our results suggest that deaf readers who are ASL-English bilinguals employ second-pass reading strategies that are different than those of hearing readers. Deaf signers performed fewer regressions than hearing readers and did not demonstrate evidence of phonological decoding of print to speech. These results align with several recent publications that suggest differences in how deaf signers engage with print. To our knowledge, this is the first eye-tracking investigation of child deaf signers in the United States involving the homophone foil paradigm to target phonological activation of spoken English. We hope that additional studies in this area will continue to provide insights about reading behaviors and reading development in deaf children who use signed language for everyday communication.

Context Paragraph

The current project is one of a handful of studies that investigates the eye-movement patterns of middle school-age deaf children who are native signers of ASL and attend ASL-English bilingual schools. Our research program focuses on the development and use of language skills in deaf signers. The current project was inspired in part by the discussion of speech-based phonological decoding in deaf children and an interest in understanding if deaf children who are early signers of a signed language pattern are similarly to hearing children who engage in phonological decoding. We hope this and future work will inform educational practices for deaf children, particularly regarding language choice at home and in the classroom, considering that the use of ASL has not been shown to inhibit reading skills. These results further support the hypothesis that first-language access to a signed language benefits the second-language acquisition of print at school considering that deaf signers with first-language ASL experience were not age delayed in second-language English reading. We urge other researchers to engage in work of this nature since a collective body of work could impact the development of curricula for deaf students.

References

Alegria, J. (1998). The origin and functions of phonological representations in deaf people. In C. Hulme & R. M. Joshi (Eds.), *Reading and spelling:*

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Development and disorders (pp. 263–286). Lawrence Erlbaum Associates.

Allen, T. E., Clark, M. D., del Giudice, A., Koo, D., Lieberman, A., Mayberry, R., & Miller, P. (2009). Phonology and reading: A response to Wang, Trezek, Luckner, and Paul. *American Annals of the Deaf*, *154*(4), 338–345. https://doi.org/10.1353/aad.0.0109

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). *lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-8*. http://cran.r-project.org/package=lme4

Beech, J. R., & Harris, M. (2002). The prelingually deaf young reader: A case of reliance on direct lexical access? *Journal of Research in Reading*, *20*(2), 105–121. https://doi.org/10.1111/1467-9817.00024

Bélanger, N. N., Lee, M., & Schotter, E. R. (2018). Young skilled deaf readers have an enhanced perceptual span in reading. *Quarterly Journal of Experimental Psychology*, *71*(1), 291–301. https://doi.org/10.1080/17470218.2017.1324498

Bélanger, N. N., & Rayner, K. (2015). What eye movements reveal about deaf readers. *Current Directions in Psychological Science*, *24*(3), 220–226. https://doi.org/10.1177/0963721414567527

Bosworth, R. G., & Stone, A. (2021). Rapid development of perceptual gaze control in hearing native signing infants and children. *Developmental Science*, *24*(4), Article e13086. https://doi.org/10.1111/desc.13086

Bowey, J. A. (1995). Socioeconomic status differences in preschool phonological sensitivity and first-grade reading achievement. *Journal of Educational Psychology*, *87*(3), 476–487. https://doi.org/10.1037/0022-0663.87.3.476

Cambra, C., Penacchio, O., Silvestre, N., & Leal, A. (2014). Visual attention to subtitles when viewing a cartoon by deaf and hearing children: An eye-tracking pilot study. *Perspectives Studies in Translatology*, *22*(4), 607–617. https://doi.org/10.1080/0907676X.2014.923477

Campbell, R., & Wright, H. (1988). Deafness, spelling and rhyme: How spelling supports written word and picture rhyming skills in deaf subjects. *Quarterly Journal of Experimental Psychology*, *40*(4), 771–788. https://doi.org/10.1080/14640748808402298

Carrillo, M. (1994). Development of phonological awareness and reading acquisition: A study in Spanish language. *Reading and Writing: An Interdisciplinary Journal*, *6*(3), 279–298. https://doi.org/10.1007/BF01027086

Castles, A., & Coltheart, M. (2004). Is there a causal link from phonological awareness to success in learning to read? *Cognition*, *91*(1), 77–111. https://doi.org/10.1016/S0010-0277(03)00164-1

Charlier, B. L., & Leybaert, J. (2000). The rhyming skills of deaf children educated with phonetically augmented speechreading. *Quarterly Journal of Experimental Psychology*, *53*(2), 349–375. https://doi.org/10.1080/713755898

Coltheart, V., Laxon, V., Rickard, M., & Elton, C. (1988). Phonological recoding in reading for meaning by adults and children. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*(3), 387–397. https://doi.org/10.1037/0278-7393.14.3.387

Coltheart, V., Laxon, V. J., Keating, G. C., & Pool, M. M. (1986). Direct access and phonological encoding processes in children's reading: Effects of word characteristics. *British Journal of Educational Psychology*, *56*(3), 255–270. https://doi.org/10.1111/bjep.1986.56.issue-3

Costello, B., Caffarra, S., Fariña, N., Andoni Duñabeitia, J., & Carreiras, M. (2021). Reading without phonology: ERP evidence from skilled deaf readers of Spanish. *Scientific Reports*, *11*, Article 5202. https://doi.org/10.1038/s41598-021-84490-5

De Loureiro, C. S., Braga, L. W., Souza Ldo, N., Nunes Filho, G., Queiroz, E., & Dellatolas, G. (2004). Degree of illiteracy and phonological and metaphonological skills in unschooled adults. *Brain and Language*, *89*(3), 499–502. https://doi.org/10.1016/j.bandl.2003.12.008

Doctor, E. A., & Coltheart, M. (1980). Children's use of phonological encoding when reading for meaning. *Memory & Cognition*, *8*(3), 195–209. https://doi.org/10.3758/BF03197607

Duncan, L. G., Seymour, P. H., & Hill, S. (1993). *Echelle de vocabulaire en images Peabody. Adaptation française du Peabody Picture Vocabulary Test Revised*. Psycan.

Dyer, A., MacSweeney, M., Szczerbinski, M., Green, L., & Campbell, R. (2003). Predictors of reading delay in deaf adolescents: The relative contributions of rapid automatized naming speed and phonological awareness and decoding. *Journal of Deaf Studies and Deaf Education*, *8*(3), 215–229. https://doi.org/10.1093/deafed/eng012

Easterbrooks, S. R., & Beal-Alvarez, J. S. (2012). States' reading outcomes of students who are d/Deaf and hard of hearing. *American Annals of the Deaf*, *157*(1), 27–40. https://doi.org/10.1353/aad.2012.1611

Ehri, L. C. (2014). Orthographic mapping in the acquisition of sight word reading, spelling memory, and vocabulary learning. *Scientific Studies of Reading*, *18*(1), 5–21. https://doi.org/10.1080/10888438.2013.819356

Emmorey, K., & Lee, B. (2021). The neurocognitive basis of skilled reading in prelingually and profoundly deaf adults. *Language and Linguistics Compass*, *15*(2), https://doi.org/10.1111/lnc3.v15.2

Feng, G., Miller, K., Shu, H., & Zhang, H. (2001). Rowed to recovery: The use of phonological and orthographic information in reading Chinese and English. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*(4), 1079–1110. https://doi.org/10.1037/0278-7393.27.4.1079

Glezer, L. S., Weisberg, J., O'Grady Farnady, C., McCullough, S., Midgley, K. J., Holcomb, P. J., & Emmorey, K. (2018). Orthographic and phonological selectivity across the reading system in deaf skilled readers. *Neuropsychologia*, *117*, 500–512. https://doi.org/10.1016/j.neuropsychologia.2018.07.010

Glushko, R. J. (1979). The organization and activation of orthographic knowledge in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance*, *5*(4), 674–691. https://doi.org/10.1037/0096-1523.5.4.674

Goswami, U. C., & Bryant, P. E. (1990). *Phonological skills and learning to read*. Lawrence Erlbaum Associates.

Gutierrez-Sigut, E., Vergara-Martínez, M., & Perea, M. (2017). Early use of phonological codes in deaf readers: An ERP study. *Neuropsychologia*, *106*, 261–279. https://doi.org/10.1016/j.neuropsychologia.2017.10.006

Hall, W. C., Levin, L. L., & Anderson, M. L. (2017). Language deprivation syndrome: A possible neurodevelopmental disorder with sociocultural origins. *Social Psychiatry and Psychiatric Epidemiology*, *52*(6), 761–776. https://doi.org/10.1007/s00127-017-1351-7

Hollingshead, A. A. (1975). *Four-factor index of social status*. Unpublished manuscript, Yale University.

Hrastinski, I., & Wilbur, R. B. (2016). Academic achievement of deaf and hard-of-hearing students in an ASL/English bilingual program. *Journal of Deaf Studies and Deaf Education*, *21*(2), 156–170. https://doi.org/10.1093/deafed/env072

Izzo, A. (2002). Phonemic awareness and reading ability: An investigation with young readers who are deaf. *American Annals of the Deaf*, *147*(4), 18–28. https://doi.org/10.1353/aad.2012.0242

Jared, D., Ashby, J., Agauas, S. J., & Levy, B. A. (2016). Phonological activation of word meanings in Grade 5 readers. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *42*(4), 524–541. https://doi.org/10.1037/xlm0000184

Johnston, R. S., Thompson, G. B., Fletcher-Flinn, C. M., & Holligan, C. (1995). The functions of phonology in the acquisition of reading: Lexical and sentence processing. *Memory & Cognition*, *23*(6), 749–766. https://doi.org/10.3758/BF03200927

Korat, O. (2009). The effect of maternal teaching talk on children's emergent literacy as a function of type of activity and maternal education level. *Journal of Applied Developmental Psychology*, *30*(1), 34–42. https://doi.org/10.1016/j.appdev.2008.10.001

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.

Leybaert, J., & Alegria, J. (1993). Is word processing involuntary in deaf children? *British Journal of Developmental Psychology*, *11*(1), 1–29. https://doi.org/10.1111/j.2044-835X.1993.tb00585.x

Li, D., & Lin, K. (2020). DEAF Students' phoneme repetition awareness in sentence reading. *The Journal of Deaf Studies and Deaf Education*, *25*(4), 505–516. https://doi.org/10.1093/deafed/enaa011

Lieberman, A. M., & Borovsky, A. (2020). Lexical recognition in deaf children learning American sign language: Activation of semantic and phonological features of signs. *Language Learning*, *70*(4), 935–973. https://doi.org/10.1111/lang.12409

Lieberman, A. M., Borovsky, A., & Mayberry, R. I. (2018). Prediction in a visual language: Real-time sentence processing in American sign language across development. *Language, Cognition and Neuroscience*, *33*(4), 387–401. https://doi.org/10.1080/23273798.2017.1411961

Lieberman, I. Y., Shankweiler, D., & Lieberman, A. M. (1989). *The alphabetic principle and learning to read*. National Institute of Child Health and Human Development.

Lonigan, C. J., Burgess, S. R., & Anthony, J. L. (2000). Development of emergent literacy and early reading skills in preschool children: Evidence from a latent-variable longitudinal study. *Developmental Psychology*, *36*(5), 596–613. https://doi.org/10.1037/0012-1649.36.5.596

MacSweeney, M., Goswami, U., & Neville, H. (2013). The neurobiology of rhyme judgement by deaf and hearing adults: An ERP study. *Journal of Cognitive Neuroscience*, *25*(7), 1037–1048. https://doi.org/10.1162/jocn_a_00373

Martin, F., Claydon, E., Morton, A., Binns, S., & Pratt, C. (2003). The development of orthographic and phonological strategies for the decoding of words in children. *Journal of Research in Reading*, *26*(2), 191–204. https://doi.org/10.1111/1467-9817.00196

Mastrantuono, E., Saldaña, D., & Rodríguez-Ortiz, I. R. (2017). An eye-tracking study on the perception and comprehension of unimodal and bimodal linguistic inputs by deaf adolescents. *Frontiers in Psychology*, *8*, Article 1044. https://doi.org/10.3389/fpsyg.2017.01044

McQuarrie, L., & Parrila, R. (2014). Literacy and linguistic development in bilingual deaf children: Implications of the "and" for phonological processing. *American Annals of the Deaf*, *159*(4), 372–384. https://doi.org/10.1353/aad.2014.0034

Meade, G., Grainger, J., Midgley, K. J., Holcomb, P. J., & Emmorey, K. (2019). ERP effects of masked orthographic neighbour priming in deaf readers. *Language, Cognition and Neuroscience*, *34*(8), 1016–1026. https://doi.org/10.1080/23273798.2019.1614201

Miller, P. (1997). The effect of communication mode on the development of phonemic awareness in prelingually deaf students. *Journal of Speech, Language, and Hearing Research*, *40*(5), 1151–1163. https://doi.org/10.1044/jslhr.4005.1151

Morford, J. P., Wilkinson, E., Villwock, A., Piñar, P., & Kroll, J. F. (2011). When deaf signers read English: Do written words activate their sign translations? *Cognition*, *118*(2), 286–292. https://doi.org/10.1016/j.cognition.2010.11.006

Nithart, C., Demont, E., & Metz-Lutz, M. N., Majerus, S., Poncelet, M., & Leybaert, J. (2011). Early contribution of phonological awareness and later influence of phonological memory throughout reading acquisition. *Journal of Research in Reading*, *34*(3), 346–363. https://doi.org/10.1111/j.1467-9817.2009.01427.x

Paul, P. (2001). *Language and deafness* (3rd ed.). Singular.

Paul, P. V., & Lee, C. (2010). The qualitative similarity hypothesis. *American Annals of the Deaf*, *154*(5), 456–462. https://doi.org/10.1353/aad.0.0125

Pennington, B. F., Lefly, D. L., Van Orden, G. C., Bookman, M. O., & Smith, S. D. (1987). Is phonology bypassed in normal or dyslexic development? *Annals of Dyslexia*, *37*(1), 62–89. https://doi.org/10.1007/BF02648060

Perfetti, C. A., Beck, I., Bell, L. C., & Hughes, C. (1987). Phonemic knowledge and learning to read are reciprocal: A longitudinal study of first grade children. *Merrill-Palmer Quarterly*, *33*(3), 283–319.http://www.jstor.org/stable/23086537

Petitto, L. A., Langdon, C., Stone, A., Andriola, D., Kartheiser, G., & Cochran, C. (2016). Visual sign phonology: Insights into human reading and language from a natural soundless phonology. *WIREs Cognitive Science*, *7*(6), 366–381. https://doi.org/10.1002/wcs.1404

Rayner, K. (1997). Understanding eye movements in reading. *Scientific Studies of Reading*, *1*(4), 317–339. https://doi.org/10.1207/s1532799xssr0104_2

Rayner, K., Chace, K. H., Slattery, T. J., & Ashby, J. (2006). Eye movements as reflections of comprehension processes in reading. *Scientific Studies of Reading*, *10*(3), 241–255. https://doi.org/10.1207/s1532799xssr1003_3

Reardon, S. F., Valentino, R. A., & Shores, K. A. (2012). Patterns of literacy among U.S. students. *The Future of Children*, *22*(2), 17–37. https://doi.org/10.1353/foc.2012.0015

Sehyr, Z. S., Petrich, J., & Emmorey, K. (2017). Fingerspelled and printed words are recoded into a speech-based code in short-term memory. *Journal of Deaf Studies and Deaf Education*, *22*(1), 72–87. https://doi.org/10.1093/deafed/enw068

Share, D. (2008). Orthographic learning, phonological decoding, and self-teaching. In R. Kail (Ed.), *Advances in child development and behavior* (pp. 31–81). Elsevier.

Stainthorp, R., & Hughes, D. (1998). Phonological sensitivity and reading: Evidence from precocious readers. *Journal of Research in Reading*, *21*(1), 53–68. https://doi.org/10.1111/1467-9817.00042

Stone, A., Kartheiser, G., Hauser, P. C., Petitto, L.-A., Allen, T. E., & Dick, F. (2015). Fingerspelling as a novel gateway into reading fluency in deaf bilinguals. *PLOS ONE*, *10*(10), e0139610. https://doi.org/10.1371/journal.pone.0139610

Sundstrom, S. (2010). *Coding in multiple regression analysis: A review of popular coding techniques* (U.U.D.M. Project report 2010:14).

Szarkowska, A., Krejtz, I., Klyszejko, Z., & Wieczorek, A. (2011). Verbatim, standard, or edited? Reading patterns of different captioning styles among deaf, hard of hearing, and hearing viewers. *American Annals of the Deaf*, *156*(4), 363–378. https://doi.org/10.1353/aad.2011.0039

Thompson, R., Emmorey, K., & Kluender, R. (2006). The relationship between eye gaze and verb agreement in American Sign Language: An eye-tracking study. *Natural Language & Linguistic Theory*, *24*(2), 571–604. https://doi.org/10.1007/s11049-005-1829-y

Traxler, M. J., Banh, T., Craft, M. M., Winsler, K., Brothers, T. A., Hoversten, L. J., Piñar, P., & Corina, D. P. (2021). Word skipping in deaf and hearing bilinguals: Cognitive control over eye movements remains with increased perceptual span. *Applied Psycholinguistics*, *42*(3), 601–630. https://doi.org/10.1017/S0142716420000740

Villwock, A., Wilkinson, E., Piñar, P., & Morford, J. P. (2021). Language development in deaf bilinguals: Deaf middle school students co-activate written English and American Sign Language during lexical processing. *Cognition*, *211*, Article 104642. https://doi.org/10.1016/j.cognition.2021.104642

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin*, *101*(2), 192–212. https://doi.org/10.1037/0033-2909.101.2.192

Wang, Y., Trezek, B. J., Luckner, J. L., & Paul, P. V. (2008). The role of phonology and phonologically related skills in reading instruction for students who are deaf or hard of hearing. *American Annals of the Deaf*, *153*(4), 49–76. https://doi.org/10.1353/aad.0.0061

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock–Johnson III tests of cognitive abilities*. Riverside.

Yan, G., Lan, Z., Meng, Z., Wang, Y., & Benson, V. (2021). Phonological coding during sentence reading in Chinese deaf readers: An eye-tracking study. *Scientific Studies of Reading*, *25*(4), 287–303. https://doi.org/10.1080/10888438.2020.1778000

Yan, M., Pan, J., Bélanger, N. N., & Shu, H. (2015). Chinese Deaf readers have early access to parafoveal semantics. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *41*(1), 254–261. https://doi.org/10.1037/xlm0000035

Zhou, W., Shu, H., Miller, K., & Yan, M. (2018). Reliance on orthography and phonology in reading of Chinese: A developmental study. *Journal of Research in Reading*, *41*(2), 370–391. https://doi.org/10.1111/1467-9817.12111

Zhou, X., & Marslen-Wilson, W. (2000). The relative time course of semantic and phonological activation in reading Chinese. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *26*(5), 1245–1265. https://doi.org/10.1037/0278-7393.26.5.1245

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin*, *131*(1), 3–29. https://doi.org/10.1037/0033-2909.131.1.3

Appendix

Eye-Movement Measurements on Target Words by Group and Sentence Condition

Measurement	Group	Correct	Homophone error	Spelling control
Single fixation duration (ms)	Deaf	215.66 (50)	223.76 (53)	217.78 (49)
	Hearing	215.08 (64)	230.31 (71)	231.73 (64)
First fixation probability	Deaf	0.67 (0.47)	0.71 (0.46)	0.68 (0.47)
	Hearing	0.77 (0.42)	0.78 (0.42)	0.79 (0.4)
Rereading time (ms)	Deaf	351.93 (185)	383.12 (227)	348.86 (195)
	Hearing	365.36 (273)	391.07 (294)	497.71 (324)
Regression probability	Deaf	0.16 (0.37)	0.36 (0.48)	0.28 (0.45)
	Hearing	0.24 (0.43)	0.43 (0.5)	0.55 (0.5)

Received July 24, 2020
Revision received December 13, 2022
Accepted December 14, 2022 ■

This document is copyrighted by the American Psychological Association or one of its allied publishers.
This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.