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Eyes on Morphology: Investigating the role of morphological processing for deaf readers

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Eyes on Morphology:
Investigating the role of morphological processing for deaf readers

A Dissertation submitted in partial satisfaction of the requirements
for the degree Doctor of Philosophy
in

Language and Communicative Disorders

by

Emily Corinne Saunders

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The Dissertation of Emily Corinne Saunders is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

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2024

DEDICATION

When I heard the learn’d astronomer,
When the proofs, the figures, were ranged in columns before me,
When I was shown the charts and diagrams, to add, divide, and measure them,
When I sitting heard the astronomer where he lectured with much applause in the lecture-room,

How soon unaccountable I became tired and sick,
Till rising and gliding out I wander’d off by myself,
In the mystical moist night-air, and from time to time,
Look’d up in perfect silence at the stars.

~

Walt Whitman

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John Donne once wrote that no man is an island. He almost certainly wasn't talking about grad school, but certainly no grad student is an island, either. My friends and family have persevered through this as much as I have, and this dissertation is lovingly dedicated to all of them. To my sister, Marie Saunders, whose love and support has been literally life changing. To

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I am so grateful to have fallen in love with science in a way that complimented and drew from my humanities background. Although I may have spent this dissertation focused on the minute neurocognitive details of how humans read, I will never stop wondering at the simple magic of it. May we all strive to be like the student listening to Whitman’s learn’d astronomer; despite our commitment to the charts and figures, may we always wander off by ourselves, to look up in perfect silence at the stars.

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FIELD OF STUDY

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Reading processes of deaf readers
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ABSTRACT OF THE DISSERTATION

Eyes on Morphology:
Investigating the role of morphological processing for deaf readers

by

Emily Corinne Saunders

Doctor of Philosophy in Language and Communicative Disorders

University of California San Diego, 2024
San Diego State University, 2024

Professor Karen Emmorey, Co-Chair
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Prelingually and profoundly deaf individuals learn to read without complete access to the sounds of language. Nevertheless, many become proficient readers, and the neurocognitive underpinnings of deaf readers' processes differ from those of hearing readers, particularly in orthographic processing. In English, morphological structure is relatively orthographically transparent, unlike its opaque phonological system. For skilled readers, who frequently encounter morphologically complex words, morphological awareness is vital for reading and vocabulary development. This skill may be especially important for deaf readers, who rely more on spelling-to-meaning mappings than sound-to-meaning mappings. This dissertation presents three experiments on morphological awareness and its relationship to reading skill among deaf readers. Chapter 1 examines the relationship between reading subskills (vocabulary, spelling, and morphology) and reading comprehension in similarly skilled deaf and hearing readers. Chapter 2 uses event-related potentials (ERPs) to study brain responses to morphological structure in single-word processing. Chapter 3 employs eye-tracking to explore the processing of morphological structure in the parafovea during sentence reading for both groups. The results show that morphology plays a distinct role for deaf readers, evident primarily in those with high morphological awareness skills. Deaf readers with higher morphological awareness exhibited a strong relationship between morphology assessments and reading comprehension, unlike deaf readers with low morphological awareness or hearing readers at any morphological awareness level. Differences were also observed in online processing of morphological structure, including neural responses and eye movement behaviors. These findings suggest that including targeted morphology instruction in reading interventions could enhance reading outcomes for deaf readers, providing them with an accessible and efficient skill set for reading development.

INTRODUCTION

Most models of the development of skilled reading hinge on the ability to integrate sound-based phonological information with spelling and meaning in order to successfully decode written language. However, these models rarely take into account the success of readers who do not have full access to phonological information due to early and profound deafness. Deaf readers vary widely in their background, including educational environment, access to hearing technology, use of a sign language, and socioeconomic status (Mayberry et al., 2011). It comes as no surprise, therefore, that reading outcomes are also highly variable within the population (Qi & Mitchell, 2012; Traxler, 2000; Kelly & Barac-Cikoja, 2007). However, deaf readers are not always less successful than hearing readers simply because of their reduced access to the sounds of language; some deaf adults have overcome this obstacle and are highly skilled readers. Prior research has established that the neurocognitive processes and eye movement behaviors during reading for this group are different from those of reading-matched hearing readers (Emmorey & Lee, 2021). In addition, skills related to orthography and semantics are stronger predictors of reading ability for deaf readers than phonological awareness, which is often the strongest predictor for hearing readers (Sehyr & Emmorey, 2022; Cates et al., 2022; Clark et al., 2011).

One sub-skill of reading that is highly related to orthographic-to-semantic mapping is morphological awareness, or the ability to identify and manipulate meaningful parts of complex words. The ability to efficiently decode morphological cues from the orthographic structure of words may therefore play a stronger role in the achievement of reading success for deaf than for hearing readers. This ability is measured with tests of morphological awareness, or the ability to identify and manipulate morphemic units in a complex word (Levesque et al., 2017). Morphological awareness has also been shown to be a factor in reading resilience, or success despite reading difficulties or disabilities (Farris et al., 2021; Haft et al., 2016), making it an informative lens through which to analyze the reading abilities of deaf readers. Developing a detailed understanding of the underlying processes of skilled reading is critical to improving reading instruction and interventions for deaf children and adults.

Once deaf individuals have learned to read, they must transition to “reading to learn.” It is at this stage that the ability to recognize and manipulate the components of complex input becomes critical to expanding vocabulary and accessing new content. Morphological awareness is one area that may be particularly advantageous to deaf students in the process of developing this skill, yet it is understudied with deaf readers. This dissertation will analyze in detail the cognitive underpinnings of morphological processing for deaf adults who have achieved reading success. Demonstrating the relationship between morphological awareness and reading skill would illustrate the ways that adult deaf readers take advantage of accessible morphological structure in word recognition and sentence processing. These findings can be applied to the development of reading interventions for deaf children and adults that leverage their unique linguistic potential for morphological and orthographic processing.

This dissertation investigates various aspects of morphological processing for adult deaf and hearing readers, including morphological awareness, single word processing, and sentence processing. The following experiments employ both behavioral and neurophysiological methods (morphological awareness tests, eye-tracking, and event-related potentials) in order to build a detailed picture of the unique cognitive processes that underlie morphological processing during reading for deaf adults. These processes were analyzed for their relationship with various measures of reading skill in order to identify how they contribute to efficient reading.

Chapter 1 examines the relationship between reading subskills (vocabulary, spelling, and morphology) and reading comprehension in similarly skilled deaf and hearing readers. The chapter investigates the possibility that due to the importance of orthographic and semantic skills for deaf readers, morphological awareness plays a more crucial role in reading comprehension and vocabulary acquisition for deaf readers than it does for hearing readers. By exploring these relationships, the chapter aims to uncover the unique contributions of morphological processing to reading development in deaf individuals.

Chapter 2 uses event-related potentials (ERPs) to study brain responses to morphological structure in single-word processing. This chapter investigates how deaf and hearing readers segment morpho-orthographic structure, hypothesizing that deaf readers may rely more on orthographic cues than hearing readers, leading to enhanced neural responses to these stimuli. The study aims to identify distinct neural mechanisms underlying morphological processing in both groups.

Chapter 3 employs eye-tracking to explore the processing of morphological structure in the parafovea during sentence reading. The chapter hypothesizes that morphological awareness influences parafoveal processing differently in deaf and hearing readers. Specifically, it examines whether deaf readers show enhanced preview benefits from morphological structure in the parafovea due to their differences in orthographic processing. This study additionally seeks to provide insights into the role of morphological awareness in parafoveal processing, determining the extent to which skill differences affect online processing differences.

There is currently a gap in reading achievement between hearing and deaf adults in the United States, which affects the ability of the latter group to achieve their academic and professional goals. This project aims to contribute to a growing body of research that characterizes the reading profile of adult deaf readers who have achieved reading success, identifying processes that are efficient and accessible based on their unique linguistic experiences. The end goal of this research is to aid in developing more appropriate and efficient targeted reading interventions for deaf children and adults in order to close the achievement gap.

CHAPTER 1: The role of morphological awareness in predicting reading skill for deaf and hearing adults

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Abstract

Both deaf and hearing readers take advantage of morphological awareness, or the ability to identify and manipulate component parts of complex words, to decode and comprehend printed English. Particularly for readers at more advanced skill levels, morphological decoding is critical to building vocabulary and expanding access to more advanced content. Morphological structure is relatively regular and orthographically transparent in English, in contrast to an opaque phonemic system. Deaf readers, for whom phonological awareness is a relative weakness while orthographic sensitivity is a strength, may have a different relationship with morphology than similarly skilled hearing readers. This study investigated the impact of various reading sub-skills—spelling, vocabulary size, morphological awareness, and phonological awareness— on reading comprehension for deaf and hearing readers. Results indicated that morphological awareness had a stronger relationship with reading comprehension for deaf readers than for hearing readers, particularly for those deaf readers with advanced morphological skills. Morphology and vocabulary were also more strongly related for the deaf group, indicating that deaf readers leverage morphology to decompose complex input and expand their word knowledge. Overall, the findings highlight the unique and significant role of morphological awareness in the skilled deaf reader's "toolbox" and underscore the importance of morphological instruction in supporting the reading development of deaf individuals.

Keywords: Deaf readers, morphological awareness, reading comprehension, vocabulary

Introduction

Reading is a complex task that requires the coordination of multiple linguistic and cognitive skills working in concert. Typical readers must recognize arbitrary symbols, connect them to the sounds of the corresponding spoken language, identify the meaning of individual words, and finally integrate them into a larger context. There are a number of sub-skills that make up the “toolbox” with which readers approach this complex linguistic task, including spelling ability, vocabulary size, and phonological awareness. Phonological awareness in particular has long been considered a vital component of successful reading for all readers. However, there exists a sizable population of readers who manage the complex linguistic task of reading without complete access to phonological information: those who were either born deaf or became deaf before acquiring spoken language. Some deaf individuals become very successful readers and read at levels equal to or surpassing their hearing peers, despite their relative weakness in phonological representations (see Emmorey & Lee, 2021, for review).

Reduced access to phonological information of the corresponding spoken language is therefore not an insurmountable obstacle to reading success. Research with adult deaf readers has aimed to characterize the unique processes by which they achieve reading proficiency, and particularly which skills are most important to those processes. Sehyr & Emmorey (2022) examined the relative contribution of various lexical quality variables for skilled adult readers, finding that while phonological awareness was a strong predictor for hearing readers, it was not a significant contributor to reading comprehension for deaf readers (matched in reading ability). Furthermore, spelling skill was only a significant predictor for deaf readers, indicating that orthographic representations play a stronger role in the reading process for deaf than hearing readers. The authors interpreted these results as indicating that skilled deaf readers develop precise orthographic representations of lexical items, and rely on the direct mapping between orthography and semantics to access word meaning when reading. This interpretation implies a unique division of labor that prioritizes the orthographic and semantic components of the Seidenberg (2005) triangle model of reading, compensating for poorer phonological representations. Other studies examining deaf adults' reading comprehension have also indicated that phonological awareness does not significantly predict reading success, while spelling and vocabulary-related skills do (Cates et al., 2022; Clark et al., 2011), further supporting the hypothesis that orthographic and semantic representations are particularly important to deaf readers.

One sub-skill of reading that is highly related to orthographic-to-semantic mapping is morphological awareness, or the ability to identify and manipulate meaningful parts of complex words (Levesque et al., 2017). In order to effectively process these complex words, skilled readers must be able to correctly decompose roots, stems, and affixes to identify the meaning of the whole word. Furthermore, readers must understand how derivational morphology changes the syntactic class of words (i.e., adding a noun suffix to an adjective or verb, resulting in a noun; *operate* → *operation*) and interpret clauses and phrase structure accordingly (Wilson-Fowler & Apel, 2015). As such, morphological processing recruits from multiple levels of linguistic understanding to effectively meet processing demands (Carlisle, 2003). Understanding morphological structure and the processes by which morphemes are combined in words (i.e, morphological awareness) likely plays a large role in the success of developing readers (Foorman et al., 2012; Kirby et al., 2012). Particularly for a language with an orthography as phonetically opaque as English, familiarity with morpheme boundaries and frequent affixes can aid readers in resolving ambiguities and determining the correct pronunciation of new words

(Rastle, 2019). Indeed, the spelling-to-meaning mapping of morphemes is often more consistent than the spelling-to-sound mapping (Berg & Aronoff, 2017).

Importantly, morphological awareness is also known to be a compensatory factor for hearing readers with phonological deficits such as dyslexia (Farris et al., 2021; Haft et al., 2016), possibly due to the fact that the English morphological system is orthographically regular and less dependent on phonology. Particularly once readers pass a middle school reading level, where the majority of words encountered are morphologically complex (Nagy & Anderson, 1984), morphological awareness may become more important to word reading and overall comprehension as readers use known morphemes as a guide to infer meanings of new words (Levesque et al., 2017).

Both deaf and hearing readers have been shown to take advantage of morphological awareness to comprehend complex words, with several studies finding links between students' awareness of morphological structure and their performance on word decomposition and decoding tasks (Carlisle, 2000; Deacon et al., 2011; Trussell & Easterbrooks, 2017; Wilson-Fowler & Apel, 2015; Kotzer et al., 2021). For example, a common measure of students' ability to derive and decompose morphological structure is the Test of Morphological Awareness (Carlisle, 2000; see also Bernstein et al., 2020 for a version adapted for older students). In this task, students are given a simple word and asked to add the correct affix(es) in order to fit the context of a sentence (*Perform. We watched the* ___. Correct answer *performance*). Additionally, they do the opposite task and strip affixes from a complex word to fit a sentence (*Discussion. The friends have a lot to* ___. Correct answer *discuss*).

While the majority of studies use morphological awareness measures to predict reading comprehension, Kotzer et al. (2021) investigated the reading sub-skills that contribute to morphological awareness. For college students (all skilled readers) vocabulary and spelling skills were both found to significantly predict morphological awareness. This result emphasizes the way in which morphology recruits both orthographic and semantic representations, and skilled reading involves the successful integration of both. Kotzer et al. (2021) also found that phonological decoding skill (identifying pseudohomophones) was a significant but weaker predictor of morphological awareness. We expect that this relationship would be even weaker (or not significant) for deaf readers.

Reading outcomes remain highly variable for deaf students. Deaf students often test at reading levels below their hearing peers (Kelly & Barac-Cikoja, 2007; Traxler, 2000; Qi & Mitchell, 2012), but some deaf readers do achieve high levels of reading skill (Mayberry et al., 2011). Research with these skilled deaf readers has determined that they have a different reading profile compared to hearing readers, which is characterized by comparable orthographic and semantic sensitivity without automatic recruitment of phonological codes (Bélanger et al., 2012; Emmorey & Lee, 2021; Sehyr & Emmorey, 2022). Morphological awareness is therefore an ideal candidate for study with skilled deaf readers, for whom phonology is a relative weakness, but orthographic sensitivity is a strength. There have been a few studies that have measured deaf children and adults' morphological awareness skills (Clark et al., 2011; Gaustad et al., 2002; Gaustad, 2004; Trussell & Easterbrooks, 2017). For example, Clark et al., (2011) implemented a morphological awareness task with 50 deaf college students who were asked to match morphologically complex words with possible meanings. The students were instructed to use "decoding" strategies to break down unfamiliar or novel words, i.e., identifying parts of the word that they did recognize to give them hints as to the novel word's meaning. The task included both mono- and multimorphemic words. Participants also completed a phonological awareness test.

Performance on the morphological awareness test, but not the phonological awareness test, was significantly related to the students' English placement level that was assigned upon entry to Gallaudet University (Developmental, Entry Level, Advanced, or Honors). For the students in the higher levels of English placement, morphological decoding of unfamiliar complex words was an effective strategy leading to greater success in determining novel word meanings based on familiar morphemes.

Importantly, Clark et al., (2011) did not assess students' performance on other reading skills, such as spelling or vocabulary, which could interact with morphological skills. Further, other studies investigating the factors that predict deaf readers' reading comprehension have not included a measure of morphological awareness (e.g., Cates et al., 2022; Sehyr & Emmorey, 2022). If deaf readers' morphological awareness contributes to reading skill over and above other related skills, it could indicate that these readers rely on the specific decoding process that relates to morpho-semantic segmentation. The present study aims to investigate the relationships between morphological awareness ability as well as other reading sub-skills (spelling ability and vocabulary size) for a group of skill-matched deaf and hearing readers.

We predict that morphological awareness will have a stronger association with reading comprehension for deaf compared to hearing readers, indicating that this skill plays a more important role in reading for deaf readers. We will also conduct a linear regression analysis to characterize the relative contributions of these different reading sub-skills to reading comprehension ability. We predict that morphological awareness will account for more variance in the deaf group's reading comprehension than the hearing group, indicating that morphological awareness contributes to reading skill over and above spelling and vocabulary. Following Kotzer et al., (2021), we also predict that spelling and vocabulary skill will predict morphological awareness. Furthermore, following other recent studies (Sehyr & Emmorey 2022; Mayberry et al,. 2011; Clark et al., 2011; Cates et al., 2022), we predict that phonological awareness will not predict morphological skill or reading comprehension for deaf readers, but it may be a predictor for the hearing group.

Methods

Participants

This study included a total of 80 participants: 40 deaf adults (Mean age= 35.76, SD= 8.25) and 40 hearing adults (Mean age= 29.65, SD= 10.89). Deaf participants were all prelingually and profoundly deaf and reported using ASL as a primary means of communication. All reported being exposed to ASL before age 7 (mean age of ASL exposure = 1.5 years: SD = 2.6) and reported no reading or learning disabilities. Deaf participants reported an average of 5.88 years of post-high school education (SD = 3.18). Hearing participants were all native English speakers with no reading or learning disabilities. Hearing participants reported an average of 3.7 years of post-high school education (SD = 1.63).

Assessments

All assessments were administered in person, in ASL or English, as appropriate for each group. Participants were tested individually, either in a single session or over the course of other sessions as part of a larger battery of language and cognitive assessments being conducted for other projects (not reported here). All participants took all assessments, except for the Phonemic Awareness Test, for which data were available for only a subset of participants.

Woodcock Johnson IV Passage Comprehension Subtest (LaForte et al., 2014): Participants were asked to read short passages (1-2 sentences) containing one blank and to fill in the blank with the correct missing English word. Both deaf and hearing participants wrote out their answers (i.e., no verbal response was required). Spelling errors were not counted. Raw scores were calculated by subtracting errors from the ceiling item.

Test of Receptive Spelling (Andrews & Hersch, 2010): Participants were given a list of 87 printed words, some of which were spelled incorrectly, and asked to circle only the incorrectly spelled items. Raw score was calculated by subtracting errors (i.e., missed “incorrect” words or falsely circled “correct” words) from the total number of words (87).

Peabody Picture Vocabulary Test IV (PPVT-IV) adapted for deaf individuals (Dunn & Dunn, 2007; Sarchet et al., 2014): In the adapted version of the PPVT-IV, participants read an English word in the center of a page and are asked to identify which of four pictures on the same page is the most accurate representation of the English word. Raw scores were calculated by subtracting errors from the ceiling item.

Morphological Awareness Tests: Morphological awareness was assessed with two measures: the Modified Test of Morphological Structure (MTMS) and the Nonword Choice Task. Raw scores were calculated by subtracting errors from the total number of items (48). See Table 1.1 for example items.

Modified Test of Morphological Structure (MTMS) (Bernstein et al., 2020): In Part 1 (Derivation), participants were provided with a simple root word and a sentence containing a blank, then asked to derive a complex word using the root that fits a sentence frame. In part 2 (Decomposition), participants were provided with a complex word and another sentence frame that contained a missing word, then asked to remove an affix or affixes from the complex word to produce the simple word that successfully completes the sentence. Spelling did not count as long as the participant's answer consisted of the correct stem and the correct affix or affixes (for example, if the target item was *assistance, assistence* would be an acceptable answer, but *assistion* would not). There were 15 items in each part.

Nonword Choice Task (McCutchen & Logan, 2011): Participants were provided with a sentence containing one orthographically plausible nonword that contained possible English affixes (e.g., acquitation) and were asked to choose from three options to identify the most plausible meaning for the nonword. There were 18 total items.

Table 1.1. Example items from MTMS and Nonword Choice Tasks that comprised our measure of Morphological Awareness.

Task	*Example item*	*Correct Answer*
Modified Test of Morphological Structure (Part 1)	Assist. The teacher will give you ______.	Assistance
Modified Test of Morphological Structure (Part 2)	Discussion. The friends have a lot to _____.	Discuss
Nonword Choice Task	On the property was a PERIMETOUS wall. Answer options: - Encircling - Deteriorating - Rough stone	Encircling

Phonemic Awareness Test (PA) (Miller, 1997): A subset of the participants (26 deaf, 16 hearing) had also taken a phonological awareness assessment as part of other ongoing projects. Participants first familiarized themselves with a series of simple drawings that represented one-syllable English words (i.e., star, crown, dice). In the first part of the test, they were shown four of the drawings and asked to determine which two words began with the same sound (for example, *nose* and *knife*). In the second part, they were asked to determine which two words ended with the same sound (for example, *horse* and *bus*). Participants were given 30 seconds to respond to each question. Raw score was calculated by subtracting errors from the total number of items (12).

Analyses

Following Sehyr & Emmorey (2022) and Kozter et al. (2021), we first conducted correlation analyses including reading comprehension (WJ score) and various reading sub-skills (spelling, vocabulary, morphological awareness) for both the hearing and deaf groups (n = 40 in each group). To compare the correlation coefficients between the two groups, we calculated the Pearson correlation coefficients for each pair of variables in both groups, resulting in two correlation matrices and Bonferroni-corrected p-values for each correlation.

We then assessed the contribution of reading sub-skills to morphological awareness for each group using multiple linear regression analysis with morphological awareness as the dependent variable and group (deaf, hearing), spelling, and vocabulary as independent variables.

We then ran a regression model with reading comprehension (WJ score) as the dependent variable. The independent variables were group, vocabulary (PPVT scores), spelling (Receptive spelling test scores), morphological awareness (sum of Derivation, Decomposition and Nonword Choice scores), and the interaction between group and each reading sub-skill.

Finally, for the subset of participants for whom phonological awareness test scores were available (n=26 deaf, 16 hearing), we ran versions of the morphological awareness and reading comprehension models that also included phonological awareness and the interaction between group and phonological awareness as independent variables.

Results

Deaf and hearing participants were matched on reading comprehension ability (WJ scores), but the groups differed on reading sub-skills. The deaf readers were significantly better spellers, while the hearing readers had larger vocabularies and scored higher on the morphological awareness tests. The descriptive statistics for each group are shown in Table 1.2. A subset of participants (n=16 hearing, 26 deaf) also had a phonological awareness score available; the hearing readers performed significantly better at this task (Deaf: M= 6.15, SD= 2.97; Hearing: M= 10.38, SD= 1.41; *p*<0.01).

Table 1.2. Descriptive statistics of mean raw scores on reading assessments. Standard deviations are reported in parentheses.

	Reading Comprehension	*Spelling*	*Vocabulary*	*Morphological Awareness (Total)*	*MA-Derivation*	*MA-Decomposition*	*MA-Nonword Choice*
Deaf	36.98 (3.76)	74.78 (7.27)	199.12 (14.73)	29.23 (5.72)	7.3 (2.2)	9.98 (2.7)	11.83 (2.1)
Hearing	37.95 (2.52)	71.52 (8.53)	206.55 (9.18)	33.48 (4.37)	8.2 (2.07)	11.95 (1.71)	13.33 (2.19)
p-value	0.18	0.07	0.01	<0.01	0.06	<0.01	<0.01

Correlation matrices

As shown in Table 1.3, the deaf group had significant positive correlations between reading comprehension and each of the reading sub-skills, while the hearing group had a significant correlation only between spelling and reading comprehension. For the deaf group, morphological awareness ability was correlated with both spelling and vocabulary, but only spelling correlated with morphological awareness for the hearing group. Figure 1.1 illustrates the stronger correlation between morphological awareness and reading comprehension for deaf readers compared to hearing readers.

Table 1.3. Correlations among reading sub-skills (** = Bonferroni-corrected $p < 0.05$, * = Bonferroni-corrected $p < 0.09$).

	Reading Comprehension	Spelling	Vocabulary	Morphological Awareness
	DEAF			
Reading Comprehension	1.00			
Spelling	0.41**	1.00		
Vocabulary	0.42**	0.46**	1.00	
Morphological Awareness	0.43**	0.44**	0.40*	1.00
	HEARING			
Reading Comprehension	1.00			
Spelling	0.44*	1.00		
Vocabulary	0.32	0.32	1.00	
Morphological Awareness	0.29	0.38*	0.25	1.00

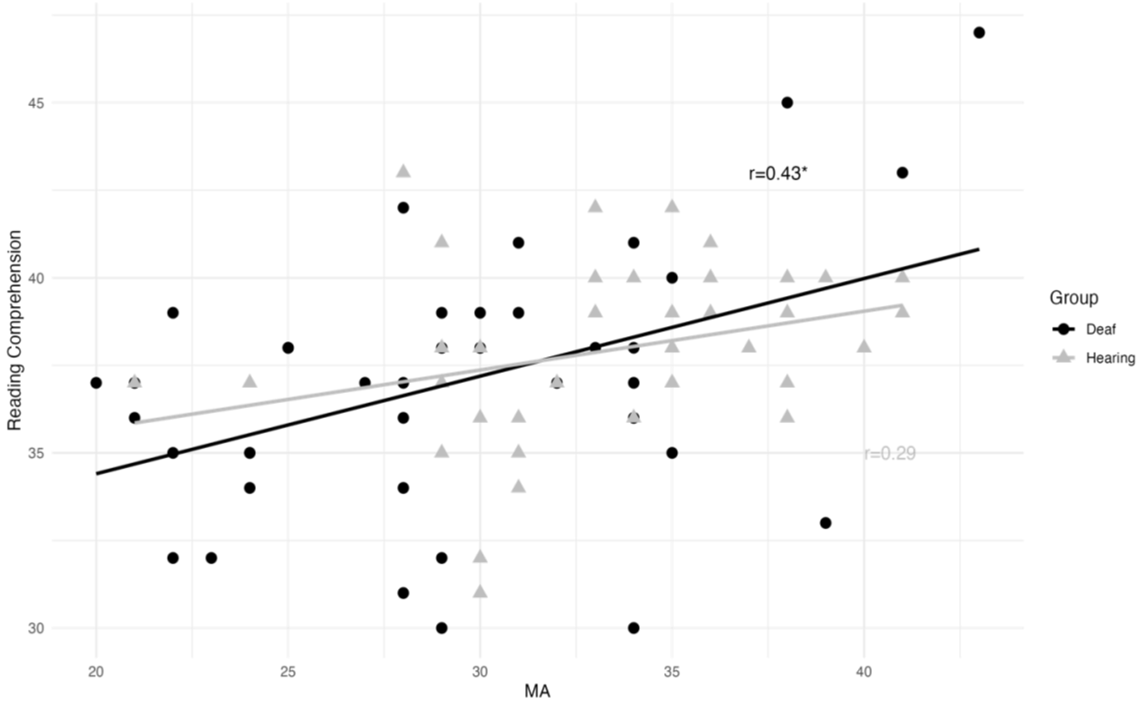

Figure 1.1. Association between morphological awareness (summed subtest scores) and reading comprehension (WJ score) for deaf and hearing readers.

Morphological Awareness Model

In the regression model predicting morphological awareness, we found that the hearing readers scored higher on the morphological awareness assessments overall (*p* = 0.002). Spelling skill was a significant predictor of morphological awareness for both groups (*p* = 0.01). There were no interactions with group (see Table 1.4).

Table 1.4. Predictors of morphological awareness

	Morphological Awareness			
Predictors	*Estimates*	*std. Error*	*Statistic*	*p*
Intercept	31.35	0.61	51.80	**<0.001**
Group	3.97	1.21	3.28	**0.002**
Spelling	1.63	0.62	2.62	**0.011**
Vocab	*1.11*	*0.66*	*1.68*	*0.098*
Group*Spell	-0.37	1.25	-0.30	0.768
Group*Vocab	-0.19	1.32	-0.14	0.885
Spell*Vocab	0.18	0.50	0.36	0.718
Group*Spell*Vocab	1.13	1.00	1.13	0.261
Observations	80			
R^2 / R^2 adjusted	0.346 / 0.282			

Reading Comprehension Model

In the regression model predicting reading comprehension from the reading sub-skills, we found that spelling was a significant predictor of reading comprehension for both groups (p=0.02), such that better spellers were stronger readers overall. There were no other main effects or interactions (see Table 1.5). Given our a priori hypothesis, however, we conducted additional separate regressions for each group.

Table 1.5. Linear regression predicting reading comprehension with group and reading sub-skills.

	Reading Comprehension			
Predictors	*Estimates*	*std. Error*	*Statistic*	*p*
Intercept	37.54	0.40	94.48	**<0.001**
Group	0.47	0.79	0.59	0.559
Vocab	0.70	0.41	1.70	0.094
Spelling	0.89	0.38	2.33	**0.022**
MA	0.54	0.41	1.31	0.194
Group*Spell	-0.18	0.77	-0.24	0.814
Group*MA	-0.31	0.82	-0.38	0.705
Group*Vocab	-0.12	0.83	-0.15	0.884
Observations	80			
R^2 / R^2 adjusted	0.274 / 0.204			

For the hearing readers, there was a marginal three-way interaction between spelling, vocabulary, and MA (*p* = 0.06); see Table 1.6. To visualize this interaction, we used median splits for MA skill (low, high), spelling skill (low, high), and vocabulary skill (low, high) as shown in Figure 1.2. For hearing readers with poorer MA and smaller vocabularies, spelling ability was associated with reading comprehension (better spellers were better readers). For those with good MA and larger vocabularies, there was no relationship between spelling skill and reading comprehension.

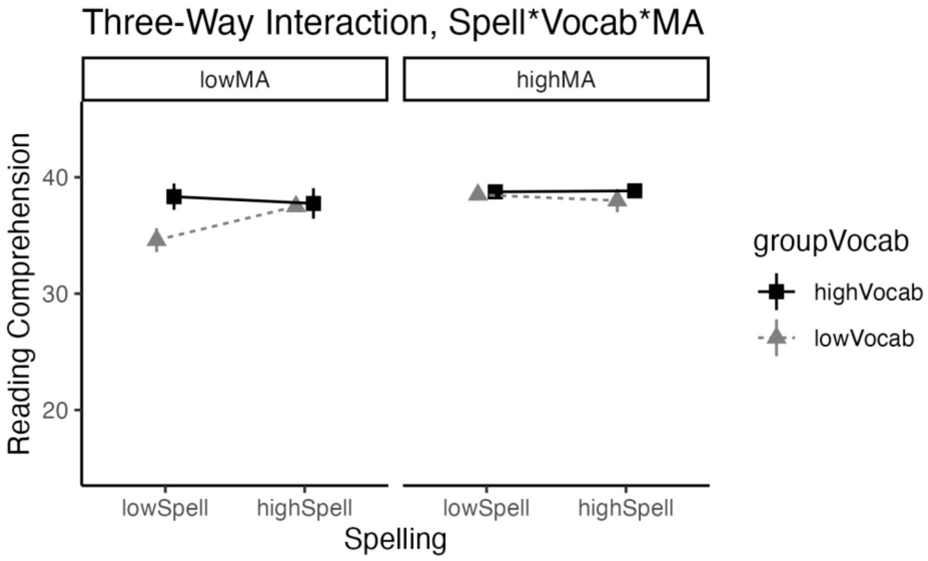

Figure 1.2. Visualization of spelling, vocabulary, and morphological awareness interaction

Table 1.6. Predictors of reading comprehension for the hearing group

	Hearing Reading Comprehension			
Predictors	*Estimates*	*std. Error*	*Statistic*	*p*
Intercept	37.68	0.45	83.11	**<0.001**
Spelling	0.42	0.41	1.03	0.312
Vocab	0.61	0.61	1.00	0.326
MA	0.95	0.57	1.68	0.103
Spell*Vocab	-0.43	0.42	-1.04	0.306
Spell*MA	-0.32	0.64	-0.50	0.623
Vocab*MA	-1.27	0.84	-1.52	0.138
Spell*Vocab*MA	1.96	1.02	1.91	*0.065*
Observations	40			
R^2 / R^2 adjusted	0.386 / 0.251			

The analysis with deaf readers (Table 1.7) revealed that those with larger vocabularies were stronger readers overall ($p = 0.01$). There was also a marginal effect of spelling, such that better spellers tended to be stronger readers overall (p = 0.07). There was also an interaction between vocabulary and morphological awareness ($p = 0.03$), such that deaf readers with large vocabularies and high morphological awareness were better readers than those who had large vocabularies but low morphological awareness (see Figure 1.3).

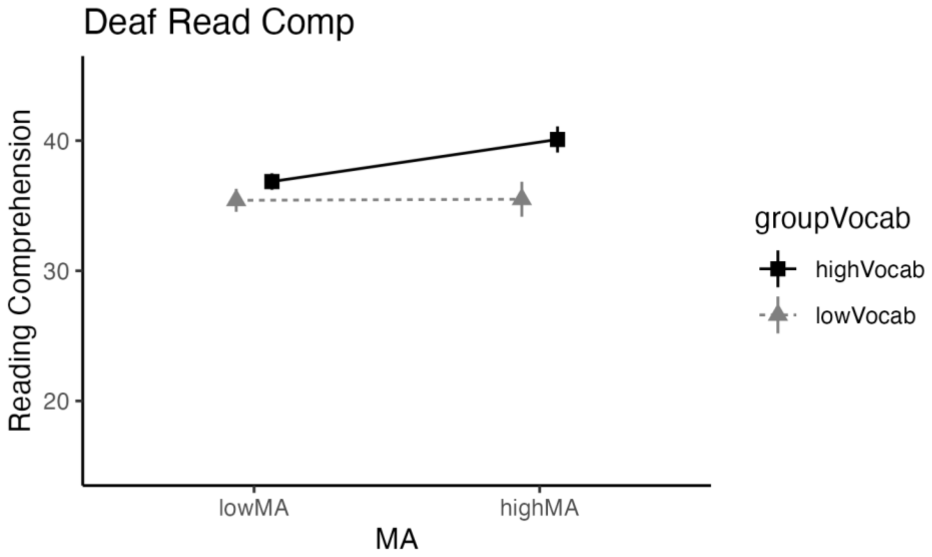

Figure 1.3. Interaction between vocabulary and morphological awareness for deaf participants.

Table 1.7. Predictors of reading comprehension for the deaf group.

	Deaf Reading Comprehension			
Predictors	*Estimates*	*std. Error*	*Statistic*	*p*
Intercept	36.93	0.64	58.08	**<0.001**
Spelling	1.29	0.69	1.88	*0.070*
Vocab	1.69	0.62	2.73	**0.010**
MA	0.85	0.72	1.18	0.246
Spell*Vocab	-0.76	0.56	-1.36	0.182
Spell*MA	0.17	0.66	0.26	0.793
Vocab*MA	1.18	0.53	2.23	**0.033**
Spell*Vocab*MA	-0.44	0.33	-1.36	0.183
Observations	40			
R^2 / R^2 adjusted	0.431 / 0.307			

The correlation analyses and the separate group regressions suggested that deaf readers have a different relationship with morphology than the hearing readers, although the full regression model (Table 1.5) indicated no significant interaction between group and morphology. We speculated that the differential relationship between morphological awareness and reading comprehension may have been obscured when the data were averaged across the whole range of MA skills. To test this hypothesis, we conducted additional exploratory analyses. First, we organized the dataset by morphological awareness score based on a median split of each group. We then calculated correlations between morphological awareness and reading comprehension for each skill group. There was only a significant correlation for the deaf group with high MA skill (*p* =0.02) (see Figure 1.4).

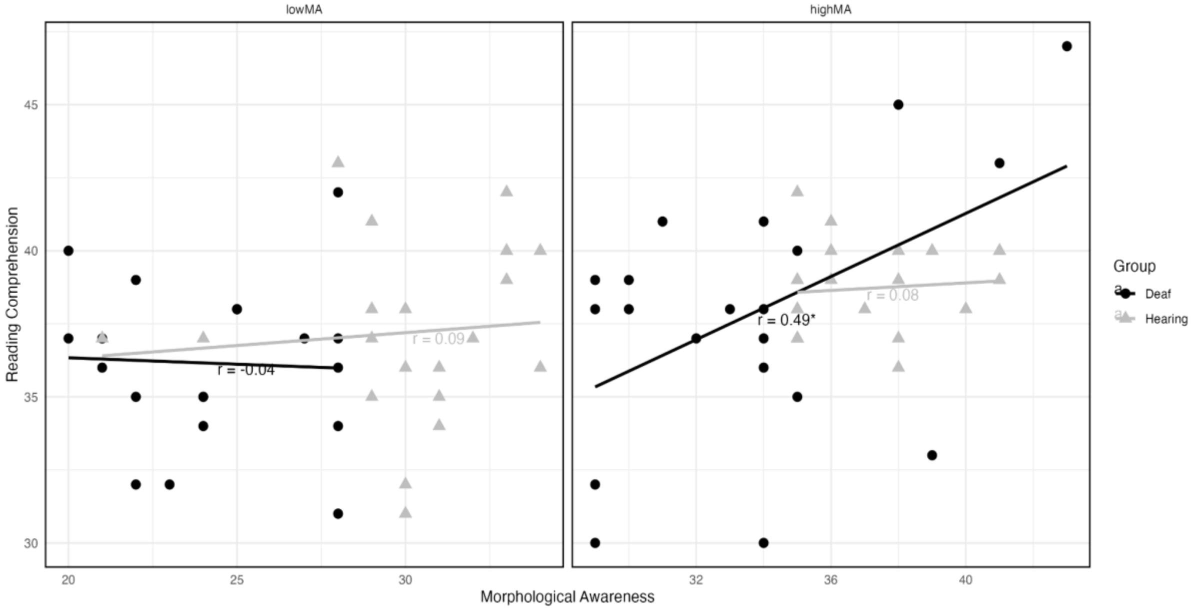

Figure 1.4. Correlations between morphological awareness and reading comprehension, split by hearing status and MA skill group.

Given this result, we then ran separate linear regressions for the deaf and hearing groups including morphological awareness skill as a group factor. For the hearing group, the better spellers were marginally better readers overall (*p*=0.06), consistent with the full reading comprehension model with a main effect of spelling (Table 1.5). There was no interaction between MA Group and MA score, indicating that morphological awareness was not a strong predictor of reading comprehension for either the high or low morphological awareness group (Table 1.8, see also Figure 1.2).

Table 1.8. Predictors of reading comprehension including MA Group for hearing readers

	Hearing Reading Comprehension			
Predictors	*Estimates*	*std. Error*	*Statistic*	*p*
Intercept	37.46	0.64	58.75	**<0.001**
Vocab	0.76	0.57	1.34	0.190
Spelling	0.76	0.40	1.92	*0.063*
MA Score	-0.00	0.95	-0.00	0.998
MA Group	1.41	1.64	0.86	0.395
MA Group*MA Score	-0.56	1.68	-0.33	0.742
Observations	40			
R^2 / R^2 adjusted	0.258 / 0.149			

For the deaf group (Table 1.9), readers with larger vocabularies were also stronger readers (*p* =0.046), as expected from the deaf-only regression analysis (Table 1.7). In contrast to the hearing readers, the strength of morphological awareness as a predictor of reading comprehension depended on MA group. Specifically, morphological skill was a stronger predictor of reading comprehension for the highly skilled group than it was for the less-skilled group (*p* = 0.046), a result that is consistent with the correlation analysis (Figure 1.4).

Table 1.9. Predictors of reading comprehension including MA group for deaf readers.

	Deaf Reading Comprehension			
Predictors	*Estimates*	*std. Error*	*Statistic*	*p*
Intercept	35.03	2.09	16.79	**<0.001**
Vocab	1.12	0.54	2.08	**0.046**
Spelling	0.74	0.67	1.10	0.278
MA Score	-1.41	1.64	-0.86	0.397
MA Group	1.45	2.21	0.65	0.518
MA Group*MA Score	3.91	1.89	2.07	**0.046**
Observations	40			
R^2 / R^2 adjusted	0.376 / 0.284			

Finally, we examined the contribution of phonology for the subset of our participant group for whom a phonological awareness score was available (n=26 deaf, 16 hearing).

Phonological Awareness Subgroup – Morphological Awareness Model

Better spellers had higher morphological awareness for both groups (p= 0.004), as expected from the full group analysis (Table 1.4). Somewhat surprisingly, *both* deaf and hearing readers with higher phonological awareness (PA) also had higher morphological awareness (p= 0.002). There was also a marginal interaction between group and PA (p=0.089), such that the association between phonological awareness and morphological awareness was stronger for the deaf readers than the hearing readers (see Figure 1.5). Note, however, that while the deaf and hearing high PA groups (median split) had comparable scores (Deaf: M=10.13, SD=2.03; Hearing: M= 11.44, SD=0.52), the low-scoring hearing group had nearly double the score of the low-scoring deaf group (Deaf: M=4.6, SD=0.91; Hearing: M=9.0, SD=0.81). [Hearing range: 8-12, Deaf range: 0-12].

Table 1.10. Predictors of morphological awareness, phonological awareness subgroup

	MA			
Predictors	*Estimates*	*std. Error*	*Statistic*	*p*
Intercept	30.59	0.92	33.33	**<0.001**
Group	4.62	2.39	1.94	*0.061*
Vocab	0.30	0.66	0.46	0.649
Spelling	2.29	0.75	3.05	**0.004**
PA	2.77	0.82	3.37	**0.002**
Group*PA	-4.20	2.40	-1.75	*0.089*
Observations	42			
R^2 / R^2 adjusted	0.498 / 0.428			

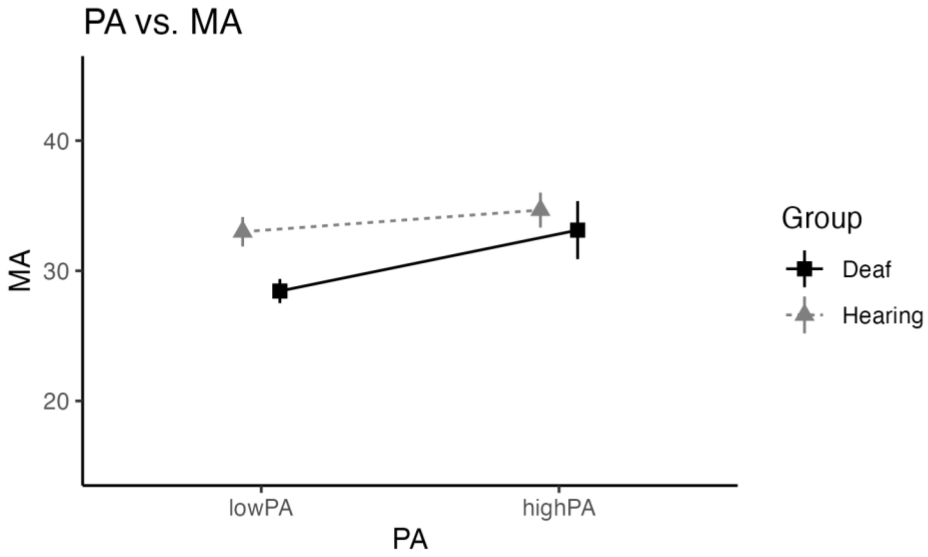

Figure 1.5. Relationship between phonological and morphological awareness

Phonological Awareness Subgroup – Reading Comprehension Model

For the hearing group, phonology was the only significant predictor of reading comprehension ($p = 0.004$). For the deaf group, better spellers were marginally better readers ($p = 0.07$) and those with larger vocabularies were better readers ($p = 0.03$). Phonological awareness did not impact reading comprehension for the deaf group (see Table 1.11).

Table 1.11. Predictors of reading comprehension including phonological awareness for subgroup of participants.

Reading Comprehension									
	Hearing					Deaf			
Predictors	*Estimates*	*std. Error*	*Statistic*	*p*		*Estimates*	*std. Error*	*Statistic*	*p*
Intercept	34.92	1.2	29.09	<0.001		37.73	0.82	46.17	<0.001
Spelling	-0.59	0.65	-0.92	0.379		1.72	0.9	1.9	*0.071*
Vocab	0.52	0.62	0.83	0.426		1.47	0.66	2.24	**0.036**
PA	3.94	1.11	3.57	**0.004**		0.92	0.84	1.1	0.285
MA	0.3	0.83	0.36	0.723		0.52	0.92	0.57	0.577
Observations	16				Observations	26			
R2 / R2 adjusted	0.574 / 0.419				R2 / R2 adjusted	0.464 / 0.362			

Discussion

This study investigated predictors of reading comprehension for a group of similarly skilled deaf and hearing readers, with a focus on the impact of morphological awareness. We first conducted correlation analyses to characterize the relationships among the various sub-skills of reading: spelling, vocabulary size, and morphological awareness. This analysis was followed up with a regression model predicting morphological awareness from these sub-skills, then a regression model predicting reading comprehension. Finally, we analyzed the subgroup of participants for whom a phonological awareness score was also available, including phonology in the model predicting morphological awareness.

The omnibus correlation matrices revealed that for deaf readers, morphological awareness had a stronger positive correlation with reading comprehension compared to hearing readers, suggesting that morphology may be a stronger contributor to skilled reading for deaf readers. Morphological ability also had a stronger relationship with vocabulary size for deaf readers than for hearing readers. This finding suggests that morphological awareness may be an important factor in how deaf readers infer the meaning of unfamiliar words and increase their vocabularies.

In the regression model predicting morphological awareness, we found that the hearing group was more skilled at morphological awareness overall, with significantly higher scores on the morphology assessments (see Table 1.2), despite the groups being matched on reading comprehension. This result could be due to the fact that English is a second language for this group of early signing adults - ASL was their first language. In contrast, the hearing readers were all monolingual, reading in their L1. Morphological awareness for bilinguals is known to be affected by the readers’ L1 (Wu & Juffs, 2022), and while ASL does have a rich morphological system (Aronoff et al., 2005), little is known about the influence of ASL morphology on English morphological awareness. Much of ASL morphology involves non-concatenative morphological processes, such as reduplication, rather than the addition of prefixes and suffixes to a stem. Thus, although the knowledge that complex word forms can be analyzed into meaningful parts may transfer from ASL to English, there are few translation-equivalent morphemes (e.g., -ly, -ion) and word creation processes differ between ASL and English.

Nonetheless, we found a relationship between morphological awareness and reading comprehension skill for deaf readers that was not observed for hearing readers. Specifically, the strength of morphological awareness as a predictor of reading skill depended on vocabulary size for deaf readers. That is, morphological awareness was a stronger predictor of reading skill for those with larger vocabularies, indicating that morphology and vocabulary are uniquely intertwined for deaf readers. For hearing readers, spelling ability was more strongly associated with reading comprehension (better spellers were better readers), and this pattern was stronger for hearing readers with poorer morphological awareness and smaller vocabularies.

Based on the results of separate group regressions, deaf readers appear to have a different relationship to morphology than hearing readers did. However, in the full regression (see Table 1.5), there was no interaction between group and morphology. The visualization of the correlation data (see Figure 1.1) pointed to a differential relationship between morphology and reading comprehension for the readers with high morphological awareness, particularly for the deaf group. To further characterize this relationship, we calculated the correlations between morphological awareness and reading comprehension for each group, separated by MA skill. Of the four subgroups, only the deaf readers with high morphological awareness had a strong positive relationship between morphology and reading comprehension. The group of deaf readers with low morphological awareness did not have a significant relationship between the two measures, nor did either group of hearing readers. This result indicates that once deaf readers reach a certain level of morphological proficiency, this ability can play a stronger role in reading comprehension.

These correlation results motivated follow-up regression models with morphological awareness skill as a group factor. In these models, we found that vocabulary was a strong predictor for the deaf readers and spelling was a marginally significant predictor for the hearing readers, as expected from the previous models. For the deaf readers, but not the hearing readers, the strength of morphology as a predictor was dependent on morphology skill group, such that morphological awareness was only a strong predictor of reading comprehension for the deaf readers with high morphology skills, as suggested by the correlation analysis. Morphology was not a strong predictor for the hearing group, regardless of morphology skill group. This result again indicates that morphology's role in reading comprehension changes is uniquely important for deaf readers who have achieved a high level of skill in morphological awareness.

Highly skilled deaf readers with a strong grasp of morphology may be leveraging the visual accessibility of morpho-orthographic segments to decompose unfamiliar complex words when they encounter them, and thus boost their overall comprehension abilities. This hypothesis is consistent with the fact that morphologically complex words make up a majority of the words encountered by readers above middle school reading levels. Readers who read at lower skill levels may not encounter morphologically complex input as often, and would therefore have less experience and familiarity with processing such input. Hearing readers, despite having high morphological awareness, did not show a significant relationship between reading comprehension and morphology. However, this null result should be interpreted with caution given our relatively small participant group and previous results indicating that morphological skill predicts reading ability in hearing adults (e.g., Kotzer et al., 2021).

Finally, our analysis of the subgroup with a phonological awareness score revealed that phonological awareness was a strong predictor of morphological awareness for both deaf and hearing readers, with the deaf readers showing a stronger association. However, there was a much smaller range of scores on the phonological awareness test for the hearing readers, which could have reduced the strength of the association with morphological awareness. Nonetheless, phonological awareness was a very strong predictor of reading comprehension for the hearing readers ($p = 0.004$), whereas it was not a predictor for the deaf group ($p = 0.2$). This result is consistent with previous findings that phonology is less important to deaf readers than it is to hearing readers (Sehyr & Emmorey, 2022; Cates et al., 2022). The finding that deaf readers with better phonological awareness had better morphological skills is novel and somewhat surprising, given the lack of relationship between phonological skills and reading comprehension for these readers. One speculative hypothesis is that knowledge of morphological structure boosts the link between orthography and phonology, as well as the link between orthography and meaning. As proposed by Kirby and Bowers (2017, 2018), morphemes may act as binding agents, providing information about not only semantics, but also phonology and orthography. Thus, deaf readers who have stronger morphological representations may also have stronger phonological skills and stronger semantic knowledge (as evidenced by the positive correlation between vocabulary size and morphological awareness).

Future Directions

The finding that morphology is related to reading comprehension for skilled deaf readers provides support for proposals that explicit morphological instruction should be incorporated into literacy programs for deaf students. The relatively transparent orthographic-to-semantic mapping and regular structure of the English morphological system may be a more accessible and efficient pathway to word learning and reading comprehension, compared to opaque sound-to-meaning mappings. Small-scale but successful intervention studies have illustrated that morphographic analysis of spelling cues is a route through which deaf students can ascertain the meaning of new and complex words (Trussell, 2020; Trussell et al., 2018; Trussell & Easterbrooks, 2015). If explicit morphological instruction can boost deaf readers' morphological awareness skills, they may be able to leverage those skills to improve their reading comprehension overall. By specifically targeting morphological awareness, teachers and other deaf education professionals may be able to use the more accessible route to reading comprehension to help close the achievement gap experienced by many deaf students. Future research should also further investigate the relationship between morphological and phonological awareness in deaf readers to identify the direction of the effects, e.g., whether morphological skill improves phonological knowledge or vice versa.

Conclusion

This study characterizes the reading profiles of two groups of similarly skilled deaf and hearing readers, focusing on the role of morphological awareness. Correlation analyses revealed that morphological awareness had a stronger positive correlation with reading comprehension for deaf readers compared to hearing readers. Furthermore, deaf readers showed a significant relationship between morphological awareness and vocabulary size, suggesting that morphology is particularly important to inferring novel word meanings and building vocabulary. While hearing readers were generally more skilled at morphological awareness, deaf readers with high morphological skills demonstrated a stronger link between morphology and reading comprehension. Additionally, phonological awareness was a strong predictor of morphological awareness for both groups, although it was more strongly associated with reading comprehension in hearing readers. Overall, the findings highlight the unique and significant role of morphological awareness in the skilled deaf reader's "toolbox". Expanding our knowledge of morphological processing in deaf readers is crucial for the development of more effective reading interventions that tap into their unique linguistic potential.

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CHAPTER 2: Assessing the strength of the morpho-orthographic segmentation route for deaf readers using event-related potentials

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Abstract

Under the dual-route model of reading complex words, readers process morphologically complex words through two possible routes: a morpho-orthographic segmentation route that facilitates access to orthographic information such as affixes via fine-grained orthographic codes, or a morpho-semantic route that prioritizes access to semantic information through coarse-grained, whole word representations. This study investigates the strength of the first route for deaf readers, who may rely more on orthographic cues from the relatively transparent morphological structure of English. Early visual processing of orthography is one area in which deaf readers potentially differ from hearing readers, but the details of online morphological processing have been understudied with deaf readers. In an an unprimed lexical decision task to words of varying morphological complexity, deaf readers showed similar processing for complex and pseudo-complex words, whereas hearing readers had increased negativity for pseudo-complex words in the N250 component (200-250ms). No significant N400 differences were found between complex and pseudo-complex words, but deaf and hearing readers differed in processing simplex and pseudo-complex words. Reading skill correlated with amplitudes reflecting morphological segmentation for deaf readers, suggesting that better reading skill facilitated morphological processing. This study characterizes online processing of morphological structure for deaf readers, highlighting their unique relationship between reading skill and morphological segmentation.

Keywords: Morphology, deaf readers, orthographic processing, morpho-orthographic segmentation

Introduction

Morphological structure is highly visible in English. While the relationship between sound and spelling is not always transparent, morphological segments tend to be more so. The spelling-to-meaning mapping of morphemes is often more consistent than the spelling-to-sound mapping, providing “islands of regularity” in the otherwise irregular phonetic system of English. Morphemic structure presents an efficient way for readers to organize their mental lexicon of orthographic representations with roots and affixes (Berg & Aronoff, 2017). Complex words are composed of a root and one or more meaningful affixes (“farmer” = “farm” + “-er”). However, there are words in English that only have apparent morphological complexity. By a coincidence of spelling, some monomorphemic words appear to have structures that would allow them to be decomposed into a root and an affix (“pseudo-complex” words, e.g., “beaker” ≠ “beak” + “-er”). True monomorphemic words have neither an apparent affix nor a meaningful affix (“simplex” words, e.g., “freeze”).

In order to arrive at meaning from written multimorphemic words, readers can decompose these words into their component parts. This process occurs in the brain very quickly after a reader first sees a complex word. Grainger and Zeigler (2011) proposed a model of the pathways between orthography and semantics for complex words known as the dual route model (see Figure 2.1). The morpho-semantic route is more coarse-grained. Specifically, the reader processes the individual letters of a word and determines the meaning of that word by prioritizing letter combinations that are most informative of word identity, regardless of precise positional information. In contrast, the morpho-orthographic route involves a fine-grained parsing process that prioritizes access to frequently co-occurring letter combinations, such as affixes, with attention to their position in the word. The two routes operate in parallel during word recognition.

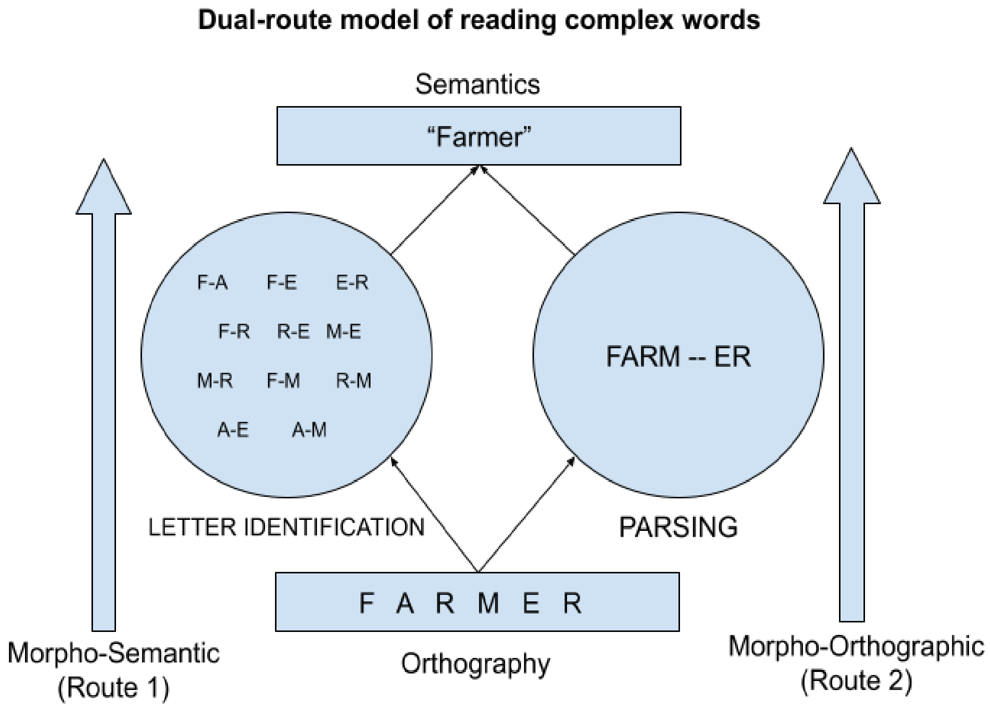

Figure 2.1. Visualization of the dual-route model for processing complex words (Grainger & Ziegler, 2011).

The neural signatures of these two routes have been identified using electroencephalography (EEG) with hearing readers. Evidence of the morpho-orthographic route is observed in early stages of processing, immediately after readers perceive a word (Lavric et al., 2012; Morris et al., 2013). Some recent research has suggested an early and automatic process of morpho-orthographic segmentation that decomposes printed words according to their *apparent* complexity in the first stages of processing, regardless of whether that complexity is reflected in the semantic content of the word (see Rastle & Davis, 2008 for review). For example, in masked priming paradigms, robust and equivalent priming effects were observed for prime-target pairs in which the prime appeared to be morphologically structured, whether or not it was semantically related to the target (e.g., corner-CORN, darkness-DARK). These priming effects were larger than those found for orthographically related primes without an apparent morphological structure (e.g., brothel-BROTH) (Longtin et al., 2003; Rastle et al., 2004). Together these findings indicate that even when readers are not consciously aware of words (due to masking), they decompose them according to their apparent morphemic constituents, leading to facilitated processing of the roots as targets.

In an ERP study using an unprimed lexical decision paradigm, Lavric et al. (2012) found additional evidence supporting morpho-orthographic segmentation. At early stages of processing (190-220ms after word onset), simple words elicited greater negative amplitudes than pseudo-complex and complex words, which did not differ from each other. This finding suggests that early in processing, words are initially parsed according to apparent complexity, regardless of whether that complexity is borne out in the eventual semantic processing of the word (Lavric et al. 2012). This latency range is similar to the typical onset window of the N250 component that has been shown to be sensitive to early orthographic processing – the mapping of letter and letter cluster representations onto whole word representations (Grainger & Holcomb, 2009).

Morris et al., (2013) also found a possible neural signature for the morpho-semantic route at a later processing stage when pseudo-complex words are reanalyzed according to their actual semantic structure. This process was observed as reduced N400 amplitudes in the 300-500 ms time window for true complex words (farmer) compared to pseudo-complex words (beaker). This a larger N400 (greater negativity) for pseudo-complex words was interpreted to index more effortful semantic processing for these words compared to true complex words (Morris et al., 2013). Specifically, readers must amend their initial, incorrect segmentation to reflect the true meaning of the pseudo-complex word, which does not include the apparent morphological units.

Early visual processing of orthography is one area in which deaf readers potentially differ from hearing readers (Emmorey et al., 2017; 2021), due to potential differences in how orthographic representations are tuned with reduced access to phonology. Fine-grained orthographic processing has been hypothesized to hold a "heavier weight" with deaf readers, for whom phonological representations are less specified (Gutierrez-Sigut et al., 2022). Deaf readers may therefore rely more on orthographic cues from the relatively transparent morphological structure of English, resulting in different processing patterns for morphological decomposition. However, online morphological processing has been understudied with deaf readers, particularly with regards to their neural responses to the morpho-orthographic segmentation process observed with hearing readers (Lavric et al., 2012; Morris et al., 2013). They may show increased neural activity when decomposing morphological segments as a result of being more strongly attuned to the orthographic forms of words.

Furthermore, given that orthographic parsing, spelling skill, and vocabulary size are stronger predictors of reading success for deaf readers than hearing readers (Emmorey & Petrich 2012; Sehyr & Emmorey 2022), reading skill may interact with these neural responses differently for deaf than hearing readers. More skilled readers with higher levels of morphological awareness, either hearing or deaf, may show stronger responses to morphological structure in words. Morphological awareness refers to the ability to identify and manipulate meaningful parts of complex words (Levesque et al., 2017). Both deaf and hearing readers have been shown to take advantage of morphological awareness, with several studies finding links between students' awareness of morphological structure and their performance on word decomposition and decoding tasks (Carlisle, 2000; Deacon et al., 2014; Trussell & Easterbrooks, 2017; Wilson-Fowler & Apel, 2015; Kotzer et al., 2021). While language proficiency has been shown to modulate morphological priming effects (Beyersmann et al., 2015), morphological awareness specifically has yet to be studied in its relationship to ERP responses to morphological structure. Readers' sensitivity to the component parts of complex words may influence their neural responses as they process these words.

The Present Study

In this ERP study, we investigated the morpho-orthographic segmentation process for deaf and hearing readers using an unprimed lexical decision task with English words and pseudo-words of varying morphological complexity. Following Lavric et al. (2012), complex and pseudo-complex words are expected to pattern together in the N250 window (observed as reduced negative amplitudes when compared to simplex words). If this result is observed for both deaf and hearing readers who are matched on reading skill, it would indicate that words are decomposed according to orthographic cues alone in the early stages for both types of readers. However, if deaf readers are more attuned to these cues than hearing readers, we should observe a greater difference in amplitudes in the N250 window between pseudo-complex//complex and simplex words for deaf readers compared to hearing readers. Masked priming versions of this paradigm (Morris et al, 2013) found increased negativity to pseudo-complex words in the N400 window. If deaf and hearing readers also segment the pseudo-complex words in an unprimed paradigm, we expect to see similar increased negativities in the N400 window to pseudo-complex words for both groups of readers.

Furthermore, if the morpho-orthographic segmentation process is prioritized by deaf readers due to a stronger reliance on orthographic morphological cues, then the difference in amplitude between word types should correlate with reading and morphological awareness skill for deaf readers (and possibly more so than for hearing readers).

Methods

Participants

A total of 53 adults participated in the experiment. Three hearing participants were not included in analyses due to excessive EEG artifact, and two additional hearing participants were excluded in order to more closely match the deaf and hearing groups on age and reading skill. Of the remaining 48 participants, 24 were hearing, monolingual English speakers (15 female, mean age = 28, range 18-52 years). The mean number of years of education (including K-12) for the hearing group was 16.5 years (SD = 1.48). The remaining 24 were prelingually and profoundly deaf signers (db loss ≥ 70 db) who learned ASL before age 7 (mean age of ASL exposure = 1.15 years, SD = 2.1), and for whom ASL is a primary means of communication (13 female, mean age= 34, range 20-50 years). The mean number of years of education for the deaf group was 18 years (SD = 2.72). All participants had normal or corrected-to-normal vision. Two deaf and two hearing participants were left-handed. Both groups provided informed consent according to San Diego State University IRB procedure.

Assessments

In addition to the ERP task, participants also completed a battery of reading and spelling assessments, summarized below (see Table 2.1 for a summary of participant scores).

Table 2.1. Summary of mean assessment scores. Standard deviations reported in parentheses.

	Deaf	Hearing	TTest
Reading Comprehension (WJ IV-PC)	36.12 (4.35)	39 (2.29)	$p < 0.01$
Reading Fluency (WJIV- F)	79.34 (16.72)	85.05 (12.88)	$p = 0.10$
Spelling (Test of Receptive Spelling)	75 (8.9)	76 (7.23)	$p = 0.35$
Vocabulary (PPVT)	198.39 (14.63)	207.83 (11.47)	$p = 0.01$
Morphological Awareness	28.13 (6.25)	37.11 (4.8)	$p < 0.01$

Woodcock Johnson IV Passage Comprehension Subtest (LaForte et al., 2014): Participants were asked to read short passages (1-2 sentences) containing one blank and to fill in the blank with the correct missing English word. Both deaf and hearing participants wrote out their answers (i.e., no verbal response was required). Spelling errors were not counted. Raw scores were calculated by subtracting errors from the ceiling item.

Test of Receptive Spelling (Andrews & Hersch, 2010): Participants were given a list of 87 printed words, some of which were spelled incorrectly, and asked to circle only the incorrectly spelled items. Raw score was calculated by subtracting errors (i.e., missed “incorrect” words or falsely circled “correct” words) from the total number of words (87).

Peabody Picture Vocabulary Test IV (PPVT-IV) adapted for deaf individuals (Dunn & Dunn, 2007; Sarchet et al., 2014): In the adapted version of the PPVT-IV, participants read an English word in the center of a page and are asked to identify which of four pictures on the same page is the most accurate representation of the English word. Raw scores were calculated by subtracting errors from the ceiling item.

Morphological Awareness Tests: Morphological awareness was assessed with two measures: the Modified Test of Morphological Structure (MTMS) and the Nonword Choice Task. Raw scores were calculated by subtracting errors from the total number of items (48). See Table 2.2 for example items.

Modified Test of Morphological Structure (MTMS) (Bernstein et al., 2020): In Part 1 (Derivation), participants were provided with a simple root word and a sentence containing a blank, then asked to derive a complex word using the root that fits a sentence frame. In part 2 (Decomposition), participants were provided with a complex word and another sentence frame that contained a missing word, then asked to remove an affix or affixes from the complex word to produce the simple word that successfully completes the sentence. Spelling did not count as long as the participant's answer consisted of the correct stem and the correct affix or affixes (for example, if the target item was *assistance*, *assistence* would be an acceptable answer, but *assistion* would not). There were 15 items in each part.

Nonword Choice Task (McCutchen & Logan, 2011): Participants were provided with a sentence containing one orthographically plausible nonword that contained possible English affixes (e.g., acquitation) and were asked to choose from three options to identify the most plausible meaning for the nonword. There were 18 total items.

Table 2.2. Example items from MTMS and Nonword Choice Tasks that comprised our measure of Morphological Awareness.

Task	*Example item*	*Correct Answer*
Modified Test of Morphological Structure (Part 1)	Assist. The teacher will give you ______.	Assistance
Modified Test of Morphological Structure (Part 2)	Discussion. The friends have a lot to _____.	Discuss
Nonword Choice Task	On the property was a PERIMETOUS wall. Answer options: - Encircling - Deteriorating - Rough stone	Encircling

Stimuli and Task

Stimuli consisted of 200 words and pseudowords of varying morphological complexity. Complex words contained a root and one suffix (climber; n=50), pseudo-complex words contained an apparent root and suffix (beaker; n=50), and simplex words contained neither (freeze; n=50). The probe stimuli were pseudowords containing a legal English suffix (yumbling; n=30) or pseudowords without a suffix (tront; n=20). All conditions were matched for length, frequency, bigram frequency, and concreteness (see Table 2.3). Word and nonword stimuli were presented in white Arial 22pt font in the center of a black screen such that stimuli subtended an average visual angle of 2.5° in the horizontal direction and 0.5° in the vertical direction. Stimuli were presented on a 24-inch LCD monitor (100 Hz vertical retrace frequency) placed 145 cm from the participants' eyes.

Participants were given ample practice prior to the experiment, as well as frequent rest breaks. During the practice session, participants viewed 12 randomized word and nonword items (9 words, 3 nonwords). For both practice and experimental trials, participants completed a go/no-go task, pressing a button to pseudowords. Each trial began with a fixation cross (500ms), followed by the presentation of a stimulus item (500ms), followed by a blank screen during which the participant was instructed to either press the button if the item was a nonword, or do nothing if the item was a real word (1000ms) (see Figure 2.2 for example trial).

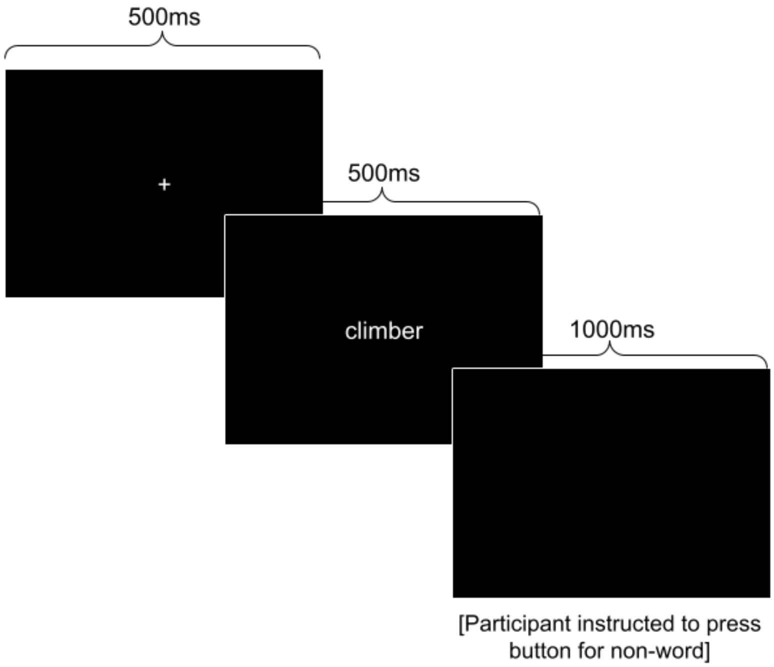

Figure 2.2. Example trial

Table 2.3. Stimuli information (means and standard deviations in parentheses). Lexical characteristics compiled from the English Lexicon Project (Balota et al., 2007)

	Length (characters)	*Zipf Frequency*	*Bigram Frequency*	*Concreteness*
Complex	7.1 (1.22)	3.12 (0.66)	14517.14 (5276)	2.99 (1.07)
Psuedocomplex	7 (1.28)	3.30 (0.69)	14758.52 (4750)	3.10 (0.98)
Simplex	6.9 (1.17)	3.15 (0.72)	13226.76 (5706)	3.08 (0.88)

EEG procedure

Participants were comfortably seated in a recording chamber while 32 channels of raw EEG were amplified using a Synamp RT Bio-amplifier system (DC to 200Hz bandpass, 500 Hz sampling rate (see Figure 2.3 for scalp montage). Separate ERPs at 29 scalp sites were averaged from artifact free trials time-locked to the onset of visual stimuli in the various conditions. Subjects with excessive eye movement or EEG artifact (i.e., greater than 10% rejected) were corrected using independent component analysis (ICA) (Makeig et al., 1996) (n=13 participants).

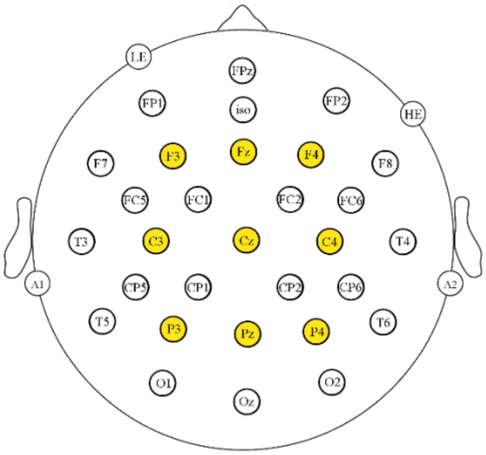

Figure 2.3. Scalp montage of recorded electrode sites. Highlighted sites reflect the subset of nine representative electrode sites (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) included in the analyses to give adequate coverage of the scalp and allow for a single ANOVA (including scalp distribution) per epoch. We have used this strategy successfully in previous studies (e.g., Mott et al., 2020; Holcomb et al., 2024).

Based on priming studies indicating that orthographic information has the strongest influence in the earliest part of the N250 (Grainger et al., 2006; Grainger & Holcomb, 2009), analysis of the N250 component focused the time window of 200-250 ms, overlapping with the epoch used by Lavric et al., (2012). The N400 time window was set as 300-500ms. All time windows were subjected to Group (Deaf, Hearing) X Anteriority (Frontal, Central, Posterior) X Laterality (Left, Midline, Right) X Type (Complex, Pseudocomplex, Simplex) ANOVAs (see Figure 2.3 for montage of analyzed sites). Any main effects or interactions with Type were followed up with ANOVAs comparing pairs of target word conditions (Type), i.e., complex vs. simplex, psuedocomplex vs. simplex, and complex vs. pseudocomplex. Similarly, any main effects or interactions with Group were followed up with separate Group analyses.

Results

Behavioral Results

On the go/no-go lexical decision task (press to a pseudoword), the hearing group was more accurate than the deaf group (t = 2.25, df = 45, *p* = 0.03), although both had over 90% accuracy. The groups did not significantly differ in reaction time (*p* = 0.55). See Table 2.4 for group means.

Table 2.4. Behavioral results

	% Accurate (Hits)	*% Accurate (False Alarms*	*RT (Hits) in ms*
Hearing	95.25 (5.74)	95.25 (5.74)	95.25 (5.74)
Deaf	90.42 (9.51)	90.42 (9.51)	90.42 (9.51)

ERP Results

The ERP waves for all three word type conditions at all analyzed electrode sites are shown in Figure 2.4 for the deaf readers and in Figure 2.5 for the hearing readers. The N250 time window and the N400 time window are indicated with boxes in the figures.

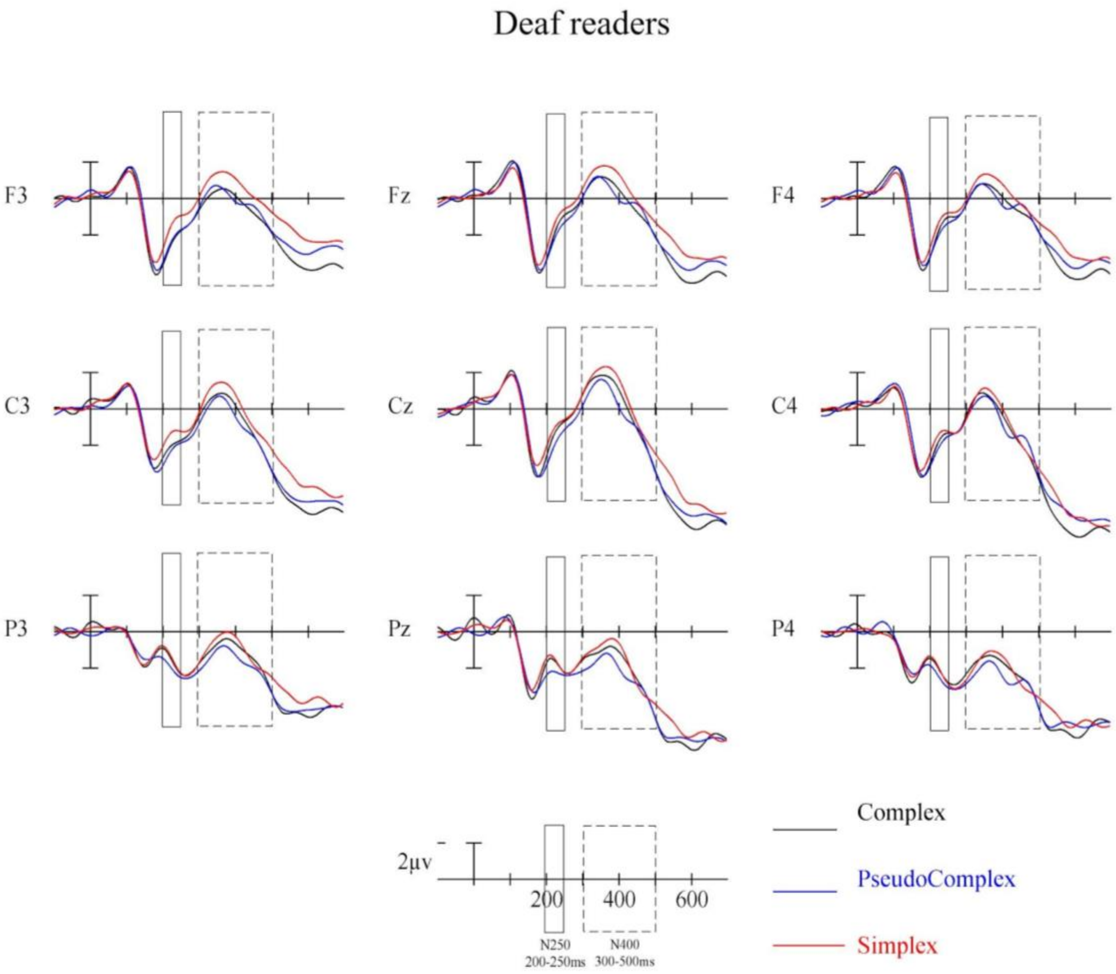

Figure 2.4. Deaf group ERPs

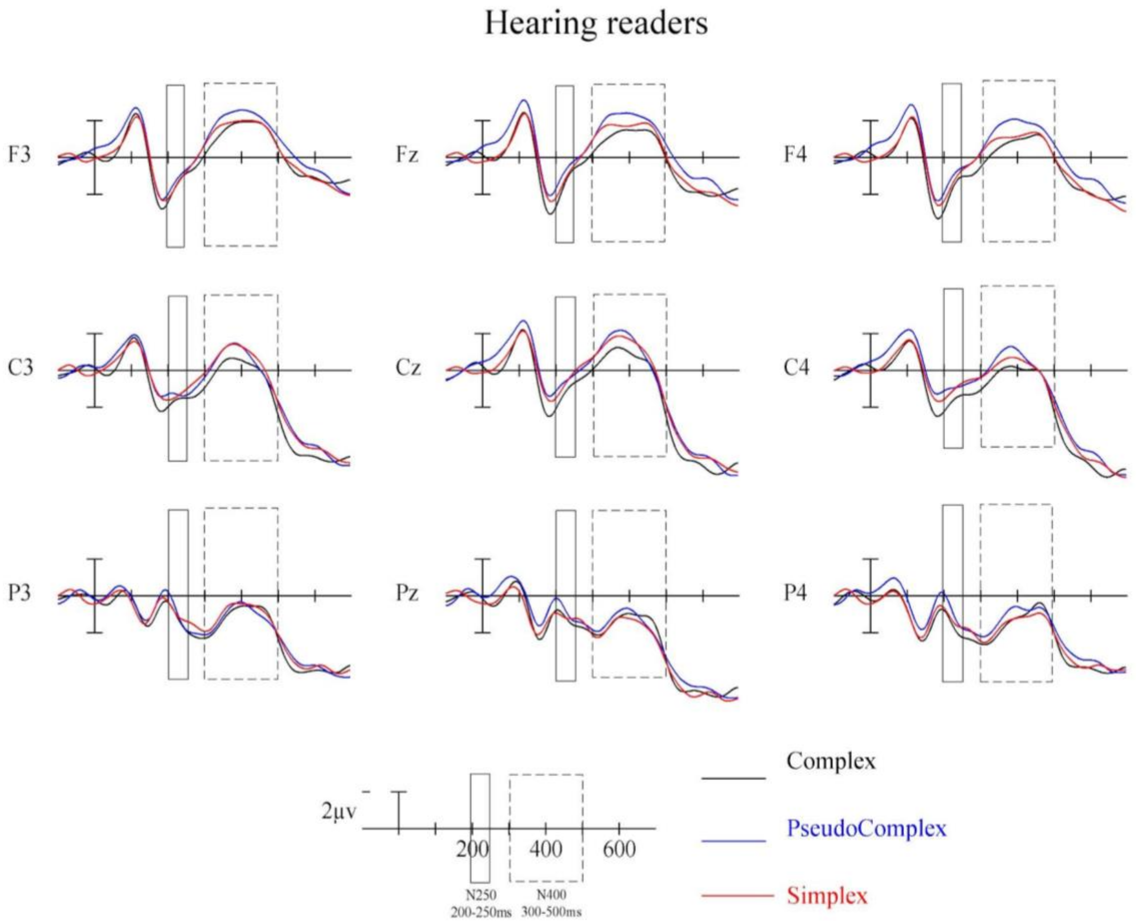

Figure 2.5. Hearing group ERPs

<u>Early N250 (200-250 ms)</u>

The omnibus ANOVA revealed a significant Group X Type X Laterality interaction (F = 2.74, df = 4, p = 0.04, partial $\eta^2 = 0.06$). We then ran follow-up pairwise ANOVAs comparing each pair of word types.

Complex vs. Simplex Words

There was a significant interaction of Group X Type X Laterality (F= 4.09, df = 2, p = 0.02, partial $\eta^2 = 0.08$) and a significant four-way interaction of Group X Type X Laterality X Anteriority (F = 3.5, df = 4, p = 0.01, partial $\eta^2 = 0.07$). For deaf readers, complex words elicited reduced negative amplitudes compared to simplex words, which was marginally more pronounced in leftward and anterior electrodes (*F*= 2.32, df = 4, $p = 0.09$, partial $\eta^2 = 0.09$) – see Figure 2.6A. For hearing readers, no main effects or interactions were significant (all *p*s > 0.1).

Psuedocomplex vs. Simplex words

There were no Group or Type interactions between Pseudocomplex and Simplex words in the early N250 (200-250ms) (all ps > 0.1) for either group – see Figure 2.6B.

Complex vs. Pseudocomplex

There was a significant interaction of Group X Type X Laterality ($F = 4.22$, df = 2, $p = 0.02$, partial $\eta^2 = 0.08$). For hearing readers, complex words elicited reduced negative amplitudes compared to pseudocomplex words in rightward electrodes ($F = 4.04$, df = 2, $p = 0.03$, partial $\eta^2 = 0.15$) – see Figure 2.6C. In contrast, for deaf readers there were no significant differences between complex and pseudocomplex words.

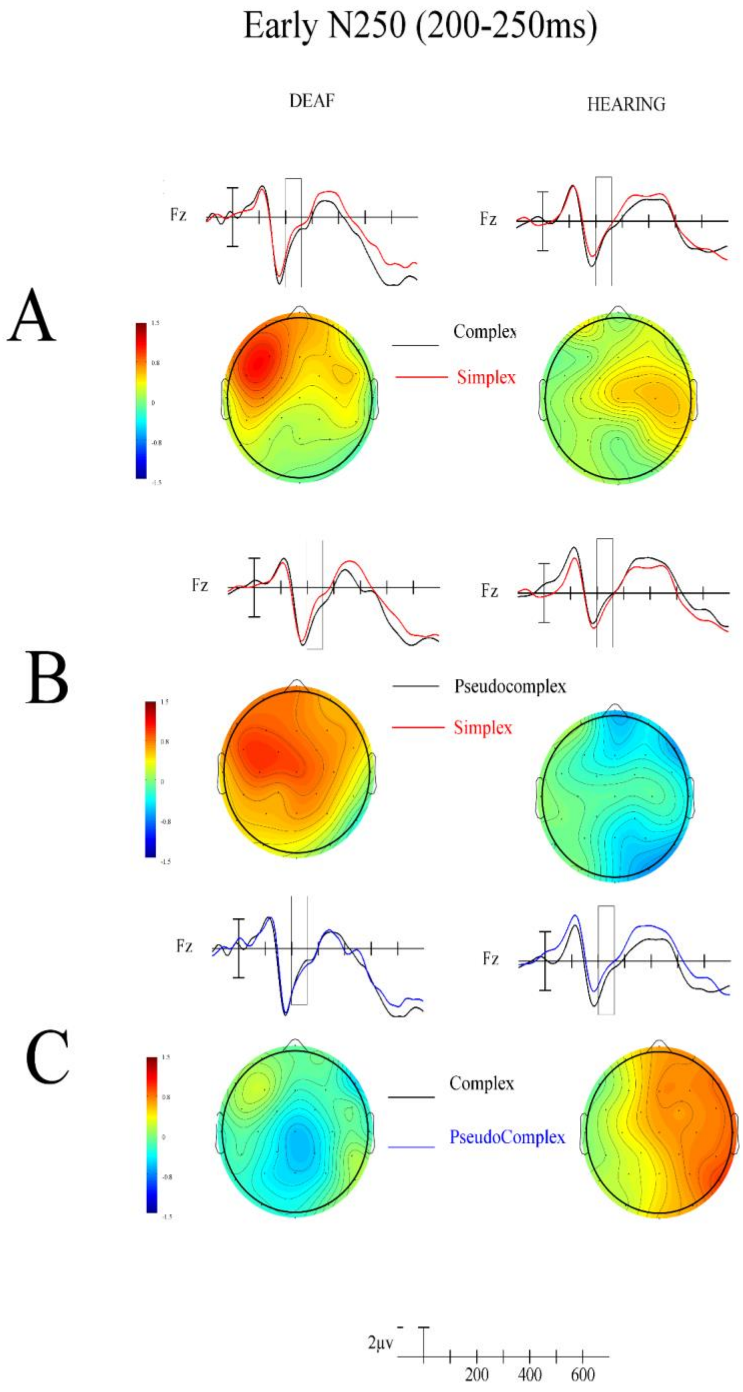

Figure 2.6. Early N250 for deaf (left) and hearing (right) participants, organized by pairwise comparisons of each stimulus type.

N400 (300-500ms)

The omnibus ANOVA with Group (Hearing, Deaf), Type (Complex, Pseudocomplex, Simplex), Laterality (Left, Right, Center), and Anteriority (Frontal, Central, Posterior) revealed a significant interaction of Type X Laterality (F = 3.13, df = 4, p = 0.02, partial η^2 = 0.063), but no interactions with Group (ps > 0.1). However, given our a priori hypotheses we conducted follow-up analyses of Type that included Group.

Complex vs. Simplex Words

There was a marginally significant interaction for Type X Anteriority (F = 3.08, df = 2, p = 0.08, partial η^2 = 0.06), but there were no significant interactions with Group (ps > 0.1). Complex words elicited reduced negative amplitudes compared to simplex words in the frontal electrodes for both groups – see Figure 2.7A.

Pseudocomplex vs. Simplex Words

There was a significant interaction for Type X Laterality (f = 7.46, df = 2, p = 0.002, partial η^2 = 0.14). The Group interactions were not significant (ps > 0.1)[1]; however, the amplitude differences were in opposite directions for the two groups (see Figure 2.7B). Pseudocomplex words elicited reduced negative amplitudes compared to simplex words in the leftward electrode sites for the deaf group (F = 3.5, df = 2, p = 0.05, partial η^2 = 0.13). In contrast, the simplex words elicited reduced negative amplitudes compared to pseudocomplex words in the same sites for the hearing group (F = 4.49, df = 2, p = 0.02, partial η^2 = 0.16).

Complex vs. Pseudocomplex Words

There was a marginally significant interaction for Group X Laterality X Anteriority (F = 2.52, df = 4, p = 0.059, partial η^2 = 0.05). Both groups showed a significant Laterality X

Anteriority interaction (Deaf: $F = 7.8$, df = 4, $p < 0.001$, partial $\eta^2 = 0.25$; Hearing: ($F = 3.14$, df = 4, $p = 0.03$, partial $\eta^2 = 0.12$), but no interactions with type (all ps > 0.1).

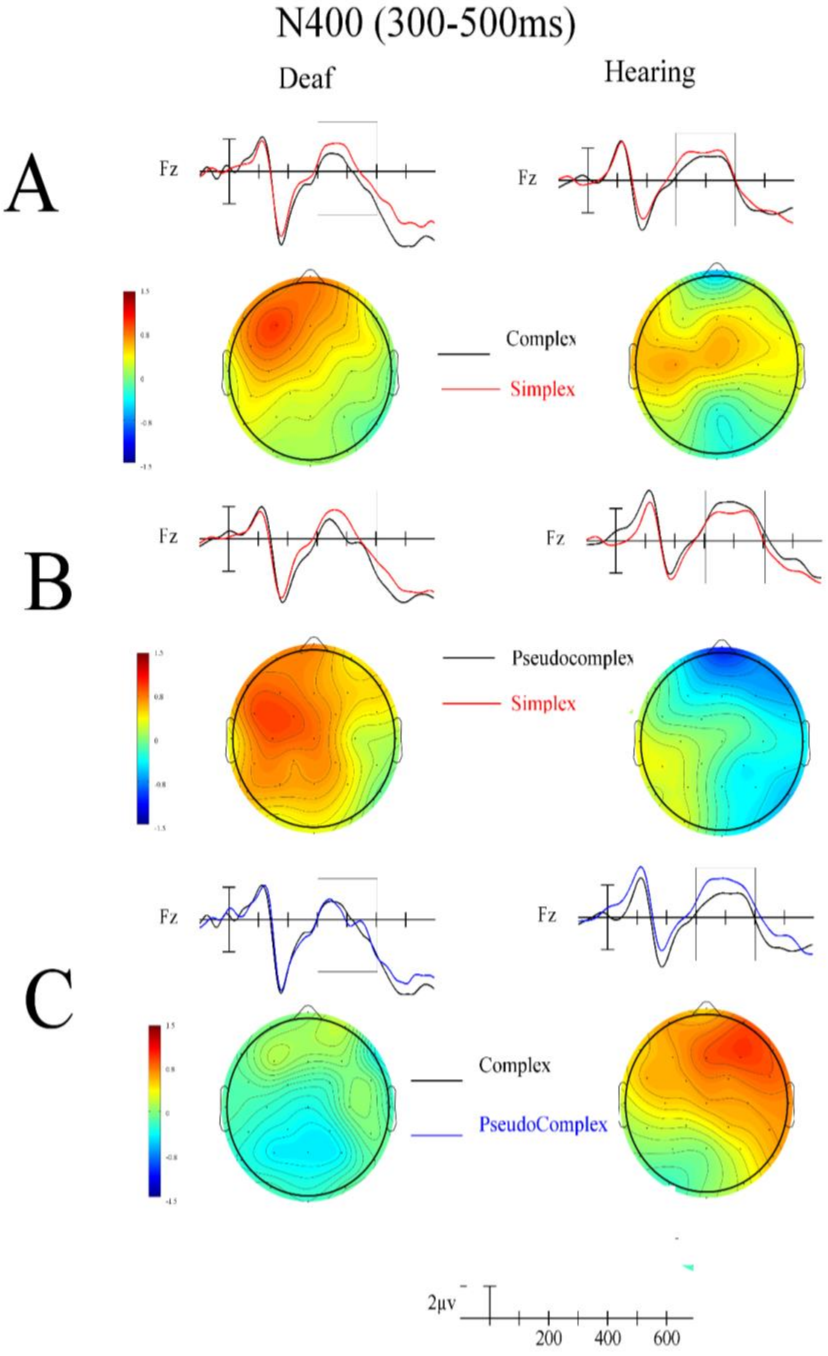

Figure 2.7. N400 for deaf (left) and hearing (right) participants, organized by pairwise comparison of each stimulus type.

Correlations between amplitude differences and reading skill

We also calculated the correlations between reading skill (WJ-Comprehension score) and the ERP amplitude difference for each pairwise comparison at each time window. The correlation between reading skill and the ERP amplitude for the complex-simplex difference in the early N250 was statistically significant for deaf readers ($r = 0.43$; $p = 0.03$), but not for hearing readers ($r = -0.05$; $p = 0.8$). Deaf readers with better reading skill exhibited a larger difference between complex words and simplex words in the early N250 window. There were no significant correlations between reading skill and ERP amplitude in the N400 window for either group.

We also calculated correlations between morphological awareness and the ERP amplitude difference for each pairwise comparison at each time window. There were no significant correlations (all ps > 0.1).

Discussion

To investigate the morpho-orthographic segmentation process for deaf and hearing readers, we conducted an unprimed lexical decision task with English words and pseudowords of varying morphological complexity. Following Lavric et al., (2012), we hypothesized that complex (hunter) and psuedocomplex (corner) words would pattern together in the N250 component for deaf and hearing readers alike, indexing a semantically blind morpho-orthographic segmentation process.

While the hearing readers were more accurate at the task (unsurprising, given that they were also stronger readers overall), both groups performed the task successfully, with over 90% accuracy. Their response times were also equivalently fast. This indicates that while the neurocognitive underpinnings of morpho-orthographic processing are different for the two groups, they do not necessarily hinder the lexical access or word recognition process.

The results indicated that the deaf readers were processing the complex and pseudo-complex words similarly in the early N250 window (200-250ms); however, the hearing readers showed increased negative amplitudes to pseudo-complex compared to complex words. This pattern indicates that the deaf readers processed the pseudo-complex words according to their apparent complexity, based on the orthographic cues. The presence of an apparent suffix such as "-er" in "corner" cued the deaf readers to segment the word, even when that segmentation would not cue the true meaning of the item. In contrast, hearing readers processed the words according to the actual morphological complexity of the word, rather than the apparent morphological structure based on orthographic cues. This top-down processing stream did not appear to influence the deaf readers' processing of the stimuli during the lexical decision task.

In primed versions of this paradigm (corner-CORN; see Morris et al., 2012), complex and pseudo-complex words are expected to diverge in the N400 component, when the actual semantic content of the word is processed. Because participants are responding to the stems of the words (i.e., CORN), they must reanalyze and "un-segment" the pseudo-complex words to successfully process the root. However, in the current study, participants respond to the full word (i.e., corner), and do not see the "decomposed" stem. Therefore, the task does not require participants to separate the root word from the affix, and would not incur any error by incorrectly identifying an affix like the "-er" in corner. In this case, this "reanalysis" effect may not be observed in the N400 component. Indeed, our results show that neither hearing nor deaf participants showed a significant difference between complex and pseudo-complex words in the

N400 component, suggesting that the semantic “re-analysis” process observed in primed paradigms may be a task-specific effect.

However, the two groups appear to differentiate between pseudo-morphological structure and a clear lack of it, evidenced by the difference in their responses to pseudo-complex and simplex items in the N400 window. For deaf readers, simplex words (“freeze”) elicited larger negative amplitudes than pseudo-complex words (“corner”) in the leftward electrode sites. Hearing readers, in contrast, had larger negative amplitudes to pseudo-complex than simplex words at these same sites. This pattern indicates that while both groups were sensitive to the pseudo-morphological structure, it influenced processing demands in opposite ways. Pseudo-complex words were easier to process than simplex for the deaf readers, and simplex were easier for the hearing readers.

Finally, we hypothesized that for deaf readers, who may rely more heavily on visually salient morphology than hearing readers, the amplitude differences between the conditions would be more strongly correlated with reading skill than hearing readers. The results aligned with this hypothesis; reading skill was positively correlated with the complex-simplex amplitude difference in the early processing window (200-250ms) for the deaf, but not the hearing readers. The better deaf readers showed a larger amplitude difference (more reduced negativity to complex words) between the words that required morphological segmentation, compared to those that did not, indicating that reading skill facilitated deaf readers’ segmentation process.

Conclusions

The present study used event-related potentials to characterize the morpho-orthographic segmentation process for deaf and hearing readers. Deaf readers chiefly processed words according to their orthographically cued segments in early word processing, regardless of the true morpho-semantic structure, while hearing readers distinguished between orthographically cued pseudo-morphological structure and true morphological structure. Both groups were successful at the lexical decision task, indicating that “incorrectly” segmenting the pseudocomplex stimuli did not hinder their ability to recognize them as real English words. For the deaf readers, amplitude differences between true complex and simplex words were positively correlated with reading skill, such that processing the true complex words was less effortful for stronger readers. This correlation was not observed for hearing readers, indicating a unique relationship between reading skill and morphological segmentation for deaf readers.

Footnotes

In an ANOVA limited to just the leftward sites, the Group X Type X Anteriority interaction was significant (F = 4.28, df = 2, p = 0.016, partial η^2 = 0.08).

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CHAPTER 3: Morphological processing in the parafovea during sentence reading for deaf and hearing readers

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Abstract

Evidence of parafoveal preprocessing of morphology is mixed for English readers. A preview benefit from morphology has been observed for suffixed words, but not compound or prefixed words, for typical hearing readers. Deaf readers, who learn to read with reduced access to the sounds of spoken language, show differences in their orthographic processing that may affect how they process morphology in the parafovea. Deaf readers appear to have a particularly tight connection between orthography and semantics, which may also allow them to more efficiently identify and process morphological structure, particularly because morphological processing is chiefly motivated by orthographic structure during initial word recognition. The combination of deaf readers' ability to attend to information further into the periphery and their sensitivity to orthography in early word processing may contribute to possible differences in morphological processing compared to their hearing peers. Furthermore, morphological awareness has been shown to influence reading skill for both deaf and hearing readers, although little is known about how it affects their online processing during sentence reading. Using a gaze-contingent display change paradigm, we tested whether deaf and hearing readers with varying morphological awareness showed differences in parafoveal processing of morphology during sentence reading. We found that deaf readers with high morphological awareness showed a graded priming effect, with shorter gaze durations on target words ("sadness") following a pseudomorphological preview ("sadment") compared to a nonmorphological preview ("sadnard"). Hearing readers were unaffected by the morphological preview, regardless of skill level. These results suggest that deaf readers are attuned to morphological structure in the parafovea during sentence reading, but only if they have a higher level of morphological awareness.

Introduction

Morphology is the study of how meaning-bearing units are combined and analyzed in words. These units range from small affixes that do not stand on their own (bound morphemes) to whole words that have their own lexical status (free morphemes) (Carlisle, 2003). All types of these units are combined in a consistent, rule-ordered structure. In order to effectively process morphological structure, skilled readers must be able to correctly decompose roots and affixes to identify the meaning of the whole word. Many studies of morphological processing analyze the decomposition of morphemes in single word contexts using masked priming paradigms (see Rastle & Davis, 2008 for review). These studies provide evidence for a semantically-blind decomposition of morphemes based on their orthographic form, referred to as morpho-orthographic segmentation (Rastle et al., 2004). When making lexical decisions about single morpheme words (e.g., HUNT), readers are equivalently primed by morphologically-related derived primes (e.g., hunter-HUNT) as they are by pseudo-complex primes that consist of a real stem and a real affix, but do not share a morpho-semantic relationship (e.g., corner-CORN), in contrast to prime-target pairs that share the same amount of orthographic overlap but lack an apparent affix (e.g., turnip-TURN) (Rastle et al., 2004; Rastle & Davis, 2008). This decomposition process is thought to be prelexical, occurring before the identification of the whole word, due to evidence from studies using morphologically structured nonwords as primes (Meunier & Longtin, 2007). Recognition of a target stem was facilitated when nonword primes included a real but invalid affix, where the combination does not result in an existing word (e.g., rapidifier-RAPID, sportation-SPORT), suggesting that the complex nonwords were still decomposed according to their morphological structure (Meunier & Longtin, 2007).

Morphological structure also influences word processing in sentence contexts. In sentence reading, lexical characteristics of individual morphemes impact how long readers fixate when reading multimorphemic words. Both whole-word and constituent frequency influence fixation durations on compound words (Andrews et al., 2004; Bertram & Hyönä, 2003; Inhoff et al., 2008). For example, for “headed” compounds where the first lexeme is dominant (*human* is the dominant determiner of meaning for the compound *humankind*), first fixation durations are shorter for more frequent first lexemes. “Tailed” compounds, such as *handbook*, followed the same pattern, with frequent dominant lexemes resulting in shorter first fixation durations. These results indicate that multimorphemic words are decomposed during early word recognition in sentence reading.

The earliest stages of word recognition during natural reading occurs while the word is still in the reader’s parafovea, between 2 and 5º of visual angle from the central fixation. The processing of these upcoming words influences when and where readers fixate in a sentence. Recognizing that an upcoming word is morphologically complex may influence readers’ eye movements. When fixated, component parts of morphologically complex words influence fixation durations on the whole word (frequency effects, Bertram & Hyönä, 2003). However, preprocessing (morphological decomposition) of these complex words in the parafovea may facilitate readers’ processing of the target word once they fixate on it. Such a result would be consistent with single-word priming studies that show readers are faster to recognize a simple word if preceded by a complex word containing that root (Rastle & Davis, 2008). A parallel to priming in single word recognition studies is the parafoveal preview paradigm. In this paradigm, a quick, lower-resolution glimpse of a word (a prime) in the parafovea can facilitate word recognition when the reader fixates on the target word (preview benefit).

Numerous studies have demonstrated that related orthographic information in a parafoveal preview yields a preview benefit compared to unrelated orthographic information (Balota et al., 1985; Briihl & Inhoff, 1995; Drieghe et al., 2005). When letter identity information of the upcoming word is preserved or related in the preview, readers are able to initiate lexical processing of that word, which facilitates their lexical access to that word when they fixate on it (Schotter et al., 2012). This facilitation is thought to occur at the orthographic level, evidenced by studies that observed stronger preview benefits from transposed-letter previews (*jugde-judge*) than replaced letter previews (*jupbe-judge*) (Johnson et al., 2007). This benefit arises whether or not previews are valid words. Johnson & Dunne (2012) observed similar preview benefits from transposed-letter previews that produced words (*calm-clam*) and those that produced nonwords (*caml-clam*). These results all indicate that readers are clearly attuned to orthographic information in the parafovea.

Orthographic codes are active slightly earlier in the word processing stream than phonological codes (Lee et al., 1999), but preview benefits have also been observed for phonological information in hearing readers (Schotter et al., 2012; Pollatsek et al., 1992). These results indicate that parafoveal processing extends beyond early, orthographic level processing. However, results are mixed on other levels of processing in the parafovea, including morphological processing.

Using the eye-contingent display change paradigm (Rayner, 1975), a parafoveal preview benefit from morphological structure has been found for German (Mousikou & Schroeder, 2019), Chinese (Yen et al., 2008), and Hebrew (Deutsch et al., 2000), but not English (Kambe, 2004; Lima, 1987) or Finnish (Bertram & Hyönä, 2007). In German, readers were able to extract the identity of embedded stems from a pseudomorphological or nonmorphological prime;

fixation durations on a real word target were shorter for both conditions compared to an unrelated prime (Mousikou & Schroeder, 2019). The researchers concluded that readers were able to begin processing the embedded stems in the parafovea, regardless of whether they were accompanied by an affix. However, in English, the parafoveal preview benefit was not different for prefix-only compared to stem-only letter information (for a target word *review*: prefix preview *rexwsz*, stem preview *cmview*) (Kambe, 2004); that is, participants were equally primed by both types of partial preview, with no difference depending on whether the preview was the prefix or the stem. Kambe (2004) concluded that there was no evidence of morphologically motivated preprocessing in English sentence reading, but rather that any related letter information in the parafoveal preview facilitated processing of a target. This result was consistent with Lima (1987), who also found no evidence of parafoveal preprocessing of prefix information.

However, a more recent study with English using the gaze-contingent boundary paradigm found evidence that morphological preprocessing in English does occur, but only for suffixed words (Dann et al., 2021). Readers showed a preview benefit from morphology, such that preview words with pseudo-morphological suffixes such as *stressary* yielded a larger priming effect on a target word “stressful”, compared to preview words non-morphological endings (*stressard*). In contrast, readers showed no preview benefit from prefixed or pseudo-prefixed words, replicating Kambe (2004). These results suggest that readers are able to decompose morphologically complex previews in the parafovea, but only when the more salient stem (as opposed to a prefix) falls in the highest acuity area of the parafoveal region directly next to the fixation (Dann et al., 2021). The authors additionally suggest that the legitimacy of the suffix (i.e., its status as a real English suffix, as opposed to the pseudo-suffixes) contributed a “boost” to the priming effect of the stem. Readers were more easily able to decompose (and therefore preprocess) the stem when it was attached to a familiar English suffix, following accounts of morphological decomposition in which stems and affixes are segmented according to orthographic characteristics, regardless of their true semantic relationship.

One population who may show differences in their morpho-orthographic processing patterns is skilled readers who are prelingually and profoundly deaf. Deaf readers, who learn to read with reduced access to the sounds of spoken language, show equivalently precise orthographic representations as hearing readers despite less precise phonological representations (e.g., Meade et al., 2020). Rapid activation of these orthographic codes may result in more efficient access to the semantic information of the word (see Bélanger and Rayner, 2015 for a discussion of the Word Processing Efficiency Hypothesis). Deaf readers, like hearing readers, have been shown to process orthographic information in the parafovea. Both skilled and less-skilled deaf readers showed a parafoveal preview benefit from orthographic information in early word processing measures (first fixations and gaze durations), such that fixations were shorter if the preview was orthographically similar (*beard-board*) (Bélanger et al., 2013). This result indicates that deaf readers across skill levels rapidly activated orthographic codes from a preview word in the parafovea.

Furthermore, deaf individuals' allocation of visual attention tends to be distributed more widely across the periphery than for hearing individuals (Bavelier et al., 2006), which has been hypothesized to affect deaf readers' eye movements during sentence reading (Bélanger & Rayner, 2015). Indeed, studies with skilled deaf readers have demonstrated that they have a wider effective perceptual span than skill-matched hearing readers, reaching up to 18 characters to the right of fixation compared to 14-15 for hearing readers (Bélanger et al., 2012) and reaching up to 10 characters to the left of fixation compared to 4 for hearing readers (Stringer et al., 2024). Deaf readers thus have a more symmetrically distributed reading span, which may contribute to their enhanced reading efficiency. Deaf readers have been found to read with shorter fixations, more frequent skipping, and fewer regressions compared to skill-matched hearing readers (Traxler et al., 2021; Schotter et al., 2024; Cooley et al., 2024). Being able to process upcoming words farther into the periphery may allow deaf readers to spend less time on words once they land on them.

The combination of deaf readers' efficiency at attending to information further into the periphery and their sensitivity to orthography in early word processing may contribute to possible differences in deaf readers' morphological processing compared to their hearing peers. Bélanger and Rayner (2015) proposed that deaf readers have a particularly tight connection between orthography and semantics. This strong mapping may also allow them to more efficiently identify and process morphological structure, particularly because morphological processing is chiefly motivated by orthographic structure during initial word recognition (Rastle & Davis, 2008). Indeed, morphological awareness, or the ability to identify and manipulate component parts of complex words, appears to have a different relationship to reading for deaf compared to hearing readers. For deaf college students, morphological awareness was significantly related to reading skill (as measured by English placement levels assigned upon entry to university), while phonological awareness, a well-established predictor of reading skill for hearing readers, was not (Clark et al., 2011). In another study investigating how morphological awareness interacts with other reading skills, deaf readers had a uniquely strong relationship between morphology and reading comprehension, as well as a stronger relationship between morphology and vocabulary size (see Chapter 1 of this dissertation).

Morphological processing in a sentence context has yet to be investigated for deaf readers and may be an important contributor to their reading efficiency. The ability to extract semantic information from upcoming morpho-orthographic cues in a sentence may convey a considerable advantage, particularly for adult readers who read at higher levels where they encounter a wealth of morphologically complex words in sentence contexts. An additional factor that may influence how readers process morphology in the parafovea is their level of morphological awareness, or their ability to recognize and manipulate component parts of complex words (Levesque et al., 2017). To our knowledge, no study of parafoveal processing of morphology in English has included offline measures of participants' morphological awareness. However, morphological awareness has been shown to influence reading comprehension skill for both deaf and hearing readers (Kotzer et al., 2021; Chapter 1 of this dissertation). Nonetheless, little is known about how morphological skill affects online processing during sentence reading. The extent to which deaf readers preprocess morphological structure in the parafovea will provide insight as to the relationship between their efficient orthographic-to-semantic mappings and their enhanced reading span. Including a measure of morphological awareness will also account for the ways in which skill differences affect this online process for both deaf and hearing readers.

The Present Study

Using a gaze contingent display change paradigm (Rayner, 1975), we tested whether deaf and hearing readers with varying morphological awareness skill showed differences in parafoveal processing of morphology during sentence reading. Based on research that suggests that parafoveal preview benefits in English are restricted to suffixed words (Dann et al., 2021), target words all consisted of a stem and a suffix, while preview words either had a pseudomorphological suffix (“sadment”), a nonmorphological suffix (“sadnard”), or were unrelated nonwords (“florous”). When participants' eyes cross the boundary preceding the target word, the preview word in one of four conditions is replaced by the target word by the time they fixate on it. Participants typically do not perceive the display change because it occurs as their eyes move (saccadic suppression (Matin, 1974)). This boundary in the text is not visible to the participants.

Both hearing and deaf readers are expected to show faster fixation durations on target words following parafoveal primes that share a root with the real word target (both morphological and non-morphological primes). Unrelated non-morphological controls should result in no facilitation effect for the target word. If deaf readers are indeed more attuned to morphological structure, they should show stronger preview benefits from morphological relationships than hearing readers, resulting in larger differences in fixation times between the pseudomorphological and nonmorphological conditions for the deaf group. In other words, deaf readers are expected to show a graded priming effect, with the most benefit from pseudomorphological previews, then nonmorphological, then unrelated nonword previews. Finally, those readers (either deaf or hearing) with better morphological awareness may show larger morphological preview benefits.

Methods

Participants

Two groups of adult participants were recruited: 1) 24 hearing, monolingual English speakers (15 women, mean age = 30.4 years, SD = 13.5 years), and 2) 24 prelingually and profoundly deaf signers (13 women, mean age = 36 years, SD = 8.7 years). All deaf participants learned ASL before age 7 (M= 2.07 years, SD=2.94 years), and use ASL as a primary means of communication. All participants had normal or corrected-to-normal vision and no reading or learning disabilities. Background information (education, knowledge of other languages) was collected for both groups. Hearing participants reported an average of 4 years post-high school education (SD = 1.26). Deaf participants reported an average of 5.48 years post-high school education (SD = 3.35 years).

Assessments

In addition to the eye-tracking experiment, participants also completed a battery of reading assessments, summarized below (see Table 3.2. for a summary of participant scores).

<u>Woodcock Johnson IV Passage Comprehension Subtest:</u> Participants were asked to read short passages (1-2 sentences) containing one blank and to fill in the blank with the correct missing word. (LaForte et al., 2014) Raw scores were calculated by subtracting errors from the ceiling item. This test measures readers' general reading comprehension level.

<u>Test of Receptive Spelling:</u> Participants were given a list of 87 printed words, some of which were spelled incorrectly, and asked to circle only the incorrectly spelled items (Andrews & Hersch, 2010). Raw score was calculated by subtracting errors (i.e., missed "incorrect" words or falsely circled "correct" words) from the total number of words (87). Because this test does not involve dictation or auditorily presented test items, it is an appropriate and comparable measure of spelling skill to be used with both deaf and hearing readers.

Peabody Picture Vocabulary Test IV (PPVT-IV) adapted for deaf individuals: In the adapted version of the PPVT-IV, participants read an English word in the center of a page and are asked to identify which of four pictures on the same page is the most accurate representation of the English word (Dunn & Dunn, 2007; Sarchet et al., 2014). Raw scores were calculated by subtracting errors from the ceiling item. This test represents participants' vocabulary size.

Participants' summed scores on the MTMS and the Nonword Choice Task (summarized below) comprised our measure of morphological awareness (MA). Raw scores were calculated by subtracting errors from the total number of items (48). See Table 3.1 for example items.

Modified Test of Morphological Structure (MTMS): In part one of this assessment (derivation), participants were provided with a simple root word and a sentence containing a blank, then asked to derive a complex word using the root that fits a sentence frame. In the second part (decomposition), participants were provided with a complex word and another sentence frame that contained a missing word, then asked to remove an affix or affixes from the complex word to produce the simple word that successfully completes the sentence (Bernstein et al., 2020). Part 1 (derivation) measures participants' ability to generate complex words by applying the correct affixes to a root word. Part 2 measures participants' ability to identify which parts of complex words are the roots and affixes, and then extract the appropriate root based on the sentence context.

Nonword Choice Task: Participants were provided with a sentence containing one orthographically plausible nonword that contains possible English affixes (e.g., acquitation) and asked to choose from three options to identify the most plausible meaning for the nonword (McCutchen & Logan, 2011). This task assesses participants' ability to infer the meaning of novel words by using familiar affixes and roots.

Table 3.1. Example items from MTMS and Nonword Choice Tasks, comprising measure of Morphological Awareness.

Task	*Example item*	*Correct Answer*
Modified Test of Morphological Structure (Part 1: Derivation)	Assist. The teacher will give you ______.	Assistance
Modified Test of Morphological Structure (Part 2: Decomposition)	Discussion. The friends have a lot to _____.	Discuss
Nonword Choice Task	On the property was a PERIMETOUS wall. Answer options: - Encircling - Deteriorating - Rough stone	Encircling

Table 3.2. Mean scores on assessments for each participant group (standard deviations reported in parentheses).

Measure	*Assessment*	*Deaf Readers*	*Hearing Readers*	*P-value (T-test)*
Reading comprehension	Woodcock-Johnson IV (Passage Comprehension subtest)	36.5 (4.8)	38.04 (2.97)	0.19
Spelling	Andrews and Hersch (2010) receptive spelling test	72.88 (8.34)	72.83 (7.78)	0.99
Vocabulary	Peabody Picture Vocabulary Test (PPVT) adapted for deaf individuals	198.54 (15.86)	208.92 (9.64)	0.01
Morphological awareness	Summed score[1] on Modified Test of Morphological Structure (parts 1 and 2) and Nonword Choice Task	28.125 (6.80)	35.8 (4.52)	0.00

Stimuli

The target words were all morphologically complex real words. Preview words were in one of four conditions (see Table 3.3): identity, pseudomorphological nonword, non-morphological nonword, and unrelated nonword control.

Table 3.3. Stimuli conditions and examples

Condition	*Example preview word*	*Target word*
Identity	sadness	sadness
Pseudomorphological nonword	sadment	sadness
Non-morphological nonword	sadnard	sadness
Unrelated nonword control	florous	sadness

Morphologically complex pseudowords were formed by combining the target root with an existing English suffix that does not form an existing English word. Non-morphological pseudowords were formed by combining the target root with an orthographically plausible but meaningless string of letters. Unrelated pseudoword controls were formed by combining an unrelated root and an unrelated suffix to form a pseudoword with the same number of letters as the target.

A sentence frame was constructed for each target word such that the target word fell in the middle of the sentence. The sentences were between 6 and 14 words long (M = 10.2, SD = 1.4). Based on the number of participants in each group (n=24), we included 64 sentences per condition for 256 total sentences, in order to achieve Brysbaert and Stevens' (2018) recommendation of 1,600 data points per condition for sufficient statistical power. 100 stimuli items (target/preview words and their corresponding sentences) were taken from Dann et al., (2021)’s suffixed stimuli, and remaining items were constructed with the same parameters. See example sentence and preview conditions in Figure 3.1.

Identity:	The man tried hiding his sadness from his best friends.
PseudoMorphological nonword:	The man tried hiding his sadment from his best friends.
NonMorphological nonword:	The man tried hiding his sadnard from his best friends.
Unrelated nonword control:	The man tried hiding his florous from his best friends.

Figure 3.1. Example sentences with each type of preview. The vertical line indicates the location of the invisible boundary.

Procedure

Participants sat comfortably in front of a computer screen and silently read single-line sentences while their eye movements were tracked with an Eyelink 1000+ in desktop configuration or an Eyelink Portable Duo. Stimuli were presented in 14pt black Courier New font on a light gray background on a 24-inch LCD monitor with 75 Hz refresh rate. The screen was placed 60 cm from the participants' eyes, providing ~3.5 letters/degree of visual angle. Participants first performed a 3-point calibration and then read silently. When participants' eyes crossed the programmed invisible boundary, the preview word either changed from one of the display change conditions or remained in the target condition. Participants pressed a gamepad button when they finished reading a sentence to move on to the next trial. To ensure they were reading for comprehension, participants answered Yes/No questions with buttons on the gamepad after 20% of the trials.

Analyses

Continuous eye movement measures (first fixation durations, gaze durations) were analyzed using a linear mixed effects model with item and subject as random effects and group, preview condition, and centered morphological awareness score as fixed effects.

Preview condition was contrast coded as follows:

Contrast 1: NonMorphological (sadnard) vs. PseudoMorphological (sadment)

Contrast 2: Shared Root (sadment/sadnard) vs. Control (florous)

Contrast 3: Any nonword preview (sadment/sadnard/florous) vs. Identity (sadness)

Models were fitted with the lmer and lmerTest functions from the lme4 package (Bates et al., 2015) in the R statistical computing environment. Fixed effects were deemed reliable if $p < 0.05$.

First Fixation Duration

For both groups, first fixation durations were shorter on target words preceded by a preview with a shared root (sadnard/sadment), compared to an unrelated control (florous) ($p<0.001$); see Table 3.4, Figure 3.2a. There was also a significant main effect of any display change, such that fixation durations were shorter when there was no display change ("identity" preview) ($p < 0.001$). There was also an interaction between group and display change, such that hearing readers were more disrupted by a display change overall than deaf readers ($p = 0.002$) (see Figure 3.2b).

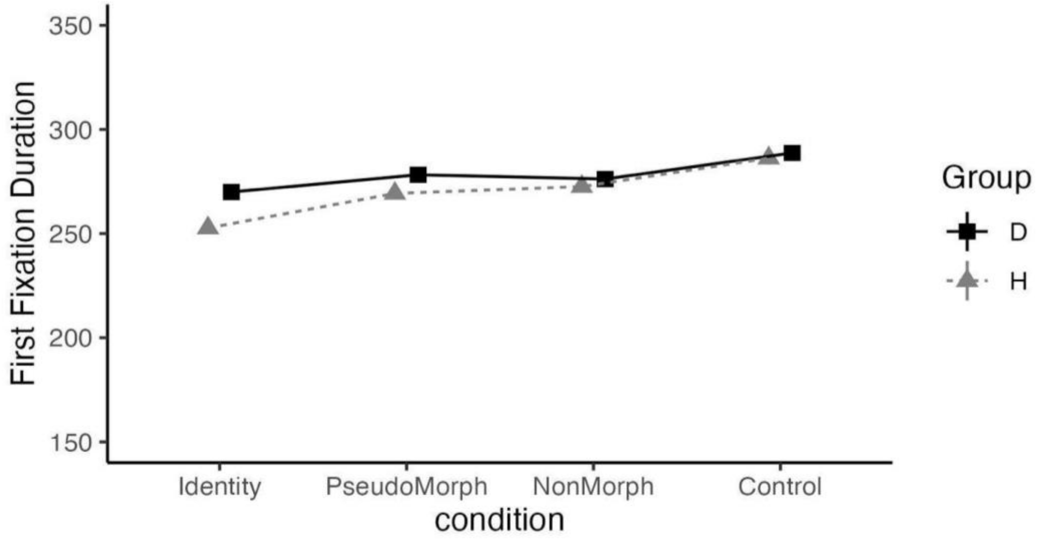

Figure 3.2a. First fixation durations on target words for each preview condition.

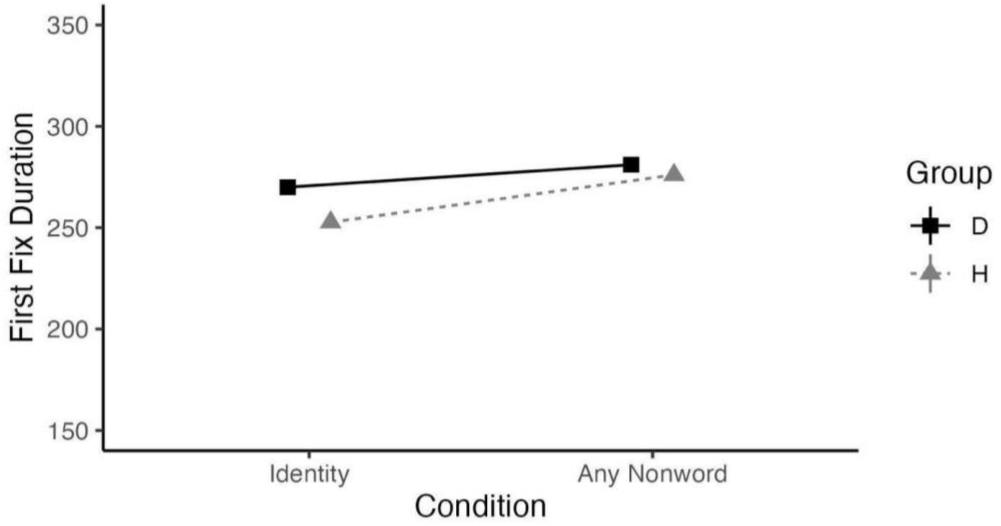

Figure 3.2b. First fixation durations on target words, no display change vs. any nonword preview.

Table 3.4. LME results, first fixation durations

	First Fixation Duration			
Predictors	*Estimates*	*std. Error*	*Statistic*	*p*
(Intercept)	269.40	11.00	24.49	**<0.001**
Group	7.80	15.54	0.50	0.616
NonMorph -> PsuedoMorph	-2.10	1.66	-1.26	0.207
Shared Root -> Control	5.07	0.96	5.29	**<0.001**
Any Nonword -> Identity	-5.87	0.68	-8.63	**<0.001**
MA	-3.80	10.99	-0.35	0.730
Group * Morph	3.43	2.36	1.46	0.146
Group * Shared Root/Control	-1.28	1.36	-0.94	0.348
Group * Any Nonword	3.01	0.96	3.13	**0.002**
Group * MA	-0.78	15.53	-0.05	0.960
NM->PM * MA	0.94	1.65	0.57	0.571
Shared Root/Control * MA	-1.48	0.95	-1.55	0.120
Any Nonword * MA	-0.08	0.68	-0.11	0.910
Group * NM->PM * MA	-0.48	2.35	-0.20	0.839
*Group * Shared Root/Control * MA*	*2.27*	*1.35*	*1.68*	*0.094*
Group * Any Nonword * MA	-0.97	0.96	-1.01	0.310
Random Effects				
σ^2	8257.71			
τ_{00} TRIAL_INDEX	37.62			
τ_{00} subject_ID	2866.43			
ICC	0.26			
N subject_ID	48			
N TRIAL_INDEX	256			
Observations	11946			
Marginal R^2 / Conditional R^2	0.012 / 0.269			

Gaze Duration

On average, deaf readers had longer gaze durations on target words across preview conditions than hearing readers (Deaf: M = 363.88ms, SD = 164.1ms; Hearing: M = 338.42ms, SD = 170.84ms; $t = 8.3$, $p<0.01$), although this difference did not result in a significant main effect of group in the LME model.

As in the first fixation duration model, gaze durations were significantly shorter following a preview with a shared root compared to an unrelated preview for both groups ($p<0.001$). Gaze durations were also significantly longer after any kind of display change than after an identity preview for both groups ($p<0.001$). There was also a significant three-way interaction between group, morphological awareness, and contrast 1 (the difference between a pseudo-morphological preview “sadment” and a non-morphological preview “sadnard”) ($p = 0.02$). Gaze durations were shorter after pseudo-morphological previews than after non-morphological previews, more so for deaf readers with higher morphological awareness (see Table 3.5, Figure 3.3).

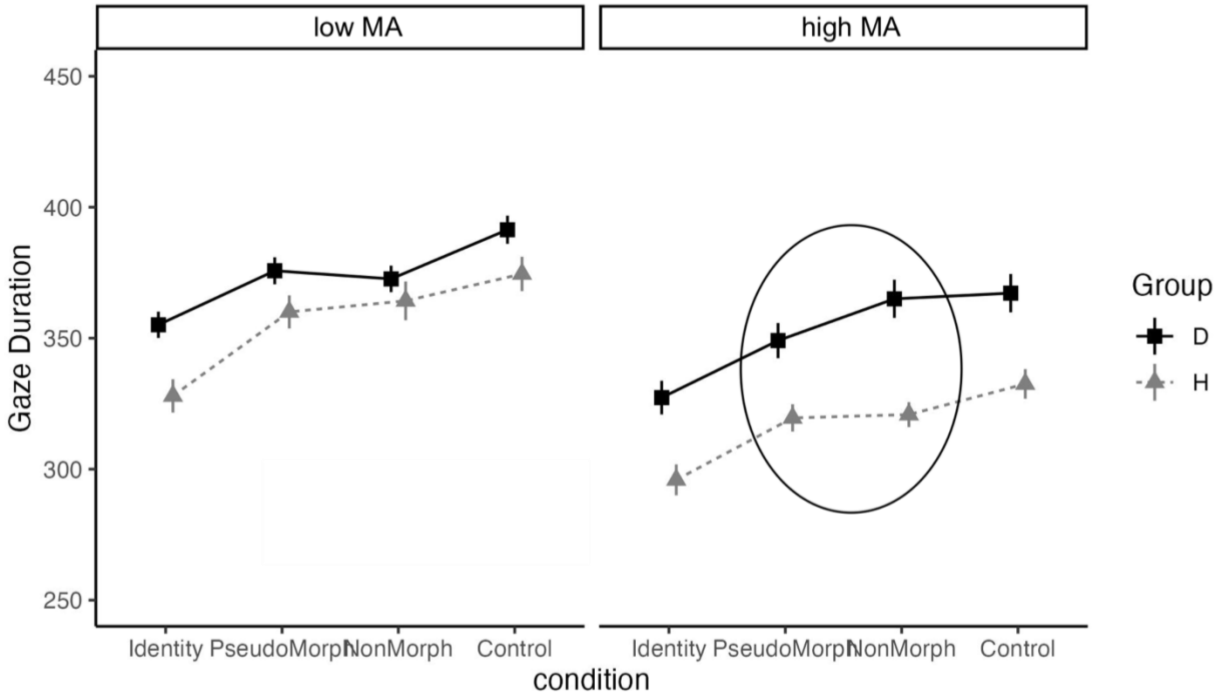

Figure 3.3. Interaction between group, morphological awareness, and preview condition. The circle highlights the three way interaction between group, morphological awareness, and preview condition (pseudomorphological vs. nonmorphological previews).

Table 3.5. LME results, gaze duration

	Gaze duration			
Predictors	*Estimates*	*std. Error*	*Statistic*	*p*
(Intercept)	336.68	17.70	19.02	**<0.001**
Group	25.18	25.03	1.01	0.314
NonMorph -> PsuedoMorph	-2.19	2.63	-0.83	0.404
Shared Root -> Control	4.14	1.52	2.73	**0.006**
Any nonword -> Identity	-8.48	1.08	-7.88	**<0.001**
MA	-20.69	17.70	-1.17	0.242
Group * Morph	-0.11	3.73	-0.03	0.977
Group * Shared Root/Control	0.43	2.15	0.20	0.841
Group * Any Nonword	1.25	1.52	0.82	0.413
Group * MA	2.31	25.01	0.09	0.926
*NM->PM * MA*	*4.36*	*2.61*	*1.67*	*0.096*
Shared Root/Control * MA	-0.20	1.51	-0.13	0.894
Any Nonword * MA	0.78	1.07	0.72	0.469
Group * NM->PM * MA	-8.37	3.72	-2.25	**0.024**
Group * Shared Root/Control * MA	1.40	2.14	0.65	0.515
Group * Any Nonword * MA	-2.03	1.52	-1.33	0.182
Random Effects				
σ^2	20743.58			
τ_{00} TRIAL_INDEX	0.00			
τ_{00} subject_ID	7436.07			
N subject_ID	48			
N TRIAL_INDEX	256			
Observations	11946			
Marginal R^2 / Conditional R^2	0.036 / NA			

For an additional exploratory analyses of the (non-significant) correlation between morphological awareness score and the size of the priming effect from psuedomorphological previews, see Supplementary Materials.

Discussion

The present study investigated parafoveal preprocessing of morphological structure for deaf and hearing readers using a gaze contingent display change paradigm. We measured participants' fixation durations on a morphologically complex target word ("sadness") that was preceded by a preview word that either contained a pseudomorphological suffix ("sadment"), a nonmorphological suffix ("sadnard"), or was an unrelated nonword ("florous"). Both the hearing and the deaf participants were expected to show a priming effect from preview words with a shared root, with shorter fixation durations on the target word following primes that share a root with the real word target (both pseudomorphological and nonmorphological). Following Dann et al., (2021), readers were also expected to show a difference in the amount of priming between the pseudo- and non-morphological conditions; pseudomorphological primes should result in shorter fixation durations than nonmorphological primes. If deaf readers are indeed more attuned to morphological structure, they should show stronger preview benefits from pseudomorphological relationships than hearing readers, resulting in a stronger priming effect from morphologically structured previews for the deaf group.

As expected, we found a significant priming effect from previews with a shared root compared to unrelated previews in first fixation durations for both deaf and hearing readers. This priming effect was also observed in gaze durations for both groups. This result indicates that both deaf and hearing readers are able to extract a target root word (i.e., "sad") from a parafoveal preview, and the presence of that root, whether or not the whole word is a valid English word (i.e., “sadment” or “sadnard”), facilitates access to the target word once readers fixate on it.

Deaf readers had longer gaze durations on targets across preview conditions than the hearing readers. This finding contrasts with previous research that found overall shorter fixation durations for deaf readers during typical reading, i.e., without a parafoveal preview manipulation (e.g., Traxler et al., 2021). This result could reflect a greater sensitivity to the invisible boundary manipulation for deaf readers, perhaps due to heightened sensitivity to fast visual changes (e.g., Bottari et al., 2011). Another possible explanation is that deaf readers attended more than hearing readers to these relatively long, low frequency target words, particularly because the deaf participants had smaller vocabularies than the hearing participants. Nevertheless, this overall difference did not result in a main effect of group in the LME model that included preview condition and morphological awareness.

For the hearing readers, there was no overall difference in gaze durations between the pseudomorphological and nonmorphological previews; the two types of preview elicited an equivalent priming effect on the target word. For the deaf readers, however, we found a different pattern that depended on the readers’ morphological awareness. The deaf readers with low morphological awareness showed the same pattern as the hearing readers and were similarly primed with both types of preview with a shared root. This result suggests that deaf readers with low morphological awareness were not segmenting the pseudomorphological endings differently from the nonmorphological endings. In contrast, we found that the group of deaf readers with high morphological awareness exhibited the hypothesized graded priming effect from morphological structure in the parafovea. For deaf readers with higher MA, psuedomorphological previews resulted in significantly shorter gaze durations on the target words than nonmorphological previews (see Table 3.5 and Figure 3.3). In fact, the nonmorphological previews elicited similar gaze durations to the completely unrelated pseudoword preview for these readers. This pattern of results suggests that deaf readers with high morphological awareness were segmenting pseudomorphological structure in the parafovea. They were more easily able to extract the root when the suffix was a true suffix, even though this segmentation did not result in a valid English word (sadment), compared to when the suffix was not a valid English suffix (sadnard). This segmenting process facilitated their access to a morphologically complex target word.

It is important to note that based on the median split of scores for each group, the deaf group with high morphological awareness still had lower scores overall than the hearing group with high morphological awareness (Deaf: M= 33.9, SD = 3.5; Hearing: M = 39.7, SD = 2.7; $p < 0.01$). This pattern indicates that the parafoveal preprocessing of morphological structure was not a result of high morphological awareness alone, but rather this pattern was a characteristic unique to the reading process of skilled deaf readers.

The results of the present study indicate that deaf readers with relatively good morphological knowledge process morphology differently than both hearing readers (regardless of morphological skill) and deaf readers with weak morphological awareness. This enhanced ability to attend to morphological structure in the parafovea facilitates processing of complex multimorphemic words. Given that morphologically complex words make up the majority of words encountered by skilled readers, this difference could play an important role in the documented efficiency of deaf readers more generally. These findings also provide support for suggestions to include targeted morphological instruction in reading interventions for deaf readers; if morphological awareness skill plays a role in how efficiently deaf readers process complex input, boosting this skill in deaf readers can aid in improving their overall reading development.

Future Directions

Previous research with prefixed previews concluded that (hearing) readers of English did not preprocess morphological structure in the parafovea, likely because the most informative part of the preview (the stem) was too far from the central fixation to result in a preview benefit. Deaf readers, however, who can process word information further into the periphery, may exhibit a parafoveal preview benefit from prefixed information where hearing readers did not. Further research should investigate whether deaf readers exhibit morphological priming with prefixed stimuli similar to those used in Kambe (2004) and Dann et al., (2021).

Conclusions

This study reported the first evidence of parafoveal preprocessing of morphological structure during sentence reading for deaf readers. We observed a larger preview benefit from pseudomorphological preview items than nonmorphological preview items that shared a root with the target word, but only for deaf readers with high morphological awareness. Hearing readers, regardless of morphological awareness, did not show a difference between pseudo- and nonmorphological preview items, although both types of preview with a shared root elicited a preview benefit compared to an unrelated preview. Segmentation of morphologically structured pseudoword cues facilitated access to a root word, and by extension, the real target word. This pattern of results suggests a unique relationship between morphological awareness and the segmentation of complex multimorphemic words during sentence reading for deaf readers.

Supplemental Analysis: Difference in mean preview effect and correlation with MA skill

Based on the interaction between group, morphological awareness, and morphology priming in the regression model (Table 3.5), we conducted a follow-up analysis to further characterize the difference between pseudo-morphological and non-morphological preview. We calculated a “prime score” for each participant that subtracted their average gaze duration in the pseudo-morphological (sadment) and non-morphological (sadnard) preview conditions from their average gaze duration in the unrelated control preview condition. Thus, a positive prime score would reflect that participants were more primed by the pseudo- or non-morphological conditions than the unrelated control condition. We then calculated the difference between their pseudo-morphological prime score and their non-morphological prime scores, generating a “prime difference” value for each participant.

We then compared the correlations between morphology priming and morphological awareness for each group (Figure 3.4). For the deaf group, there was a correlation of 0.31. For the hearing group, the correlation was -0.2. Neither correlation was statistically significant (p = 0.14 and 0.34, respectively). However, when we calculated the difference between the correlations using the standard error and t-statistic of the differences between the two correlations, the difference was marginally significant (p = 0.09).

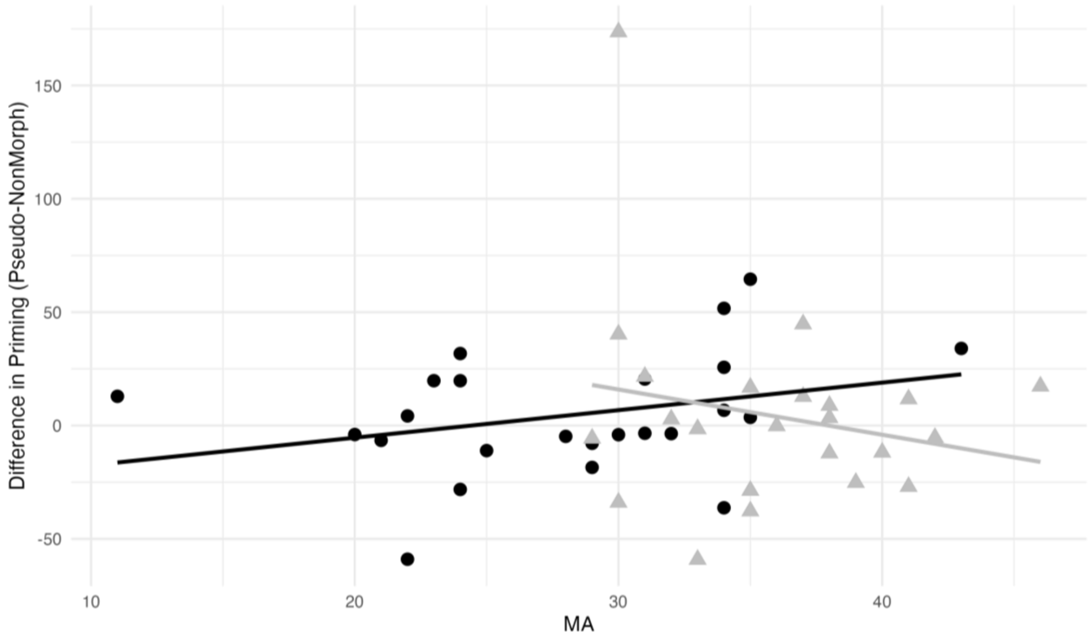

Figure 3.4. Scatter plot of Morphological Awareness and difference in gaze duration

Footnotes

1. See Table 3.6 for breakdown of morphological awareness scores by test section.

Table 3.6. Scores on individual sections of morphological awareness assessment

	MTMS Part 1: Derivation	*MTMS Part 2: Decomposition*	*Nonword Choice*
Deaf	6.88 (2.58)	9.42 (3.12)	11.71 (2.49)
Hearing	8.92 (2.12)	12.71 (1.43)	14.17 (2.32)
T-test (p-value)	<0.01	<0.01	<0.01

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Psychonomic Society 65th Annual Meeting in November 2024. Saunders, E., Schotter, E., & Emmorey, K. (in preparation). Morphological processing in the parafovea during sentence reading for deaf and hearing readers. The dissertation author was the primary investigator and author of this paper. Preparation of this manuscript was supported by National Science Foundation Grants BCS-2120546 and BCS-2120507.

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CONCLUSION

This dissertation explores the reading processes of deaf and hearing readers, emphasizing the critical role of morphological awareness in reading comprehension and vocabulary acquisition. The first study characterized the relationship among various sub-skills involved in the complex linguistic task of reading for deaf and hearing readers, including spelling, vocabulary, morphological awareness, and phonological awareness. The study demonstrated that morphological awareness has a stronger positive correlation with reading comprehension for deaf readers than for hearing readers. Deaf readers also showed a significant link between morphological awareness and vocabulary size, underscoring the importance of morphology in building vocabulary and decomposing novel words. These findings highlight the unique role of morphological awareness in the skilled deaf reader's "toolbox," suggesting that morphology could be effectively incorporated into reading interventions that leverage the unique linguistic potential of developing deaf readers.

The second study utilized event-related potentials to investigate the neural signature of morpho-orthographic segmentation in deaf and hearing readers. Results indicated that deaf readers process words according to orthographic segments early in word recognition, regardless of true morpho-semantic structure, while hearing readers differentiate between orthographically cued pseudo-morphological structures and true morphological structures. Although both groups performed the lexical decision task successfully, only deaf readers showed a positive correlation between reading skill and the neural correlates of the segmentation. This finding suggests a relationship between reading skill and morphological segmentation in deaf readers, which is not observed in hearing readers.

The third study provided the first evidence of parafoveal preprocessing of morphological structure during sentence reading for deaf readers. Deaf readers with high morphological awareness exhibited a larger preview benefit from pseudo-morphological items compared to non-morphological items, facilitating access to a morphologically complex target word. In contrast, hearing readers did not show this distinction, although they benefited from preview items sharing a root with the target word. This pattern of results suggests a unique relationship between morphological awareness and the parafoveal decomposition of complex multimorphemic words during sentence reading for deaf readers.

Collectively, these studies characterize the distinct and integral role of morphological awareness in the reading processes of deaf readers, influencing their reading comprehension, vocabulary development, and word segmentation strategies. These findings contribute to a body of research illustrating that the underlying cognitive processes of skilled reading is different for deaf readers, particularly those with advanced morphological awareness. Given that morphologically complex words make up the majority of words encountered by adult readers, these processing differences likely contribute to the enhanced efficiency of deaf readers. These findings also provide support for suggestions to include targeted morphological instruction in reading interventions for deaf readers; if morphological awareness skill plays a role in how efficiently deaf readers process complex input, boosting this skill in deaf readers can aid in improving their overall reading development. By understanding and leveraging the unique characteristics that make up the reading processes of adult deaf readers, educators can better support the literacy skills of developing deaf readers, fostering more effective and inclusive educational practices.

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