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WILEY

Teaching & Learning Guide for: The neurocognitive basis of skilled reading in prelingually and profoundly deaf adults

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1 | AUTHOR'S INTRODUCTION

Many theories propose that reading optimally builds upon speech perception and that the quality of phonological representations plays a central role in reading and in tuning the brain's response to written words. Skilled deaf readers who rely on coarse-grained phonological codes pose a challenge to these models. This article reviews key behavioral and neuroimaging evidence that reveals how reduced access to auditory phonology, along with changes in visual attention that co-occur with early deafness, leads to a unique neurocognitive profile for skilled reading in deaf adults. The article describes parallels and differences in the neural underpinnings of word-level and sentence-level reading for deaf and hearing adults who are equally skilled readers. This teaching and learning guide provides additional information and resources related to reading pedagogy for deaf children, understanding the neural systems that support reading, and ways to incorporate the study of deaf readers into courses on reading and reading instruction.

2 | AUTHOR RECOMMENDS

***American Annals of the Deaf*, Volume 159, Numbers 4 (Fall, 2014) and 5 (Winter, 2015).**

The articles in these two issues of the journal *American Annals of the Deaf* represent a two-part special issue on English reading development for children who are deaf and hard-of-hearing (DHH). The articles represent a wide range of approaches and views on literacy acquisition, and they capture many of the controversies that surround reading education in DHH children, particularly with respect to the role of English phonology in reading instruction and the use of sign language and fingerspelling as a bridge to literacy.

This guide accompanies the following article(s): Emmorey K., & Brittany Lee, B. **The neurocognitive basis of skilled reading in prelingually and profoundly deaf adults.** Language and Linguistics Compass 15/2 (2021): e12407. https://doi.org/10.1111/lnc3.12407

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

This review article documents how the study of eye movements in reading illuminates complex word and sentence processes and how deaf and hearing readers differ in their eye movement patterns. Nathalie Bélanger and Keith Rayner propose the Word Processing Efficiency Hypothesis (WPEH) to account for different reading patterns. Specifically, skilled deaf readers regress back in the text (i.e., reread) less often, refixate words less often, and skip over words more often than hearing readers with equal reading ability. The WPEH states that skilled deaf readers are more efficient at processing written words within a single fixation because deaf readers have a tighter connection between orthography and semantics, are more attuned to the visual-orthographic structure of words, and may be able to obtain more information in the parafovea (i.e., the region just to the right of fixation) compared to hearing readers. This article raises the question of whether skilled reading for deaf people necessarily involves the same word and sentence processing stages as found for skilled hearing readers.

Dehaene, S. (2009). *Reading in the brain: The new science of how we read*. Penguin.

Stanislas Dehaene provides an accessible and fascinating introduction to how the brain 'acquires' reading. Dehaene describes his neuronal recycling hypothesis whereby pre-existing brain systems (e.g., those involved in face and object recognition) are harnessed for the novel task of recognizing words. He argues that our genes have not evolved to enable us to read and writing systems were only recently invented; therefore, reading and writing systems must conform to the limits of our brain. The book demonstrates how a neuroscientific approach to reading can shed light on both typical and atypical (e.g., dyslexic) readers.

Easterbrooks, S., & Dostal, H. (Eds.) (2021). *The Oxford handbook of deaf studies in literacy*. Oxford University Press.

This large volume edited by Susan Easterbrooks and Hannah Dostal contains 31 chapters by prominent deaf and hearing researchers and educators that together provide the most up-to-date information on literacy in DHH individuals. The chapters cover current theories of reading development for DHH children who are growing up bilingual and for those who are spoken language learners only. Chapters also cover the elements of literacy in DHH learners (e.g., written word recognition and production; vocabulary learning, morpho-syntax acquisition, use of pragmatics and academic language). Another set of chapters covers assessments, interventions, and instruction methods for DHH children and adults (e.g., reading comprehension and classroom engagement). In addition, separate chapters cover literacy in emerging sign language communities (e.g., Nicaragua), in deafblind individuals, and in DHH people with disabilities. The final chapters discuss research designs for literacy and education studies and discuss the need to rethink approaches to literacy research.

Goldin-Meadow, S., & Mayberry, R. I. (2001). How do profoundly deaf children learn to read? *Learning Disabilities Research and Practice, 16*(4), 222–229. <https://doi.org/doi.org/10.1111/0938-8982.00022>

This accessible review article discusses the challenges that face deaf children when learning to read and why some deaf children nonetheless become skilled readers. Susan Goldin-Meadow and Rachel Mayberry point to research showing that better deaf readers are often also better signers. The data indicate that learning American Sign Language (ASL) does not interfere with learning to read—in fact, just the opposite: knowing ASL actually helps deaf children learn to read. The authors discuss possible mechanisms and interventions that might account for this finding.

3 | ONLINE MATERIALS

<http://asl-lex.org>

ASL-LEX is an online database of phonological and lexical properties for approximately 2700 ASL signs and provides a source of materials for understanding sign-based phonological awareness (see suggested learning exercise #1 below). The database is searchable, and the website contains a visualization of phonological networks and tutorials (in ASL and English) for how to use and download the database.

4 | SAMPLE SYLLABUS

The following sample syllabus draws from Cognitive Neuroscience, Linguistics, and Deaf Studies and is appropriate for courses in any of these fields. The syllabus outlined below may be used in its entirety for an in-depth study of deaf readers, or individual weeks may be selected as stand-alone units to supplement course content where appropriate. The syllabus follows the structure of the article it is linked to, addressing the phonological, orthographic, and semantic processes that support word reading, as well as eye tracking and neuroimaging studies of sentence reading. The goal of the syllabus is to represent deaf readers in educational conversations about literacy and recognize their contributions to understanding the mechanisms of reading more broadly. The coursework is designed for undergraduate or graduate students who have some foundation in psycholinguistics.

Week 1: Phonological processing in skilled deaf readers

During this week, students consider the role of phonology in skilled reading for deaf individuals. The first article shows how the role of speech-based phonology and its utility in reading instruction are largely dependent on deaf readers' experience with signed and spoken languages. The second article discusses the importance of speech-based and sign-based phonological awareness in the developing reading systems of deaf children. See suggested learning exercises #1 and #2 below.

Suggested readings

Hirshorn, E. A., Dye, M. W. D., Hauser, P., Supalla, T. R., & Bavelier, D. (2015). The contribution of phonological knowledge, memory, and language background to reading comprehension in deaf populations. *Frontiers in Psychology*, *6*(1153).

Lederberg, A. R., Branum-Martin, L., Webb, M. Y., Schick, B., Antia, S., Easterbrooks, S. R., & Connor, C. M. (2019). Modality and interrelations among language, reading, spoken phonological awareness, and fingerspelling. *The Journal of Deaf Studies and Deaf Education*, *24*(4), 408–423.

Week 2: Orthographic processing in skilled deaf readers

During this week, students learn that orthographic processing is largely the same for skilled deaf and hearing readers. The first article is a behavioral transposed-letter study that may be appropriate for students with less of a background in neuroscience, while the second article is an ERP study demonstrating similar effects. See suggested learning exercise #3 below.

Suggested readings

Fariña, N., Duñabeitia, J. A., & Carreiras, M. (2017). Phonological and orthographic coding in deaf skilled readers. *Cognition*, *168*, 27–33.

Meade, G., Grainger, J., Midgley, K. J., Holcomb, P. J., & Emmorey, K. (2020). An ERP investigation of orthographic precision in deaf and hearing readers. *Neuropsychologia*, *146*, 107542.

Week 3: Semantic processing in skilled deaf readers

This lesson highlights several obstacles that deaf readers may face in developing their semantic knowledge. The first article presents normative data for deaf children on a widely used assessment of expressive vocabulary development and compares this early development in signed and spoken languages. This article may be clinically useful to students of early childhood education or speech–language pathology, whereas the second article may appeal to students with more of a focus on neuroscience. The latter presents diffusion tensor imaging data from early and late signers to explore effects of late first language acquisition and language deprivation on semantic and syntactic neural pathways. See suggested learning exercise #4 below.

Suggested readings

Caselli, N. K., Lieberman, A. M., & Pyers, J. E. (2020). The ASL-CDI 2.0: an updated, normed adaptation of the Macarthur Bates Communicative Development Inventory for American Sign Language. *Behavior research methods*, *52*, 2071–2084.

Cheng, Q., Roth, A., Halgren, E., & Mayberry, R. I. (2019). Effects of early language deprivation on brain connectivity: Language pathways in deaf native and late first-language learners of American Sign Language. *Frontiers in Human Neuroscience*, *13*, 320.

Week 4: Efficient eye movements in skilled deaf readers

This lesson focuses on differences in visual processing that arise from deafness and/or sign language experience and how these differences affect word recognition in sentence reading in deaf individuals. The first article reviews eye tracking studies with deaf readers, and the second article reviews the unique visual abilities of deaf individuals. The unit should emphasize relationship between these sensory and linguistic processes. See suggested learning exercise #5 below.

Suggested readings

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

Pavani, F., & Bottari, D. (2012). Visual abilities in individuals with profound deafness: a critical review. In M. M. Murray & M. T. Wallace (Eds.), *The neural bases of multisensory processes* (pp. 421–445). CRC Press/Taylor & Francis.

Week 5: Neural underpinnings of reading in skilled deaf readers

During this week, students learn about the neural regions activated when deaf and hearing people read. The first article is an fMRI study that compares the reading networks of deaf signers, oral deaf nonsigners, and hearing speakers. The second article reviews electrophysiological and neuroimaging studies that contribute to our understanding of the reading systems of deaf adults. See suggested learning exercise #6 below.

Suggested readings

Hirshorn, E. A., Dye, M. W., Hauser, P. C., Supalla, T. R., & Bavelier, D. (2014). Neural networks mediating sentence reading in the deaf. *Frontiers in Human Neuroscience*, *8*, 394.

Emmorey, K. (2020). The neurobiology of reading differs for deaf and hearing adults. In *The Oxford handbook of deaf studies in learning and cognition* (p. 347). Oxford University Press.

Focus questions

1. How are deaf and hearing readers similar and different? Compare and contrast their visual attention, phonological awareness, orthographic knowledge, semantic knowledge, and neural networks.
2. What skills are needed to become a skilled reader? How did you develop these skills throughout your education? What are some strengths and weaknesses of reading instruction for deaf and hearing students?

3. How does language experience (or lack thereof) influence deaf children's reading development?
4. Compare and contrasts different methodologies that are used to study reading: eye tracking, ERPs, fMRI. What can each method tell you about reading?
5. What was your biggest takeaway from this unit? How can you apply this knowledge to your field of interest?

5 | SUGGESTED LEARNING EXERCISES

Learning exercise #1: Developing phonological awareness

The purpose of this exercise is to increase students' understanding of phonological awareness. The exercise can be used to introduce the concept of phonological awareness before discussing its importance in reading. Ask students to brainstorm about the units that make up words. They may say letters, sounds, affixes, etc. Explain how words can be segmented into onsets and rimes and give a few examples. Then ask the students to create word webs with a target word at the center (e.g., *cat*). Add one branch that connects to words that share the onset (e.g., *coffee, kid*) and another that connects to words that share the rime (e.g., *hat, bat*). Similar webs could be made for signs. In this case, branches would extend from the target ASL sign (e.g., WATER) to signs with the same handshape (e.g., WORLD), location (e.g., THANK YOU), and movement (e.g., DAD). Videos of these signs can be found in the ASL-LEX database (see Online Materials). Students with limited knowledge of ASL can visit the ASL-LEX website (http://asl-lex.org), which organizes networks of signs based on phonological properties. After students share their webs, have a discussion about activities they did as emergent readers. How did these activities emphasize the phonological relationships between words/signs and help build either speech-based phonological awareness (e.g., identifying word-initial sounds, sounding out words, reading books containing rhymes, etc.) or sign-based phonology (e.g., playing handshape games, A–Z stories, practicing fingerspelling, etc.)? Finally, you can foster a class discussion of whether and how instruction in speech-based phonology should be adapted for deaf students or what alternative activities might help develop their ability to manipulate the sublexical units of words and signs. This exercise gives students concrete examples of phonological knowledge and asks them to reflect on educational practices for developing this knowledge for deaf and hearing students.

Learning exercise #2: Phonological fluency test

The purpose of this exercise is to increase students' understanding of phonological awareness. The exercise is designed to have students think about sublexical units: phonemes/graphemes for words or handshapes for signs. Ask students to name or write down as many words as they can that start with the letter 'F' in 60 seconds. For signing students, the task can be completed by naming as many signs as they can that use the 'F' handshape in 60 seconds. After completing this task, ask students to reflect on their answers. Were there any patterns to the items they listed? Did they repeat any items? Did they use any strategies? How many items did they get? This exercise can be paired and contrasted with the semantic fluency test in learning exercise #5 to gain a deeper understanding of how the lexicon is organized.

Learning exercise #3: Orthographic precision tasks

This exercise is meant to demonstrate different types of orthographic knowledge through tasks that require varying degrees of orthographic precision. Prepare five slides with stimuli for

each task listed in the chart below. For each task, introduce the question that the students will need to answer, then display the stimuli one at a time, and ask them to respond.

Modality	Encoded information	Question	Sample stimuli
Spelling recognition	Single letter identity in a single letter position	Does the word start with 'm'?	Monkey (yes) Zebra (no)
	Single letter identity and with multiple possible letter positions	Does the word contain the letter 'n'?	Lion (yes) Tiger (no)
	Multiple letter identities and positions	Is the word spelled correctly?	Gorilla (yes) Aligator (no)
Spelling production	Single letter identity in a single letter position	What letter is missing?	eleph_nt (a)
	Single letter identity and with multiple possible letter positions	Where should we insert a 'p'?	Hipopotamus (Before or after the first 'p')
	Multiple letter identities and positions	How do you spell the word for this picture?	Picture of animal (giraffe)

After completing the tasks, ask the students for their reactions. Which task was easiest? Hardest? What types of orthographic knowledge did you need to be able to answer correctly? Lead a discussion on how letter identities and positions are encoded into words when writing/spelling and decoded during reading.

Learning exercise #4: Examining semantic networks

The purpose of this exercise is to increase students' understanding of semantic knowledge and semantic networks. The exercise is designed to have students think about semantic categories and how they are organized within the lexicon. Ask students to name or write down as many animals as they can in 60 seconds (other semantic categories that can be used are fruits, items of clothing, furniture, etc.). After completing this task, have students reflect on their answers. Were there any patterns to the items they listed? Did they use semantic features (animals with fur), or schemas (farm animals) to think of more responses? Did they repeat any items? Did they use any other strategies? How many items did they get? Was this easier or harder than the phonological fluency test? Think about how this task would be harder for a category where you have limited world experience and vocabulary or in your second language. This exercise can be paired and contrasted with the phonological fluency test in learning exercise #2 to gain a deeper understanding of how the lexicon is organized.

Learning exercise #5: Demonstrating eye movements during sentence reading

The purpose of this exercise is to illustrate eye movement behaviors during sentence reading and contrast patterns of eye movements for deaf and hearing readers. This exercise provides a useful recap of what students learned from the unit. Split students into two groups, and ask one group to build a profile of eye movement behaviors for a deaf reader (span of 18 letters, more skipped words, faster reading speed, etc.) and the other group to build a profile for a hearing reader (span of 14 letters, more regressions and refixations, slower reading speed, etc.). Then lay out a long scroll of paper across the classroom floor with a sentence written on it large

print. Nominate one student from each group to walk across the sentence with each footstep marking a fixation. Make sure they incorporate appropriate movements based on the profiles their groups built (e.g., the student representing deaf readers can take bigger steps, jump over some words, and walk at a faster pace; the student representing hearing readers should take smaller steps, step twice on a word for a refixation, and go back to 'reread' part of the sentence for a regression). This exercise can also be done by writing or projecting the sentence onto a white board and having students tracking their movements using different color dry erase markers, or the exercise can be adapted for online classes by typing the sentence across a blank slide and asking students to track simulated eye movements with different colors using an annotation function. Following the demonstration, ask students to summarize what they learned about eye movements during sentence reading and why visual differences matter.

Learning exercise #6: Mapping neural networks for reading

The purpose of this exercise is to teach students about neuroanatomy, neural networks for reading, and how these systems differ for deaf and hearing readers. For this jigsaw activity, provide students with a handout with a sagittal view of the left hemisphere of the brain. Break students into groups. Each group is responsible for locating one of the following regions within the reading network: superior temporal gyrus, visual wordform area, inferior frontal cortex, temporal-parietal cortex , inferior temporal cortex. Students should scan the suggested readings for their assigned region to read about its functions and describe any differences noted for deaf and hearing readers. Once students have researched their respective regions, reformulate the groups. The new groups should have one student from each of the previous groups to represent each brain region. Students take turns explaining their regions to the new group so that students leave with a completed diagram and better understanding of the reading network by the end of class.

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Karen Emmorey is a Professor of Speech, Language, and Hearing Sciences at San Diego State University. She obtained her PhD in Linguistics at UCLA in 1987 and was a Staff Scientist at the Salk Institute for Biological Studies until 2005. Her research focuses on what sign languages and the deaf and hearing people who use them can reveal about the nature of human language, cognition, and the brain.

Brittany Lee is a graduate student in the SDSU/UCSD Joint Doctoral Program in Language and Communication Disorders, and she expects to receive her PhD in the Spring of 2021. She studies reading and sign language processing using ERP, eye-tracking, and psycholinguistic methods. Her reading research focuses on identifying alternative approaches to achieving reading success.

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