How reading interfaces with sign language

Rachel I. Mayberry, Ph.D.[1]
Department of Linguistics, University of San Diego, California, USA

1. THE KEY QUESTION

The ability to read proficiency is a critical skill for children who are born severely and profoundly deaf. Indeed, one could argue that reading proficiently is more crucial to a deaf than hearing child because it provides an alternative to speech by which to engage with society and culture. The problem is that, more often than not, deaf children do not become proficient readers. Surveys in the United States suggest that only 10% of the deaf population reads at the 8th grade level or above. The Canadian government cites an 8th grade reading level as the minimum requirement to be considered literate. The key question is why reading development is difficult for so many deaf children world-wide.

The dominant hypothesis is that imperfect or absent speech blocks reading development in deaf children. The reasoning is that impaired phonological decoding and coding skills limit reading development in the deaf population. In order to discover whether and how a deaf child's ability to speak or use sign language is linked to reading development, we must first consider the nature of the reading task.

1.1 What is Reading?

Reading is a complex cognitive process made up of two basic components: (1) word recognition, or decoding, and (2) language comprehension. One of the first stages reading development is mastering the alphabet and the orthographic patterns of written language. This is referred to as word decoding, or word recognition. But reading also entails language comprehension, which itself is a complex process. Written language involves much more than single words. Reading requires comprehension of words connected in sentences, and sentences connected in discourse. Thus, to answer the question of how sign language interfaces with reading, we must ask how a deaf student's knowledge of sign language affects the ability to decode written words, and how the student's knowledge of sign language affects the ability to comprehend written text. We have conducted a number of studies that provide clues about both these reading components.

1.2 Models of Word Decoding

Before we can answer the question of how sign language affects the ability to decode written words, we must first consider the different models of word

http://grammar.ucsd.edu/mayberrylab

decoding that researchers have proposed to explain this cognitive process. These are 1) mediated lexical access; 2) direct lexical access; and 3) connectionist models of lexical access (or weighted variables as I shall call it here). The basic idea of *mediated lexical access* is that the reader must translate, or decode, written letters into the speech sounds they represent; this decoding or translating into speech then allows the reader to recognize the meaning of the word. The alphabetic principle is a powerful tool, and learning the associations between orthographic patterns and phonological patterns allows readers to recognize words they have never seen before by "sounding them out." However, not all words in all languages can be so directly decoded, or "sounded out". Words with spelling patterns that are irregular, highly frequent, or well-known words do not require this phonological decoding. In the latter case, the visual-orthographic patterns of written words are sufficient. In direct lexical access, word meaning is recognized only on the basis of the written letters themselves. A third approach, connectionist modeling, proposes that the reader's mind uses all available resources to decode word meaning and that the ones that are used the most often are the most heavily "weighted" or important. Thus, for example, a deaf child with little hearing and imperfect speech may rely more on orthographic patterns and sentence context than phonological mediation to recognize word meaning.

1.3 Research Strategy

Reading processes develop from the elementary grades to high school, and we know from research on hearing students that reading processes do not look the same in *beginning* compared to *proficient* readers. Thus, when trying to understand the reading processes of hearing students who do not read well, researchers compare them to proficient readers. We have used this paradigm to study the reading processes of deaf readers. A subset of readers who are deaf read proficiently. It is important to understand how they read and compare them to hearing proficient readers in order to understand how they differ from less skilled, or improficient, deaf readers.

Here I share eight studies of reading and language in deaf readers, all of whom use sign language. Four studies investigate word decoding and ask how these processes differ between skilled and less skilled readers in relation to hearing readers. Another four studies investigate sign language comprehension and how it relates to reading comprehension in skilled and less skilled deaf readers.

2. DECODING

Word recognition unfolds over time and research with hearing readers of French suggests that orthographic patterns are used first followed by phonological information. This can be studied using eye tracking to measure preview benefits. How the relationship between sequentially shown words in an eye tracker, such as phonologically related words or orthographically (but not phonologically related words) can reveal which features of decoding are being used by the reader to recognize words. This study was done with adult, deaf signers of LSQ (Quebec sign language), and hearing speakers of French. First, the hearing readers showed the expected pattern: they showed greater preview effects for phonological than orthographic features. The deaf readers did *not* show phonological preview effects. Instead, deaf readers, both skilled and less skilled, showed greater orthographic preview benefit. That is, when deaf readers of French saw words that looked similar orthographically, they recognized the words more quickly. When hearing readers of French saw words that were similar in terms of spoken phonology, they read the words more quickly. These results, among many others, show that the ability to use phonological decoding during on-line word recognition does not differentiate skilled from less-skilled deaf readers.

If deaf readers do not employ phonological processes in written word recognition, can we find clues in their eye movements as to how they are recognizing written words? We investigated the eye movement behaviors of skilled and less skilled readers of English, who were all signers of ASL (American Sign Language). In fact, skilled deaf readers appear to be able to take in more visual information at a single glance. That is, they have a wider perceptual span than hearing readers. The perceptual span refers to the number of letters (and words) beyond of the word currently focused on, or the number of letters to the right of the target word. The wider perceptual span of the skilled deaf readers was not due inefficiency in visual processing. To the contrary, compared to hearing readers and the less skilled deaf readers, the skilled deaf readers looked at the target words for less time; they skipped words more; and they regressed, or re-looked at words less often than hearing and less-skilled deaf readers. These results show, while both skilled and less-skilled deaf readers rely more on orthographic than phonological processing, that skilled deaf readers are much peers.

Important to our main question is the fact that most of the skilled deaf readers reported learning sign language at an early age, whereas most of the less skilled deaf readers reported learning sign language after the age of 8 or 9. Does early sign language acquisition foster the development of efficient visual processing in deaf children?

2.1 Early Sign Language and Visual Perceptual Development

Joint attention is a hallmark of early language development. When caretakers and children converse, they simultaneously and visually attend to what they are talking about, for example a doll, spilled milk, or grandma's package. Deaf children who are talked to in sign language must achieve joint attention through only one modality – vision. How do young deaf children manage to look at the topic conversation and simultaneously comprehend the sign language conversation? To answer the question we studied four, deaf mother-child dyads and closely investigated the child's eye gaze behavior in two conditions, when watching the mother reading a book in sign language, and when playing with toys with the mother. We compared the deaf children's eye gaze behavior to four hearing, mother-child dyads during book reading, matched for age. At the tender age of two to three years, deaf children develop remarkable control of eye gaze. When watching their mothers read books to them in sign language, the three year olds seamlessly switched their gaze between their mothers' signing and the book as frequently as 20 times, per minute, or 300 msec per glance. Unsurprisingly, the hearing 3 year olds hardly looked at their mothers at all. These findings show that the young deaf child learns through sign language conversations to strategically control eye gaze for language input from the environment. Indeed, the sign vocabulary of the children was correlated with how frequently the child glanced at the mother. We could say that young deaf children become visually precocious by conversing in sign language. This strengthens their intact modality, and could relate to strong orthographic decoding skills, but this is only a hypothesis at this point in time. The next important question is whether this visual precocity shows effects in the adult deaf brain.

2.2 Early Sign Language and Brain Development

To answer the question, we measured the ratio of grey to white matter in the brains of 23 deaf signers who were first immersed in sign language at ages ranging from birth to 13. The data we used came from an fMRI study that I describe below. The outer layer of the cortex is grey matter, made up of cell bodies, and involved in higher perceptual and cognitive functions. Deaf signers who were immersed in sign language from birth, had more grey matter in the primary visual areas of the occipital cortex than hearing subjects matched for age and sex. The younger the age when the signer was immersed in sign language, the more grey matter was observed in visual cortex. Importantly, we found that deaf adults who first began to learn to sign after the age of 8 had less grey matter in visual cortex compared to hearing controls. These results suggest that early sign language exposure has positive, neuroplastic effects on the visual processing centers of the brain. The second aspect of these results is that they mean that a lack of language input in early life, that is, a lack of parent-child conversation, or adult- child communication, has negative effects on cortical development. It is surprising that these negative effects relate to visual processing.

3. LANGUAGE COMPREHENSION

Language comprehension plays a significant role in the reading ability of hearing children. In beginning reading, word decoding plays a prominent role. Children are learning the alphabet and the orthographic patterns of written language. As they become more familiar with orthographic patterns, and as their decoding becomes more automatic and effortless, language comprehension plays a more prominent role in reading ability. This is shown by the fact that hearing adolescents who have reading difficulties also have language comprehension problems. Because sign language is in a different modality and is structured differently from a grammatical standpoint, the question is whether sign language ability relates to deaf students' reading ability.

3.1 Age of Acquisition Effects on Sign Language Comprehension

Hearing children are exposed to language from birth because spoken language is ubiquitous in the environment. By contrast, deaf children are first exposed to sign language at a wide variety of ages depending upon when they first interact with other people, deaf or hearing, who use sign language with them. This complicates the question of whether sign language is related to reading ability. Age of acquisition, AoA, has robust effects on the ability to learn a second language. Often deaf students learn sign language as a *first*, not a second, language at older ages. These questions cannot be answered without finding a way to measure sign language comprehension. Grammatical judgment is widely used in second language, L2, research to measure sensitivity to syntactic structure. We designed a grammatical judgment task in ASL and administered it to adult, deaf signers who first learned to sign between the ages of birth and 13 but had used ASL for 15 years or more. The sentence structures ranged from simple to complex, that is, the structures were early to later acquired by deaf children with deaf parents. AoA showed robust effects on ASL grammatical judgment across all the sentence types. We also tested a group of L2 learners of ASL who performed nearly as well as the native learners. These results show that AoA has strong effects on the outcome of first language, L1, acquisition in sign language. How do these effects relate to reading sentences?

We asked adult, deaf signers to perform a sentence-to-picture matching task by reading English sentences. Deaf adults who learned sign language in early life performed like hearing adults who learned English as an L2, showing that they were reading English like an L2. By contrast, adult deaf signers who had little or no language until attending school after the age of 8 performed poorly. Again we asked whether early language, or a lack of it, affects brain language processing.

3.2 Age of Sign Language Acquisition Effects on Brain Language Processing

Much research has shown that the left-hemisphere language areas of the brain process sign language, just like spoken language. We wondered whether and how learning an L1 at a later age would affect language processing in the brain. We neuroimaged 23 adult, deaf signers who first learned ASL between birth and 13 years of age, and who had been using sign language for 15 years or more. Adults who learned sign language in early childhood showed neural activation in the left hemisphere language areas, as expected. However, as sign language was first learned at older ages, neural activation in these language areas decreased. We observed a second and opposite effect in visual cortex. Adult, deaf signers who first learned to sign at older ages showed a great deal of neural activation in visual cortex, rather than in left hemisphere language areas. By contrast, adult deaf signers who first learned to sign in infancy showed little activation in visual cortex, but a great deal of neural activation in left hemisphere language areas. These results suggest that when sign language comprehension is highly proficient, the language areas of the brain that process spoken language also process sign language. However, when sign language comprehension is low, most of the brain's resources are devoted to perceptual-level analysis of the visual signal.

4.SIGN LANGUAGE AND READING COMPREHENSION

Now we in a position to ask whether sign language comprehension relates to reading comprehension in adult, deaf readers, just as spoken language relates to reading in hearing readers. We recruited a random sample of adult, deaf signers who had used ASL for 15 years or more and administered a battery of reading tests along with the ASL grammatical judgment task and a sign language narrative comprehension task. First we grouped the signers by reading ability: skilled readers performed at or above the grade 8 level; less skilled readers read below the 8^{th} grade level and had a mean reading level of grade 4. Next we examined the sign language proficiency of the skilled and less skilled readers. The skilled readers showed high proficiency on the ASL grammatical judgment task; and excellent comprehension of narratives given in ASL. By contrast, the less skilled readers showed low proficiency on the ASL grammatical judgment task and low levels of ASL narrative comprehension. The correlation between reading ability and ASL skills was high, $r = .70$, similar to what is found for spoken language comprehension and reading. Thus we find that skilled readers are skilled signers and the reverse holds true as well; less skilled readers are less skilled signers. This result is consistent with the results of eight published studies in the literature on deaf readers showing a strong relation between language ability and reading ability. The phenomenon is logical: sign language comprehension relates to reading comprehension in deaf readers because reading is, at heart, a language comprehension task.

5.CONCLUSIONS

The first point of these studies is that there are proficient readers among the population of deaf signers. They are highly proficient in sign language, which they learned at a young age. They read often as children and continue to read often as adults. They give more weight to the orthographic patterns of written words than to the phonological ones, and they are highly efficient at decoding. They see more words at a glance, and decode word meaning faster than hearing readers. Their brains process sign language in the same way that hearing people's brains process spoken language. However, they have more grey matter in visual cortex than hearing people. This is consistent with the fact that they are highly efficient visual processors of signed language,, which they developed at a young age.

The second point of these studies is that how written words are decoded, phonologically or orthographically, is not the primary cause of low reading ability in the deaf population. Less skilled readers are less skilled comprehenders of sign language. In this sense they are similar to adult hearing readers who have listening comprehension problems. Less skilled deaf readers, like their more skilled peers, give more weight to the orthographic patterns of words in decoding, but they are not as efficient at it as skilled readers are. This may relate to having lower language skill overall, and to reading less frequently. When deaf individuals are less skilled in sign language, they show unique patterns of brain language processing, which tend to be more posterior in nature and less centered on the classic language areas of the brain. This finding too is consistent with the profile of having less developed sign language ability. Less skilled signers typically experienced a paucity of language, spoken or signed, during early life and this linguistic impoverishment has had lifelong, negative, and cascading effects their language abilities.

References

Bélanger, N., Baum, S, & Mayberry, R. I. (2012). Reading difficulties in adult deaf readers of French: Phonological codes not guilty. *Scientific Studies of Reading, 16*, 263-285.

Bélanger, N., Slattery, T. J., Mayberry, R. I., & Rayner, K. (in press). Skilled deaf readers have an enhanced perceptual span in reading. *Psychological Science*.

Boudreault, P. & Mayberry, R. I. (2006). Grammatical processing in ASL: Age of first- language acquisition effects in relation to syntactic structure. *Language and Cognitive Processes, 21*, 608-635.

Chamberlain, C. & Mayberry R. I. (2008). ASL syntactic and narrative comprehension in skilled and less skilled readers: Bilíngual-bimodal evidence for the linguistic basis of reading. *Applied Psycholinguistics, 29*, 367-388

Liberman, A.M., Hatrak, M., & Mayberry, R. I. (in review). Learning to look for language: Development of joint attention in young deaf children.

Lieberman, A.M., Hatrak, M., & Mayberry, R.I. (2011). The development of eye gaze control for linguistic input in deaf children. In N. Danis, K. Mesh, & H. Sung (Eds.), *Proceedings of the 35th Boston University Conference on Language Development*, pp. 210-221. Sommerville, MA: Cascadilla Press.

Mayberry, R. I. (2010). Early language acquisition and adult language ability: What sign language reveals about the critical period for language. In M. Marschark & P. Spencer (Eds.), *Oxford Handbook of Deaf Studies, Language and Education, Vol 2.,* pp. 281-291. New York: Oxford

Mayberry, R.I., Chen, J.-K., Witcher, P., Klein, D. (2011). Age of acquisition effects on the functional organization of language in the adult brain. *Brain and Language 119*, 16-29.

Mayberry, R. I., del Giudice, A. A., & Lieberman, A. M. (2011). Reading achievement in relation to phonological coding and awareness in deaf readers: A meta-analysis. *Journal of Deaf Studies and Deaf Education, 16*, 164-188.

Mayberry, R.I. & Lock, E. (2003). Age constraints on first versus second language acquisition: Evidence for linguistic plasticity and epigenesis. *Brain and Language, 87*, 369-383.

Pénicauld, Klein, Zatorre, Chen, Witcher & Mayberry (in review). Structural brain changes linked to delayed first language acquisition in congenitally deaf individuals.