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Speech Perception of Global Acoustic Structure in Children with Speech Delay, with and Without Dyslexia

Mikayla Nicole Madsen

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

Speech Perception of Global Acoustic Structure in Children with
Speech Delay, with and Without Dyslexia

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Master of Science

Children with speech delay (SD) have underlying deficits in speech perception that may be related to reading skill. Children with SD and children with dyslexia have previously shown deficits for distinct perceptual characteristics, including segmental acoustic structure and global acoustic structure. In this study, 35 children (ages 7-9 years) with SD, SD + dyslexia, and/or typically developing were presented with a vocoded speech recognition task to investigate their perception of global acoustic speech structure. Findings revealed no differences in vocoded speech recognition between groups, regardless of SD or dyslexia status. These findings suggest that in children with SD, co-occurring dyslexia does not appear to influence speech perception of global acoustic structure. We discuss these findings in the context of previous research literature and also discuss limitations of the current study and future directions for follow-up investigations.

Keywords: speech delay, dyslexia, speech perception, vocoded speech recognition

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I would like to express my gratitude to all of the faculty and staff in the Communication Disorders master's program who have assisted me along my journey during graduate school. Likewise, I express my thanks to my cohort who supported and encouraged me in a role comparable to sisters, rather than classmates; we have laughed through the hard times and shared each other's burdens.

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DESCRIPTION OF THESIS STRUCTURE AND CONTENT

This thesis, *Speech Perception of Global Acoustic Structure in Children with Speech Sound Disorders, with and Without Dyslexia*, is written in a hybrid format. The hybrid format brings together traditional thesis requirements with journal publication formats. The preliminary pages of the thesis reflect requirements for submission to the university. The thesis report is presented as a journal article and conforms to length and style requirements for submitting research reports to education journals. Excerpts of this thesis may be used for publication with the thesis author being listed as a contributing coauthor. An annotated bibliography is included in Appendix A, parental permission form in Appendix B, child assent form in Appendix C, parent questionnaire in Appendix D, and vocoded speech stimuli sentences in Appendix E.

Introduction

Development of speech, language, and reading relies in part on intact phonological skills. Phonological skills refer to how children learn to correctly understand, organize, and produce speech sounds for both speaking and reading. Although many children acquire phonological skills adequately without difficulty, a subset of children struggle with phonology. The most common manifestations of these deficits are associated with a difficulty in acquiring age-appropriate speech production skills, difficulty learning to read, or both. In this study, we aim to better understand the distinct phonological profiles of children who struggle with speaking and reading by investigating speech perception in children with speech delay.

Speech delay (SD) is the most common communication disorder treated by speech-language pathologists, affecting up to 12% of all children (Lewis, Freebairn, & Taylor, 2000). Speech delay is developmental in nature and of an unknown origin (Shriberg, Tomblin, & McSweeny, 1999). A child is considered to have SD when their speech production skills are not commensurate with their same-age and gender matched peers (Pennington & Bishop, 2009). Speech delays can present as relatively simple, articulation-based errors such as distorting a sound; for example, a child might say something that sounds like "thoup" when he means to say "soup." In contrast, other SDs can be more severe, phonologically-based errors as in cases when children are deleting final consonants; for example, a child might say "ca" meaning "cat" and "da" meaning "dad." The severity of SD varies, but most children with SD typically have less intelligible speech as compared to their peers. Having SD not only affects a child's ability to be understood, but has also been found to increase the "risk of social, emotional and/or academic challenges relative to their peers with typical speech" (Hitchcock, Harel, & Byun, 2015, p. 1).

In addition to speech production deficits, research has shown that children with both resolved and unresolved SD have difficulties with other phonological skills, such as phonological memory and phonological awareness (Peterson, Pennington, Shriberg, & Richard, 2009). Furthermore, Peterson et al. (2009) found that poorer phonological skills, in conjunction with variables such as syntax and nonverbal IQ, were predictive of later reading difficulties. As such, children with SD and associated phonological difficulties are also at a higher risk for developing reading disorders, including dyslexia (Anthony et al., 2011; Lewis et al., 2011; Peterson et al., 2009).

Lyon, Shaywitz, and Shaywitz (2003) define dyslexia as a neurobiologically-based, specific learning disability often characterized by difficulties with word recognition and poor spelling. Word recognition involves decoding which is the ability to map speech sounds onto written letters (e.g., recognizing that the word “red” is comprised of phonemes /r/, /ɛ/, /d/, and the word is pronounced /rɛd/). Lyon and colleagues further explained that individuals with dyslexia experience decoding difficulty that is not expected given their cognitive abilities and adequate classroom instruction. Importantly, difficulties associated with dyslexia are thought to indicate a primary deficit in the phonological areas of language (Lyon et al., 2003; Snowling, 2000; Stanovich, 1988). A variety of studies have found a relationship between dyslexia and poorer phonological skills (Goswami, 2000; Lewis et al., 2000). For example, children with dyslexia have phonological representations that have been described as weak, or fuzzy (Elbro & Jensen, 2005; Goswami, 2000) and have generally poor phonological processing (Pennington & Bishop, 2009; Vellutino, Fletcher, Snowling, & Scanlon, 2004).

Although children with SD and children with dyslexia both manifest phonological deficits, the cause for why phonological deficits sometimes manifest as speech production deficits alone, and other times manifest in conjunction with dyslexia is not known. Some researchers have found that phonological skills are associated with specific chromosomal regions that give biological evidence for the overlap of speech and reading abilities; both genes related to SD and to dyslexia contain a common endophenotype associated with phonological skills (Lewis et al., 2011; Lewis et al., 2006). However, even given the genetic relationship of poor phonological skills, not all children with SD develop later reading difficulties. Lewis et al. (2011), found that approximately 18% of preschool-aged children with SD develop dyslexia or other reading impairments (Lewis et al., 2011). As phonological skills are a shared weakness among children with SD and children with dyslexia, it is important to assess which skills are problematic and the extent to which children with SD and children with SD *and* dyslexia have difficulty with various phonologically-based tasks. Doing so may help clinicians more readily identify children with SD who are most at risk for reading difficulty such as dyslexia. Many children with SD who also have reading difficulty are not identified as such until after they have failed to respond to reading instruction. Speech perception, a foundational skill that provides insight into underlying phonological organization in children, is one potential way to assess underlying phonological skills, even in young or pre-reading children, that may allow for early identification of children with SD at most risk for later reading difficulty.

Speech Perception

Speech perception involves the hearing and processing of acoustic cues (e.g., bursts, formant transitions, etc.) that make up the phonetic and/or phonological structure of language (Pickett, 1999). It is possible that if a child is having difficulties processing acoustic cues in speech, he may have difficulty forming correct phonological representations for speech sounds and thus have general difficulties with phonological skills, including reading. Speech perception tasks vary widely in what and how they measure perception. Relevant to the current study, we discuss the distinction between speech perception tasks that measure perception of fine temporal and spectral acoustic detail associated with phonetic segments, here termed *segmental acoustic structure*, and tasks that measure broader spectral and temporally longer features, here termed *global acoustic structure*. Tasks that measure segmental acoustic structure include category goodness judgment tasks, synthetic speech tokens varying along formant continuums/formant transitions, lexical and/or phonetic judgement, and minimal pair word identification and same/different discrimination for specific phoneme or syllable contrasts. On the other hand, tasks that measure sensitivity to global acoustic structure involve perception of broader and longer features of the speech signal including detection of amplitude rise time, prosodic features across syllable boundaries, rhythmic timing via amplitude modulation, beat perception, amplitude envelope recognition and vocoded speech recognition. In this study, we explore whether sensitivity to a specific test of global acoustic structure sensitivity, vocoded speech recognition, may be related to distinct patterns of phonological deficits for speaking or reading.

Speech Perception and Speech Delay

Connections between speech perception and speech production in children with SD have been of interest to both researchers and clinicians for many years. Clinically, the traditional articulation approach for treating children with SD posits the importance of ensuring children have adequate perception of phonemes they are not producing correctly before even attempting to teach a child the correct production (Van Riper & Irwin, 1959). Research investigating speech perception in children with SD has had mixed results. Several studies have shown that children with SDs often perform more poorly on a variety of speech perception tasks as compared to their typically developing peers (Hoffman, Daniloff, Bengoa, & Schuckers, 1985; Ohde & Sharf, 1988; Shuster, 1998), but this is not always the case (Dodd & McIntosh, 2008; Sommers, Cox, & West, 1972; Waldman, Singh, & Hayden, 1978). Because of the suspected relationship between speech perception and speech production in children with SD, several studies have specifically investigated children with SD and their ability to perceive the phonemes that they are misarticulating. This research has shown that children with SD often perform poorly on speech perception tasks that involve phonemes that they are unable to produce (Byun, 2012; Hoffman et al., 1985; Ohde & Sharf, 1988; Rvachew & Jamieson, 1989; Sénéchal, Ouellette, & Young, 2004; Shuster, 1998). Notably, these are tasks that measure segmental acoustic structure. Hoffman et al. (1985) had children determine whether two sounds were the same or different. The sounds were comprised of several synthetic speech tokens varying along a continuum of /r/ to /w/, manipulating the phonetic acoustic structure of the phonemes. Children who had articulation errors for /r/ responded less accurately than their peers without SD. Likewise, Shuster (1998) found that children with misarticulations of /r/ tended to judge both correct and incorrect productions of /r/ as correct in category goodness judgment tasks. Notably, they were better at determining the accuracy of other children's /r/ productions than making accurate judgments of their own correct productions. Other studies investigated a wide range of speech perception abilities (with tasks including both correctly articulated and misarticulated sounds) in groups of children with different severities of SD. They found no statistically significant correlations between the presence of SD and speech perception abilities (Dodd & McIntosh, 2008; Sommers et al., 1972; Waldman et al., 1978). Relatedly, others have reported that it appears that only a subset of children with SD have speech perception deficits (Geronikou & Rees, 2016; Rvachew & Jamieson, 1989). For instance, in a study by Geronikou and Rees (2016), hey found that out of a group of four children with similar speech errors, only two had difficulties with detecting mispronunciations in speech perception tasks. Additionally, in a word identification task, with the words “sheet” and “seat” varying on a continuum, Rvachew and Jamieson (1989) found that seven children with SD were able to reliably identify words, while the other five were not. It is important to note that these studies were comparing individual performance, rather than group performance.

Many studies of speech perception involve, on average, small samples of children which can make it difficult to draw conclusions about speech perception in children with SD. Recently, Hearnshaw, Baker, and Munro (2019) conducted a systematic meta-analysis of studies that investigated speech perception abilities in preschool and early school-age children. Sixty out of seventy-three studies included in the meta-analysis showed that young children with SDs had more difficulty with speech perception tasks than typically developing children. The speech perception tasks in these studies typically manipulated individual phonemes at both lexical (i.e., at the word level which engages linguistic levels of processing) and phonetic (i.e., at the phoneme or syllable level which engages more fine-tuned, acoustic processing) levels of processing, i.e., segmental acoustic structure. This is unsurprising given that when children with SD produce errors, errors are at the level of the phoneme. To date, only one known study of children with SD has examined speech perception for global acoustic structure characteristics of speech production (Johnson, Pennington, Lowenstein, & Nittrouer, 2011). Given the nature of errors produced by children with SD, we would predict their perceptual deficits would be related to individual phoneme characteristics, such as is available via the fine temporal structure of speech (e.g., formant transitions, formant frequency onset, etc.).

In summary, these studies showed that, on average, children with SD had reduced speech perception abilities when examining perception of segmental acoustic structure of speech, but did not provide insight into the abilities of children with SD to perceive global acoustic speech structure. Furthermore, although it appears that a number of children with SD have difficulty with speech perception, it is possible that this only affects a subgroup of children with SD. It is possible that children with SD who *do* have speech perception deficits may also have other phonological deficits, such as reading difficulty.

Speech Perception and Dyslexia

Given the phonological nature of dyslexia, speech perception has been extensively studied in children with dyslexia over the past several years. Relevant to the current study, Goswami et al. (2002) found that children with dyslexia consistently performed more poorly on speech perception tasks of global acoustic structure compared to both their age-matched and reading-level matched peers. In the study, the children completed an amplitude-modulated beat-perception task that required them to choose whether a stimulus was most similar to one of two training stimuli, one being a 15-ms stimuli with a clear beat and the other a 300-ms stimuli that got louder and quieter. Data from this task analyzed the rise-time continuum and how the children categorized the stimuli as one or the other. Children with dyslexia were less sensitive to rise-time in this task compared to both age-matched and reading-level matched peers which supported the hypothesis that Goswami et al. had which predicted that individuals with dyslexia may be less sensitive to global acoustic structure than their peers. As mentioned previously, global acoustic structure tasks focus more on the overall shape of the acoustic signal, including amplitude envelope and prosodic features over several syllables, rather than fine-grained spectral/phonetic characteristics of speech perception such as phonemic or phonetic contrasts in syllables. The stimuli in the Goswami et al. beat-detection task involved rise times which are longer in duration and considered a global acoustic characteristic of speech across syllables and phrases. By contrast, in a study of adults Rosner et al. (2003) found that “adults with developmental dyslexia were consistently less proficient than adults without dyslexia at comprehending sine-wave speech utterances” (p. 75). Sine-wave speech is characterized by temporal fine structure cues in the absence of any kind of amplitude envelope. In another line of work, Serniclaes, Sprenger-Charolles, Carré, and Demonet (2001) found that children with dyslexia performed better at discriminating within-category differences than typical peers, but more poorly at discriminating between-category differences. Serniclaes et al. hypothesized the reason for this was that children with dyslexia were attending too closely to segmental acoustic structure, resulting in sensitivity to phonetic contrasts that are irrelevant to phonemes in their native language which may cause perceptual confusion. It is possible that those with dyslexia rely heavily on segmental acoustic structure because of weaknesses for global acoustic structure perception. Thus, in summary, the specific nature of the perceptual deficit in children with dyslexia as it relates to their underlying phonological deficit appears to include deficits specific to global acoustic structure. It is possible that these findings can be applied to subgroups of children with SD who may present with specific patterns of perceptual deficit based on whether they present with a co-occurring dyslexia.

Investigating Speech Perception in Children with Speech Delay and Dyslexia

We propose the importance of studying children with SD and children with SD *and* dyslexia in the same study to jointly examine speech perception in children with varying, phonological deficit profiles. To date, only two known studies of speech perception have included these groups of children in the same study (Cabbage, Hogan, & Carrell, 2016; Johnson et al., 2011). By studying children with SD and children with SD + dyslexia, we can investigate how the presence of dyslexia alters performance on specific speech perception tasks for these children. Johnson et al. (2011) were the first to investigate children with a history of SD, dyslexia, and both a history of SD *and* dyslexia in the same study. These authors analyzed speech perception tasks in three different ways: phonemic contrasts for voice onset time (VOT) and sensitivity to spectral structure in fricative-vowel syllables, both measures of segmental acoustic structure; and vocoded sentence word recognition, a measure of global acoustic structure. Results showed that each group of children performed similarly on the VOT labeling task; children with history of SD weighted the spectra of fricative noises to a lesser degree than those without history of SD and the control group; and children with history of SD had better word recognition for the vocoded sentences than the children with dyslexia and dyslexia with history of SD, both of whom performed more poorly than the control group. It is important to note that this study was investigating children who had a history of SD, whereas the other studies discussed in this section investigate children with current SD. Cabbage et al. (2016) investigated speech perception in a word recognition task manipulating segmental acoustic structure in children with persistent SD, children with dyslexia, and children with both persistent SD *and* dyslexia as compared to typically developing controls. They found that in a sine-wave speech task, a measure of segmental acoustic structure, “there were no group differences between children with dyslexia and their typically-developing peers, but the children with persistent speech delay had more difficulty than the other two groups” (p. 1). Taken together, these studies suggest that children with SD and children with dyslexia have relative difficulty with segmental acoustic structure and global acoustic structure speech perception tasks, respectively.

Statement of the Problem

Research has shown that children with SD have a higher likelihood of developing later reading disorders (Anthony et al., 2011; Lewis et al., 2011; Lewis et al., 2000; Peterson et al.,

2009) and that there are genetic links between children with SD and reading disorders (Lewis et al., 2006). Knowing that not every child with SD will develop dyslexia gives cause to investigate which factors may be indicative of its later development, so children with higher risks of developing dyslexia can be identified and receive the necessary services that will best aid their development and academic success.

Statement of the Purpose

The purpose of this study is to investigate speech perception sensitivity of global acoustic structure (e.g., the overall shape of the speech signal) in children with SD with and without co-occurring dyslexia as compared to their typically-developing peers. To do this, we will use a vocoded speech recognition task.

Research Question

Specifically, we ask the following research question:

> Do children with SD, children with SD + dyslexia, and typically developing children differ in their perception of global acoustic speech structure as measured by vocoded speech recognition?

Method

Participants

Thirty-five children ranging in age from 7;0 to 9;11 participated in this study. This particular age range was important because it included children who have had reading instruction long enough to confirm a difficulty acquiring literacy skills consistent with dyslexia, but who also may still have residual SD. Children were invited to participate in this study via recruitment information distributed to speech-language pathologists in local schools and private speech therapy clinics. Additionally, members of the research team distributed recruitment information to the community through personal invitation and through social media. Each participant and their parents were informed about the study and procedures prior to participation and permitted to discontinue anytime if they desired. Written consent was obtained from the parents and children provided verbal and written assent to participate. Practices in this study were deemed ethical as approved by the Institutional Review Board of Brigham Young University. Because of known speech perception deficits in children with language impairment (Stark & Heinz, 1996; Sussman, 1993; Tallal, Stark, Kallman, & Mellits, 1980), all children were required to score within the average to above-average range on a standardized language assessment in order to participate in the study. Additionally, the participants needed to demonstrate typical cognitive skills as well as hearing within normal limits as demonstrated by passing a hearing screening at 20 dB HL or lower at 500, 1000, 2000, and 4000 Hz. All children were monolingual, American English speakers. The children were grouped into three groups: SD, SD + dyslexia, and age-matched typically developing peers. Although some children already had formal diagnoses, children were considered to have SD or dyslexia by their scores in various assessments administered by the research team in addition to parent report in a parent questionnaire as will be described.

Children were classified as having SD if they scored at the 16th percentile or below on a norm-referenced articulation assessment. Also, it was required that the child's parent reported concerns with the child's speech, reported teacher concerns with the child's speech, reported that the child had received services at any point for speech, and/or reported a family history of speech difficulties. Children were classified as having dyslexia if they scored at the 20th percentile or below in word reading on a standardized reading assessment. In addition, it was required that the child's parent reported concerns with the child's reading, reported teacher concerns with the child's reading, reported that the child had received services at any point for reading, and/or reported a family history of reading difficulties. We chose the 20th percentile cut-off for dyslexia because it is commonly used as a cut-point in research on school-age children with dyslexia (Badian, McAnulty, Duffy, & Als, 1990; Baron et al., 2018; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996). Children in the SD + dyslexia group needed to score below average on both tests of articulation and reading and have parent reports that also met the SD and dyslexia group requirements. Typically developing peers needed to produce zero articulation errors on a standardized test of articulation and score at or above the 40^{th} percentile on a standardized reading assessment and have no parental reports of parent/teacher concern about reading or speech and that the child had not ever received services at any point for reading or speech. See Table 1 for demographic data regarding the children's ages and scores.

Table 1

Demographic Data for Children

	TD (N = 17)	SD (N = 12)	SD + DYS (N = 7)
Age (Months)	102.47	95.17	100.14
GFTA-2 SIW Standard Score	104.47	77.91	82.86
CELF-5 Core Language Score	110.82	108.25	94.14
TOWRE-2 Index Grade Norms	103.53	104.58	73.29
NIX	112.94	114.50	108.71
Phonological Awareness Task	13.76	13.42	5.86
Original Sentence Words Correct	137.24	136.33	124.86

Note. TD: typically developing children. SD: children with speech delay. SD + DYS: children with both speech delay and dyslexia. *GFTA-2: Goldman Fristoe Test of Articulation 2nd edition* sounds-in-words (SIW) subtest. *CELF-5: Clinical Evaluation of Language Fundamentals 5th edition*. *TOWRE: Test of Word Reading Efficiency 2nd Edition*. NIX: Nonverbal Intelligence Index per the *Reynolds Intellectual Assessment Scales 2nd Edition*. Standardized test scores are normally distributed with average scores ranging between 85 to 115. The maximum score on the phonological awareness task was 20.

Assessment

Articulation. Participants completed the sounds-in-words subtest of the *Goldman-Fristoe Test of Articulation- 2 (GFTA-2,* Goldman & Fristoe, 2000) to determine articulation skills and eligibility for the SD grouping. A trained research assistant or a speech-language pathologist administered the *GFTA-2* and transcribed participant speech for each of the target words using broad transcription with the International Phonetic Alphabet. Two research assistants separately scored the tests and consensus scoring was implemented if there were discrepancies between any of the item's scores. Children were grouped as having a speech delay if they scored below the 16th percentile. Most speech production errors included those that are considered late-developing sounds, such as /r/, /s/, /θ/ which are common for children with SDs (Smit, Hand, Freilinger, Bernthal, & Bird, 1990).

Reading. To determine reading abilities the children completed the Sight Word Efficiency and Phonemic Decoding subtests of the *Test of Word Reading Efficiency 2 (TOWRE-2;* Torgesen, Wagner, & Rashotte, 2012). In the first subtest, the children had 45 seconds to read as many real words as they could from the test's given list of words. In the second subtest, the children had 45 seconds to read as many nonwords (e.g., ip, skree, felly, nifpate) as they could from the test's given list of nonwords. Trained research assistants or a speech-language pathologist administered these subtests. Two research assistants separately scored the tests and consensus scoring was implemented if there were discrepancies between any of the item's scores. Children were considered to have dyslexia if they scored less than or equal to a standard score of 88 on the composite scores of both subtests.

Non-verbal intelligence. Participants completed two subtests of the *Reynolds Intellectual Assessment Scales (RIAS;* Reynolds & Kamphaus, 2015) to confirm non-verbal cognitive ability. The subtests included “Odd-Item Out” and “What’s Missing.” In “Odd-Item Out,” the children were shown six items and they had to indicate which did not belong. In “What’s Missing,” the children were shown an image of an object or a scene that was missing a component and they had to indicate what was missing by verbally explaining or pointing. The subtests were administered by trained research assistants or a speech-language pathologist. Two research assistants separately scored the tests and consensus scoring was implemented if there were discrepancies between any of the item’s scores. Participants were required to receive a standard score of 79 or greater (> -1.5 standard deviations below the mean) on both subtests to continue with the study.

Language. Given the known relationship between language impairment and speech perception and to ensure language skills were within normal limits, children participated in the core language subtests of the *Clinical Evaluation of Language Fundamentals- 5 (CELF-5;* Wiig, Semel, & Secord, 2013) that were applicable to their age. Children who were eight and younger completed the following subtests: Word Structure, Formulated Sentences, Recalling Sentences, and Sentence Comprehension. In the Word Structure subtest, children were tasked with finishing sentences with grammatically correct forms of words. In the Formulated Sentences subtest, children were tasked with making sentences that correspond to a given picture using specified words. In the Recalling Sentences subtest, children were tasked with repeating verbally presented sentences. In the Sentence Comprehension subtest, children were tasked with pointing to pictures that corresponded to a verbally presented sentence. Children who were nine completed all of the previously listed subtests as well as Word Classes and Semantic Relationships. In the Word

Classes subtest, the test administrator listed a few words and the children were required to choose the two words that went together best. In the Semantic Relationships subtest, children were given a verbal prompt (e.g., a man is bigger than a…) and asked to choose two correct answers out of a few options. A trained research assistant or speech-language pathologist administered each subtest. Two research assistants separately scored the tests and consensus scoring was implemented if there were discrepancies between any of the item's scores. Children needed to score within 1.5 standard deviations of the mean in order to remain in the study.

Phonological awareness. Children's phonological awareness abilities were measured by the Elision subtest of *The Comprehensive Test of Phonological Processing – 2nd Edition (CTOPP-2;* Wagner, Torgesen, Rashotte, & Pearson, 2013). This task required children to delete syllables or phonemes from words to create new words. Two research assistants separately scored the tests and consensus scoring was implemented if there were discrepancies between any of the item's scores. This subtest was important because both children with SD and children with dyslexia have been found to have reduced phonological awareness abilities as compared to their typical peers (Anthony et al., 2011; Lyon et al., 2003; Peterson et al., 2009).

Stimuli

The vocoded speech task stimuli were 36, four-word sentences that were syntactically appropriate yet semantically inappropriate from Nittrouer, Lowenstein, and Packer in 2009 (e.g., Lead this coat home. Blue chairs speak well.) These were also the sentences used in the vocoded word recognition task by Johnson and colleagues (2011) in their study of children with a history of SD. Naturally-produced tokens of each sentence were recorded by an adult female speaker with a standard dialect of Midwest American English while seated in a single-walled isolated acoustic chamber. The sentences were randomized into three separate lists for recitation to eliminate order effects of reading during recording. All tokens were recorded at a sampling rate of 44.1 kHz and an amplitude resolution of 16 bits, using a desktop microphone (AKG C414B) and a Zoom H4N digital recorder. After recording was complete, audio files were digitally transferred to a personal computer and segmented into individual words using Adobe Audition. All sentences were screened for mispronunciations, peak clipping, and background noise (e.g., shuffling papers) and normalized at -.5 dB (re: 16 bits = 96 dB peak). Following this process, three independent raters judged the naturalness of each token and ranked the quality of each sentence. The token that had the majority vote for most natural was selected for inclusion in this study.

Vocoded versions of each sentence were created following the procedures outlined by Nittrouer et al. (2009). We used a combination of MatLab and a custom-designed program (ESN, Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995) to create the stimuli. We created both four-channel and eight-channel vocoded stimuli. All signals were first low-pass filtered with an upper cut-off frequency of 8000Hz. Table 2 presents the band-pass filters created for both the 4-channel and 8-channel stimuli.

Table 2

Band-Pass Filters for Vocoded Sentence Stimuli

Band	4-channel	8-channel
Band 1	0-800 Hz	0-400 Hz
Band 2	800-1600 Hz	400-800 Hz
Band 3	1600-3200 Hz	800-1200 Hz
Band 4	3200-8000 Hz	1200-1800 Hz
Band 5		1800- 2400 Hz
Band 6		2400-3000 Hz
Band 7		3000-4500 Hz
Band 8		4500-8000 Hz

After each signal was band-passed for each set of stimuli, each filtered band was independently processed with an envelope-shaped noise (ESN) program that was patterned after methods reported by Shannon et al. (1995). This program modulates white noise by the amplitude envelope of a speech signal with the effect of retaining the sentence's amplitude information but removing all detailed frequency, or spectral, information. This results in the preservation of global acoustic structure while removing fine-grained segmental detail. The envelope-shaped noise from each channel was then filtered again using the same band-pass filter settings as was used during the first filtering process. The envelope-shaped bands were then combined back together to create the final stimuli. In essence, this has the effect of preserving between-band frequency information while eliminating all within-band frequency. See Figures 1-3 for spectrograms representative of natural speech, 4-channel, and 8-channel stimuli.

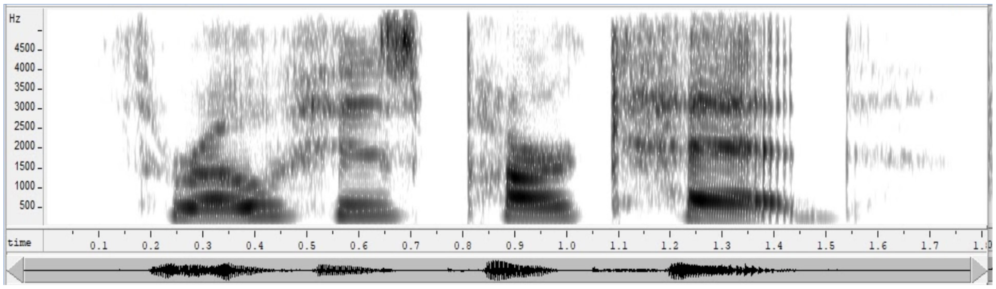

Figure 1. Natural speech spectrogram.

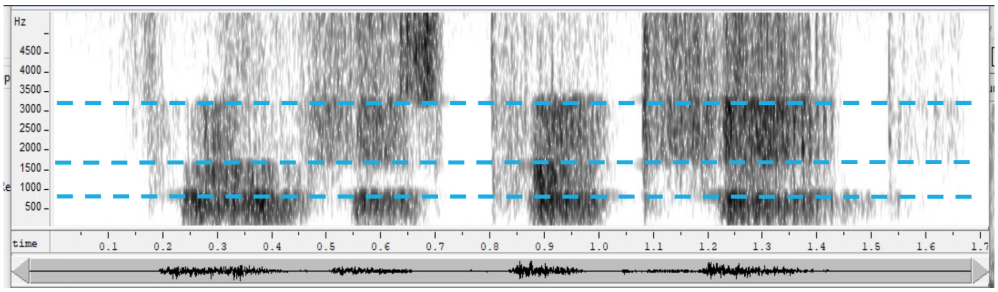

Figure 2. 4-channel vocoded speech spectrogram. Hashed lines indicate boundary frequencies between each band.

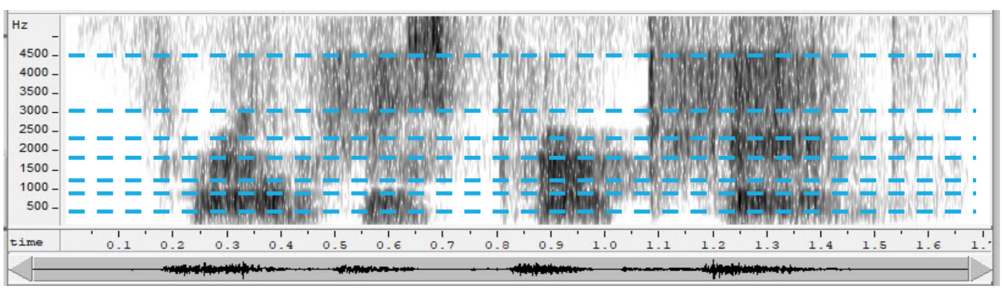

Figure 3. 8-channel vocoded speech spectrogram. Hashed lines indicate boundary frequencies between each band.

Procedures

Two research sessions were conducted for each child. During the first session, the children were administered the previously described assessments to determine eligibility and grouping. The children also participated in a hearing screening. If eligible, the children participated in a second session which included additional descriptive measures such as the phonological awareness screen, a second hearing screening if more than two weeks had transpired since the first session, and the vocoded speech perception tasks. Additional speech perception tasks were also administered during the second session, but this study will focus solely on the vocoded speech tasks. The testing took place in a child friendly room and the vocoded speech tasks were administered via a computer program on a desktop computer equipped with a Creative SB1700 sound card. The children used closed-ear circumaural headphones (Sennheiser 280 Pro) at a comfortable listening level. The vocoded speech recognition tasks required the children to listen to 4-channel vocoded speech and 8-channel vocoded speech. Fictional characters with picture icons were associated with each type of vocoded speech- Michael the mummy (4-channel vocoded), and Teddy the bear (8-channel vocoded). The stimuli were 36 syntactically appropriate, semantically inappropriate 4-word sentences as used in previous studies (Johnson et al., 2011; Nittrouer et al., 2009).

At the start of the vocoded speech tasks, children were given a training item. In the training item, the children heard a sentence with natural speech and the same sentence in vocoded speech. They were given the chance to repeat what they heard and the administrator also told them the correct words in the sentence. The training items were not scored. After the training item was complete, the children were told that it was their job to interpret what the character (either Teddy or Michael) said by verbally repeating what they heard. The children listened to a sentence, repeated what they heard, listened to the same sentence again, and again repeated what they heard. That is to say, the child had two trials of each sentence before moving on to the next sentence. Thus, each sentence was presented twice in each type of vocoded speech, resulting in a total of 288 possible words. The children's responses were typed into a document on a laptop computer in real-time by either a trained research assistant or certified speech-language pathologist. All responses were also recorded via a lapel microphone connected to a Zoom H4N digital recorder for off-line analysis to verify real-time transcription. Two trained research assistants separately listened to the recordings and graded each child's responses for correctness. Consensus scoring was used to ensure interrater reliability—if there was a discrepancy between an item's score, the scorers came together to agree on one correct score. If an agreement could not be made between the two scorers, a certified speech-language pathologist decided the final score for the item in question.

Research Design

This research was not experimental in nature, but a between-groups design comparing group differences in speech perception performance between children with SD, children with SD+dyslexia, and typically developing peers (TD).

Data Analysis

To analyze the data, we conducted a repeated measures ANOVA to determine group differences in speech perception of vocoded speech with group as the between-subjects factor (TD, SD, SD+dyslexia) and type of vocoded speech as the within-subjects factor (4-channel vocoded speech vs 8-channel vocoded speech).

Results

Figure 1 displays the mean number of words (out of 288 words) correctly repeated by each group for both the 4-channel and 8-channel vocoded speech perception tasks. A one-way ANOVA of the data showed no significant group effect, $F(2,33) = 1.667$, $p = .204$, partial $\eta^2 = .092$. Additionally, the data displayed that all groups of children performed better on the 4-channel task than the 8-channel task. A two-way ANOVA with condition as the within-groups factor and group as the between-group factor showed significant effects of condition, $F(1,33) =$

95.923, $p < .001$, partial $\eta^2 = .744$., demonstrating that all children performed better on the 8-channel sentences as compared to the 4-channel task. The effect of group, however, was not significant $F(2,33) = 1.667$, $p = .204$, partial $\eta^2 = .092$; nor was the condition X group interaction significant, $F(2,33) = 0.497$, $p = 0.613$, partial $\eta^2 = .029$. Thus, children had more difficulty recognizing words in the 4-channel condition as compared to the 8-channel condition, but this did not vary by group assignment. See Figure 4 for a graphical display of the data and Table 3 for mean performance across all groups.

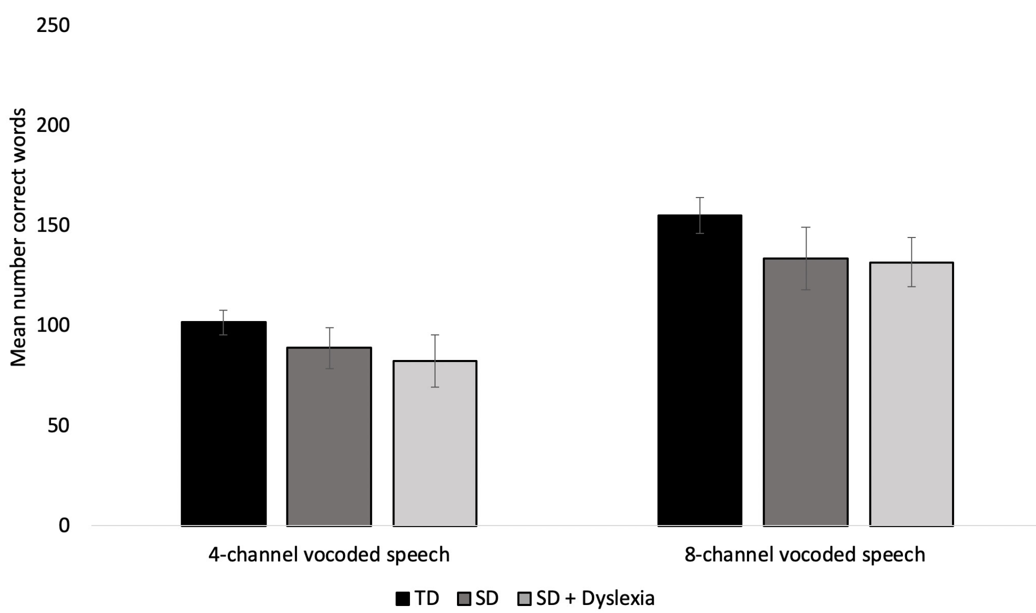

Figure 4. Mean number of words correctly repeated out of 288 possible by all groups. Error bars represent standard error of the mean. TD: typically developing children. SD: children with speech delay. SD + Dyslexia: children with both speech delay and dyslexia.

Table 3

Mean Correct Words for Vocoded Sentence Stimuli for All Groups

Condition means	TD	SD	SD + dyslexia
4-channel vocoded speech	101.71 (25.31)	88.92 (35.29)	82.29 (35.11)
8-channel vocoded speech	155.29 (36.89)	133.50 (51.66)	131.71 (32.05)

Note. Standard deviations are noted within parentheses. TD: typically developing children. SD: children with speech delay. SD + dyslexia: children with both speech delay and dyslexia.

To equalize sample sizes we conducted a planned post hoc analysis, combining both SD groups. First, combining these groups enabled an investigation of performance on vocoded speech recognition in children with SD, regardless of the presence of dyslexia, which would be only the second-known investigation of global acoustic structure sensitivity in children with SD. Second, the equalization of sample sizes in the TD *(n=17)* and SD *(n=19)* groups may serve to increase power for the overall ANOVA group comparison. Even so, similar to the analysis with three groups, the ANOVA showed no significant group effect, $F(1,34) = 3.428$, $p = .073$, partial $\eta^2 = .092$. Although no significant group effect was found, there was still a significant effect of condition, $F(1,34) = 115.270$, $p < .001$, partial $\eta^2 = .772$ demonstrating that both groups of children repeated more words for the 8-channel sentences than the 4-channel sentences, just as the analysis with three groups. The condition X group interaction was not significant, $F(1,34) = 0.784$, $p = 0.382$, partial $\eta^2 = .023$ suggesting that pattern of performance did not differ between the TD and combined SD groups. See Figure 5 for a graphical display of the data and Table 4 for mean performance across both groups.

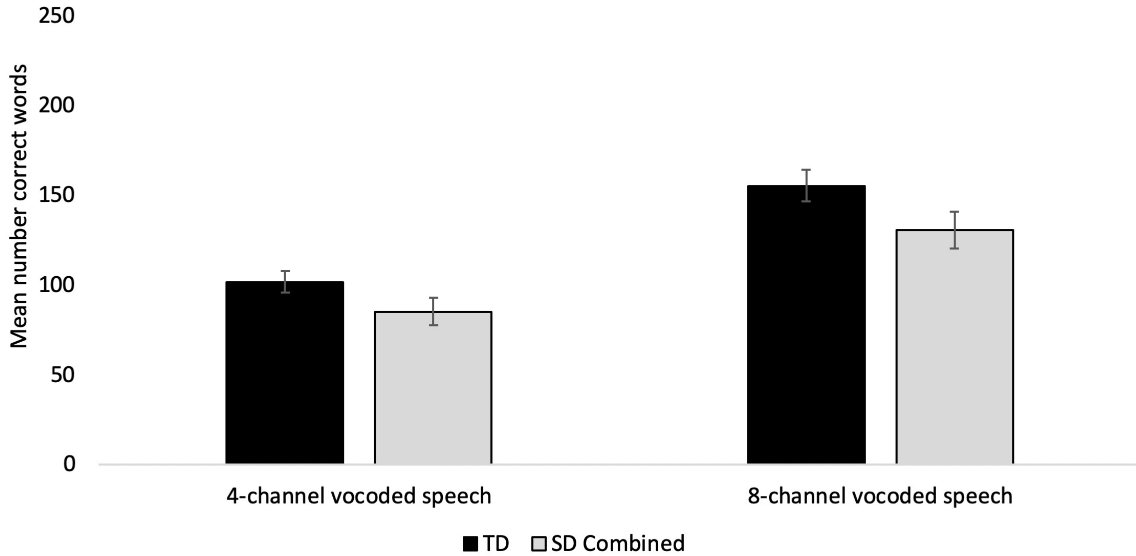

Figure 5. Mean number of words correctly repeated out of 288 possible by two groups. Error bars represent standard error of the mean. TD: typically developing children. SD Combined: children with speech delay and children with both speech delay and dyslexia.

Table 4

Mean Correct Words for Vocoded Sentence Stimuli for Two Groups

Condition means	TD	SD + dyslexia
4-channel vocoded speech	101.71 (25.31)	88.92 (34.31)
8-channel vocoded speech	155.29 (36.89)	133.50 (44.43)

Note. Standard deviations are noted within parentheses. TD: typically developing children. SD: children with speech delay. SD + dyslexia: children with both speech delay and dyslexia.

Discussion

This study aimed to compare speech perception abilities of global acoustic structure in the form of vocoded speech recognition tasks between TD children, children with SD, and children with SD+dyslexia. Furthermore, this study aimed to add to evidence that children with SD+dyslexia may be differentially sensitive to acoustically modified speech with preserved global acoustic structure. Ultimately, this study intended to help inform practices and methods of early detection of children with SD who may be at most risk for developing dyslexia.

Across both the two-group and three-group analyses, whether or not a child was typically developing, had SD, or had SD+dyslexia, there were no significant differences in their success for correctly repeating what they heard in either 4-channel or 8-channel vocoded speech. Although, the group effect approached significance for TD compared to the combined SD group, our relatively small sample sizes may have resulted in reduced power to detect group differences in the study. Data collection is ongoing and future analyses will confirm whether the current finding holds or if, with more subjects, group differences are detected. This result was unexpected and contrary to our hypothesis that children with SD+dyslexia would perform significantly poorer on a speech perception task investigating sensitivity to vocoded speech recognition compared to their TD peers and peers with SD alone. Notably, we only had seven children with both SD and dyslexia included in this study which may have been too few children to adequately investigate this hypothesis.

Although the findings of this study do not demonstrate group differences, we note a partial replication of previous research using a very similar task with slightly older children with and without a *history* of SD investigating perception of speech stimuli which preserved global acoustic structure in the form of vocoded speech (Johnson et al., 2011). Results in that study found that TD children performed better than children with a history of SD, dyslexia, and both SD+dyslexia, but only differences between TD children and the children with dyslexia and SD+dyslexia were significantly different. In the current study, we showed a very similar pattern of results, but the results did not reach statistical significance. There are a variety of factors that may have contributed to our nonsignificant findings relative to these previous findings. First, our study had a much smaller sample size, with a total of 35 children participating, rather than 66. With our original groups containing seventeen, twelve, and seven subjects, the power of the study was very likely reduced and ultimately diminished the ability to detect differences. Additionally, we attempted to equalize sample sizes by combining the SD and SD + dyslexia groups, but doing so may have masked hypothesized differences we would expect to see in children with co-occurring dyslexia. Furthermore, we originally planned on including a group with subjects who had only dyslexia, but our sample size was too small to include in the present analysis *(n = 5)*; thus, we were left with three groups—TD, SD, and SD+dyslexia. Johnson and colleagues (2011), however, included four separate groups with 16-17 subjects per group. Indeed, a power analysis using similar tasks as used in the current study revealed that a sample size of at least 18 children per group is optimal for detecting group differences on tasks like those used here. Another possible reason for differences in significance is found in how stimuli were presented to the children in the study. While we used the same 4-word sentences in both the 4-channel and 8-channel vocoded speech, the subjects in the previous study heard each sentence once, half in 4-channel and half in 8-channel speech (Johnson et al., 2011). However, in our study, to account for possible effects of vocabulary and/or differences across sentences, we chose to present each sentence in each type of speech in a counterbalanced order for each subject. This design was intended to avoid any bias due to vocabulary in specific sentences, but may have masked our effects because the children had an extra exposure to each sentence stimulus item. Lastly, the participants in the previous study were 10 to 11-year-old children which had a history of SD (Johnson et al., 2011); whereas, our study included children ages 7 to 9 with a current SD. Thus, it is possible that children with SD perform differently from children with a history of SD.

In summary, according to the results of this investigation, it does not appear that children with SD or SD+dyslexia have more difficulty perceiving global acoustic structure in vocoded speech perception tasks when compared to their typically developing peers during a vocoded speech recognition task. Furthermore, our findings cannot readily address whether children with dyslexia do or do not have difficulty perceiving global acoustic structure of speech through vocoded speech perception tasks, because of the lack of a dyslexia-only group in our analysis.

Limitations

We note several limitations in the current study. First, sample sizes were small which impacted our ability to conduct analyses sensitive enough to detect anticipated group differences. Second, our groups had unequal sample sizes which impacts the interpretation of the analysis of variance conducted to compare differences across groups. Third, our study lacked a group of children with dyslexia. A group of children with only dyslexia (without SD) is necessary to further disentangle the contribution of SD from dyslexia on perception of global acoustic structure. Fourth, this study assesses only one type of speech perception task. This limits our ability to compare group performance across multiple types of acoustically modified speech tasks in order to provide a more developed understanding of how speech perception abilities relate to SD and/or reading skill. The current study is a part of a larger study which does analyze speech perception abilities in segmental acoustic structure in addition to global acoustic structure. Analysis of how children with SD, SD+dyslexia and typically developing children perceive segmental acoustic structure is currently planned.

Implications for Future Research

In future research, it will be important to include a group of children with dyslexia only to better isolate the role of dyslexia in speech perception with children with and without SD. Additionally, future research should aim to look at a younger population of pre-reading children at known risk for dyslexia and/or follow children longitudinally in order to see whether or not this type of speech perception task has predictive power to determine later reading difficulty. In this study we examined a single task that manipulated global acoustic structure, vocoded speech recognition. Future work should explore other forms of global acoustic structure in speech.

Implications for Practitioners

Although we do not expect speech-language pathologists to administer vocoded speech recognition tasks in their practice, this work has clinical implications for how speech-language pathologists might carefully consider children on their caseloads with and without SD or dyslexia. From the findings of the current study, it does not appear that children with SD, regardless of dyslexia status, differ in how they perceive global acoustic structure. It is possible, however, that more sensitive speech perception tasks may provide clinically relevant tools for assessment or intervention. Future research is necessary to determine whether this is the case.

Conclusion

In conclusion, we found that whether or not children were typically developing, had SD, or had SD + dyslexia did not affect their ability to perceive speech that retained only global acoustic structure, as in a vocoded speech recognition task. Although there was a downward trend in performance between groups, with typically developing children performing the most accurately, children with SD following, and children with SD + dyslexia performing the most poorly, the differences were not statistically significant. However, since sample size of participants was relatively small, continued research with additional participants may indicate different results.

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APPENDIX A

Annotated Bibliography

Anthony, J. L., Aghara, R.G., Dunkelberger, M. J., Anthony, T. I., Williams, J. M., & Zhang, Z. (2011). What factors place children with speech sound disorders at risk for reading problems? *American Journal of Speech-Language Pathology, 20*, 146-160. doi: 10.1044/1058-0360(2011/10-0053)

This was a study describing research conducted with preschool-age children with SSDs, with normal speech matched on receptive vocabulary, and with typical speech and language. The children were tested in various aspects of phonological processing tasks. The group of children with SSD performed more poorly in several of the tasks compared to their same aged peers with similar language abilities. These children had lower scores on phonological awareness, speech perception, and speech production tasks and were poorer readers. This suggests that children's SSDs are likely related to their weaknesses with phonological representations. This article supports the ideas from previous studies, but went further by matching participants on age, ethnicity, and language levels. This article also cited several articles that show that children with SSDs are at a higher risk of reading difficulty. Knowing this helps us understand that SLPs should work on phonological awareness with children with SSDs because it will affect their future reading literacy abilities. This supports the reasoning behind our study--we want to identify which children will have a higher risk of reading disorders, so we can better treat them in therapy to minimize effects on literacy.

Cabbage, K. L., Hogan, T. P., & Carrell, T. D. (2016). Speech perception differences in children with dyslexia and persistent speech delay. *Speech Communication*, *82*, 14-25. doi: 10.1016/j.specom.2016.05.002

This study considered two research questions. The first question relates to our current study--whether children with dyslexia and children with persistent speech delay differed in their word recognition for sine-wave speech and amplitude-comodulated sine-wave speech. Thirty-six children from ages 7;6 to 9;6 participated in the study. Stimuli consisted of 12 pairs of rhyming consonant-vowel-consonant and/or consonant-vowel words. This portion of the study was repeated in our current study to compare the differences in speech perception abilities in children with SD v. children with SD + dyslexia when it comes to sine-wave speech, amplitude modulated sine-wave speech, and, unique to our study, vocoded speech. Like the organization of our current study, the first research session involved administration of standardized assessments and the second involved the speech perception tasks. The study showed that children with persistent speech delay had more difficulty than the other two groups. Specifically, the children with SD had difficulty recognizing words with limited acoustic structure when the stimuli involved a phoneme that they misarticulated in their own speech. The study also showed that children with dyslexia had more difficulty than their typical peers in recognizing words in sine-wave speech and had greater improvements in word recognition when amplitude modulation was added to the stimuli.

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This article researched 19 adolescents with dyslexia and 19 younger normal readers in 2nd grade matched on single word decoding. The individuals participated in reading non-words, phonemic awareness tasks, and acquisition of new phonological representations of pseudo-names for pictures. Those with dyslexia did more poorly than their reading level matched peers on all tasks which supports the hypothesis that dyslexia is associated with poorly specified phonological representations.

Goswami, U. (2000). Phonological representations, reading development and dyslexia: Towards a cross-linguistic theoretical framework. *Dyslexia, 6*, 133-151. doi: AID-DYS160>3.0.CO;2-A

This article is not an experimental study, but integrates previous research findings related to phonological development, reading development, and dyslexia. They studied this development and studied reading and reading difficulties across multiple languages. Goswami suggests that a model of the phonological representations' change over time provides a cognitive framework that helps explain many of the challenges that children with dyslexia have. Goswami explains the development of phonological representations as beginning in a more whole-word, holistic way and undergoing a restructuring that allows comprehension of increasingly segmented units (e.g., breaking words into phonemes). According to Goswami, children with dyslexia may have difficulty with that restructuring. Reading is said to help that restructuring develop. Goswami supports the research that we have reviewed that suggest children with dyslexia have phonological processing difficulties and that difficulties with phonological representations affect both speech perception and decoding.

Goswami, U., Thomson, J., Richardson, U., Stainthorp, R., Hughes, D., Rosen, S., & Scott, S. K. (2002). Amplitude envelope onsets and developmental dyslexia: A new hypothesis. *Proceedings of the National Academy of Sciences, 99*, 10911-10916. https://doi.org/10.1073/pnas.122368599

One hundred and one children participated in this study-- 24 with dyslexia, 25 age matched peers, 24 reading level matched peers, 14 precocious readers and 14 non-early readers from a previous longitudinal study. This study aimed to look at the effect of suprasegmental speech perception abilities (global acoustic structure) in children with dyslexia compared to their typical and advanced peers. Specifically, the suprasegmental quality of rhythmic timing which is determined by acoustic structure of amplitude was addressed. Through these auditory processing tasks with amplitude modulation (i.e., amplitude envelopes), the children with dyslexia performed much poorer than their typical and advanced peers. This suggests a relationship between dyslexia and poor global acoustic perception abilities that likely contribute to their phonological deficits. This supports the idea in our current study because we also hypothesize that children with dyslexia will have a harder time perceiving vocoded speech than their typical peers and also peers with SD, as those with SD struggle with more spectral acoustic properties rather than global ones.

Goswami, U. (2011). A temporal sampling framework for developmental dyslexia. *Trends in Cognitive Sciences, 15*, 3-10. https://doi.org/10.1016/j.jml.2019.03.008

Goswami presents a theory that helps give some explanation for various deficits that people with dyslexia have. His theory of the temporal sampling framework (TSF) revolves around the phonological model and integrates issues in the processing the rate of change of amplitude (rise time). Goswami discusses how people with dyslexia have impaired perception of syllabic and prosodic features of speech, not just subsyllabic properties like phonemes and onset-rimes. He gives neurological reasons that support some of these noticed behaviors. <u>If our hypothesis is correct, our study will further support this notion because syllabic and prosodic features of speech that Goswami reported children with dyslexia have difficulties perceiving are in the global acoustic structure that will be altered in the vocoded speech that we will use as stimuli.</u>

Hearnshaw, S., Baker, E., & Munro, N. (2019). Speech perception skills of children with speech sound disorders: A systematic review and meta-analysis. *Journal of Speech, Language, and Hearing Research*, *62*(10), 3771-3789.

Two reviews of articles about speech perception and its relationship to SSDs have been published previously; however, they were not systematic. This systematic meta-analysis was conducted to investigate whether preschool and early school-age children with Speech Sound Disorders (SSD) have difficulties with speech perception or not. Sixty out of seventy-three studies indicated that children with SSDs had more difficulty with speech perception tasks, of lexical and/or phonetic nature, than typically developing children. This analysis included studies with populations that had mean ages between 3;0-7;11 with SSDs. 60 out of 73 studies reported that some or all children with SSDs had speech perception difficulties. The most common used speech perception tasks were lexical and/or phonetic judgement, minimal pair word identification, and same/different discrimination of minimal pair words and most studies including these methods suggested that children with SSDs had more difficulty with speech perception. There are many lines of reasoning as to why this finding might be so. Some of the ideas include: impaired speech leads to impaired speech production; speech perception predicts articulation ability; difficulties with speech perception may be causal or contributing factor of a phonological disorder; impaired speech production affects speech perception; speech perception of children with articulation errors relates to those errors and not to a global difficulty with perception; perception and production have a bidirectional relationship; and speech perception and production are independent factors. Although, most agreed that speech perception affects speech productions. <u>This relates to our current study because it relates to the relationship between children's SSDs and their speech perception abilities; although the studies included were not focusing on global spectral structure qualities.</u>

Johnson, E. P., Pennington, B. F., Lowenstein, J. H., & Nittrouer, S. (2011). Sensitivity to structure in the speech signal by children with speech sound disorder and reading disability. *Journal of Communication Disorders, 44*, 294-314. doi: 10.1016/j.jcomdis.2011.01.001

This study investigated the perceptual abilities of children ages 10 to 11 with Speech Sound Disorders (SSD), Reading Disorders (RD), and both SSD and RD. The children's sensitivity to Voice Onset Times (VOT), Spectral structure in fricative-vowel syllables, and Vocoded sentences were examined. The VOT and Spectral structure analyses addressed the children's abilities in phoneme representations, while the Vocoded sentences addressed the children's abilities in perceiving a more global acoustic structure. Each group of children performed similarly on the VOT labeling task; children with SSD weighted the spectra of fricative noises to a lesser degree than those without SSD and the control group; and children with SSD better integrated the vocoded sentences than the children with RD and RD with SSD (but performed more poorly than the control group). A significant implication of these findings is that children with RD are less sensitive to global acoustic structure when trying to identify linguistic forms. As most studies have revolved around more spectral, phoneme based processes, this study supports the current aims to further analyze children's abilities in retrieving linguistic forms from speech stimuli composed of global structures rather than spectral structures. Additionally, this study used vocoded speech with both 4-channel and 8-channel stimuli. Our study also used vocoded sentences comprised of 4-channel and 8-channel stimuli. Furthermore, our study also supports the same idea that children's language and reading development depends on more than phoneme representations alone, but that global structure properties are also aiding in language development.

Lewis, B. A., Avrich, A. A., Freebairn, L. A., Hansen, A. J., Sucheston, L. E., Kuo, I., … Stein, C. M. (2011). Literacy outcomes of children with early childhood speech sound disorders: Impact of endophenotypes. *Journal of Speech, Language, and Hearing Research, 54*, 1628–1643. doi: 10.1044/1092-4388(2011/10-0124)

Endophenotypes can be help identify genetic components to behavioral phenotypes. SSD genes may affect the endophenotypes of oral motor skills, PA, phonological memory, processing speed, and vocabulary. PA is a endophenotype for RD and SSD and is "associated with early SSD and later reading decoding, spelling, and written expression skills." Certain regions on specific chromosomes are linked to both reading, spelling, written expression, oral motor skills, articulation, phonological memory, and vocabulary. This is showing a genetic basis for the relationship between reading disorders and SSDs which our study aims to further investigate.

Lewis, B. A., Freebairn, L. A., & Taylor, H. G. (2000). Academic outcomes in children with histories of speech sound disorders. *Journal of Communication Disorders, 33*, 11-30. doi: 10.1016/S0021-9924(99)00023-4

Some preschool-aged children with speech and language disorders go on to develop difficulties in school with reading and spelling. This study aimed to identify which factors in preschoolers with SSDs would predict later language, reading, and spelling abilities. The study included 52 children that were tested at preschool ages and later at school-ages. Factors that the study found to be indicative of later school-age language, reading, and spelling skills were scores on the GFTA, Nonsense Word Repetition Test, and the TOLD-P:2. Additionally, the percent of nuclear family members affected by speech and/or language or reading disorders also helped in these predictions. Preschool deficiencies in syntax, semantics, phonology and phonological encoding were associated with later reading impairment. This relates to our current study because it also suggests that children with SSDs are at a higher risk for reading difficulties and aimed to better understand risk factors which may be associated with later reading difficulties; it revolves around the same population that our current study is researching (children with SSDs and reading disorders.)

Lewis, B. A., Shriberg, L. D., Freebairn, L. A., Hansen, A. J., Stein, C. M., Gerry, T.H., & Iyengar, S. K. (2006). The genetic bases of speech sound disorders: Evidence from spoken and written language. *Journal of Speech, Language, and Hearing Research, 49*, 1294-1312. doi: 10.1044/1092-4388(2006/093)

Research is showing that specific gene portions and mutations of genes are associated with both SSDs and language disorders. Twin studies have shown that SSDs have some genetic component because monozygotic twins (boys) had higher concordance of SSD; MZ twins also had higher concordance of LI than dygozotic. Some studies suggest RD and SSD both result from problems with phonological representations. Therefore, if the general gene that is associated with phonological representations is affected, both reading and SSD may be altered. Essentially, genetic examination shows an overlap between LI and SSD. Furthermore, there is an association between children with SSD and their developing reading disorders in the future. Genetic overlap exists between SSD and RD, specifically chromosome 3 has traits that both SSD and RD share. This relates to our current study because we are finding that a common trait among children with SSD and SSD + RD is difficulty with speech perception. Additionally, we are finding how we can differentiate between each group's specific difficulties within speech perception.

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). Defining dyslexia, comorbidity, teachers' knowledge of language and reading: A definition of dyslexia. *Annals of Dyslexia, 53,* 1-14. doi: 10.1007/s11881-003-0001-9

This article defines dyslexia as a specific learning disability with roots in neurobiology. Dyslexia often entails difficulties with word recognition, poor spelling, and poor decoding skills. They explain that dyslexia has a deficit in phonological areas of language. According to the authors, dyslexia is a language-based disorder. Secondary to dyslexia, a child may have difficulties in reading comprehension and lack in reading experience which further impact basic knowledge and lexicon. The authors specify that the reading difficulties need to be attributable to actual difficulties and not just a lack of exposure to reading, etc. These basic definitions of dyslexia and its attributes are important to understand when we talk about dyslexia in our study.

Nittrouer, S., Lowenstein, J. H., & Packer, R. R. (2009). Children discover the spectral skeletons in their native language before the amplitude envelopes. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 1245-1253. doi: 10.1037/a0015020

This study investigated and compared the speech perception abilities of 7-year-old children who speak English, native English-speaking adults, and adults whose native language is Mandarin, but speak English as a second language. The study aimed to compare speech recognition abilities of Sine Wave (SW) speech and Amplitude Envelope (AE) speech in order to understand how these forms influenced speech perceptions and its development. The main purpose of the study was to find out whether or not children recovered linguistic forms from the SW speech or AEs as well as adults. The stimuli sentences were four monosyllabic words that were syntactically appropriate, but semantically incorrect. Both 4-channel and 8-channel stimuli was used for the AE speech recognition tasks. For recognizing 8-channel AE stimuli, English adults did best, then the children, and then Mandarin-speaking adults. For 4-channel AE stimuli, the children and Mandarin-speaking adults performed similarly, but worse than English-speaking adults. Overall, children and Mandarin-speaking adults performed worse on the AE tasks than the English-speaking adults which suggests that languages differ in AE and children have to discover the AE in their own language. The SW speech results suggest that global spectral structure is different between languages, so children have to discover SW structure in their language as well and by age 7 they have done that. Lastly, children did better perceiving sine wave speech than the 4-channel AE stimuli. These findings suggest that global spectral structure play an important part in language acquisition. This raises the possibility that infants may be using global spectral structures to eventually parse out individual words from longer speech signals. In our current study we are using both of the AE channels and the same sentence stimuli formatting from this study.

Pennington, B. F., & Bishop, D. V. M. (2009). Relations among speech, language, and reading disorders. *Annual Review of Psychology, 60*, 283-306. doi: 10.1146/annurev.psych.60.110707.163548

This article discusses that LI, SSD, and RD are complex disorders with a variety of components rather than one specific etiology or cognitive aspect. These disorders share some deficits and have some of their own unique deficits. Specifically, they share difficulties with phonological processing. This supports our claim that RD and SSD or SD have some common underlying deficits and also that there are differences sometimes between types of deficits. For example, we know both groups have difficulties with speech perception tasks, but we are hypothesizing that they may have differences between specific types of tasks within speech perception.

Peterson, R. L., Pennington, B. F., Shriberg, L. D., & Richard, B. (2009). What influences literacy outcome in children with speech sound disorder? *Journal of Speech, Language, and Hearing Research, 52*, 1175-1188. doi: 10.1044/1092-4388(2009/08-0024)

Participants for this study were children with SSDs and typical children at ages 5-6. Later at ages 7-9, their literacy abilities were compared with controls and national norms. This study aimed to see whether core phonological deficits alone or multiple deficits were related to the presence of

RD in children with SSDs. The study showed that children with SSDs had higher rates of reading disability. It also concluded that phonological awareness, syntax, and nonverbal IQ predicted literacy outcome more accurately than phonological awareness alone. Even children with SSD history, but with current normalized speech performed more poorly on phonological awareness tasks. This relates to our current study in that it supports the idea that there is a relationship between SSDs and reading disorders/dyslexia; our study supports that idea and is looking further into what abilities in speech perception do the children with SSD versus SSD + RD have and how they differ, so we can better identify those children with SSD who are at a higher risk of developing RD.

Rosner, B. S., Talcott, J. B., Witton, C., Hogg, J. D., Richardson, A. J., Hansen, P. C., et al. (2003). The perception of ''sine-wave speech'' by adults with developmental dyslexia. *Journal of Speech, Language, and Hearing Research, 46*, 68–79. doi: 10.1044/1092-4388(2003/006)

Adults and children with dyslexia have been known to perform lower than control groups in speech perception tasks involving isolated syllables and words with impoverished acoustic qualities. This study wanted to understand how adults with dyslexia would perform on speech perception tasks of acoustically impoverished conversational speech tasks. They were determined to see whether semantic and syntactic cues in continuous sine-wave speech would help adults with dyslexia perform as well as controls (from Remez et al. study where adult listeners correctly transcribed 70% of the syllables after eight successive exposures to binaurally presented sine-wave sentences). Nineteen adults with dyslexia and 14 adults without dyslexia participated in the study. They were presented with sine-wave speech and after hearing it, tried to repeat it. The sentence stimuli were semantically and syntactically appropriate and retrieved from the Haskins Laboratories as .WAV files. The sentences ranged in length (examples included five to seven words with varying syllables per word). Results showed that "adults with developmental dyslexia were consistently less proficient than adults without dyslexia at comprehending sine-wave speech utterances." However, there was overlap of abilities between the groups. Both groups found that words without stops and fricatives were easier to repeat than words with stops or fricatives. This study is relevant to our current study because it examines individuals who have dyslexia and their abilities with speech perception using acoustically impoverished sentences. However, this study used sine wave speech instead of auditory envelopes and used semantically appropriate sentences of varying lengths unlike our semantically inappropriate sentences of constant length.

Serniclaes, W., Sprenger-Charolles, L., Carré, R., & Demonet, J. F. (2001). Perceptual discrimination of speech sounds in developmental dyslexia. *Journal of Speech, Language, and Hearing Research, 44*, 384-399. doi: 10.1044/1092-4388(2001/032)

This study aimed to analyze the relationship between categorical perception and dyslexia and the nature of the deficit in categorization whether it was specific to speech or not. This study's participants were 13-year olds who were native French speakers; the participants included 19 children with dyslexia (i.e., children were two years below their chronological age in reading) and a control group of 14 average readers. Stimuli were sinewave analogues (i.e., stop then /a/ syllables that varied along a continuum for place of articulation.) There were three conditions that the sinewave stimuli were presented. 1) They were presented as electronic whistles and after completion the participants were asked if they perceived them as speech sounds. 2) The same stimuli were presented as speech-like sounds. 3) Modulated sinewave stimuli were presented as speech-like sounds. These were referred to as sinewave-acoustic, sinewave-speech, and modulated-speech, respectively. The participants were separated into two groups and each group was presented the stimuli in different orders. They were to discriminate the sounds as the same or different. Results indicated that children with dyslexia "were better at discriminating acoustic differences between stimuli belonging to the same phoneme category than were average readers." Because children with dyslexia did better than average readers at discriminating sounds that differed along a place of articulation continuum, it can be concluded that they do not have problems in processing brief auditory transitions. This goes against the idea of "temporal processing deficits." However, they have difficulty using those phonetic cues for the categorization of speech. Overall, the children with dyslexia were less categorical than average readers with perception of speech and nonspeech sounds; they had reduced discrimination of between-category differences and enhanced discrimination of within-category differences (deficit in categorical perception). This study relates to the overall idea that our study aims to study further--the relationships b/t dyslexia and speech discrimination abilities.

Shriberg, L. D., Tomblin J. B., & McSweeny, J. L. (1999). Prevalence of speech delay in 6-year-old children and comorbidity with language impairment. *Journal of Speech, Language, and Hearing Research, 42*, 1461-1481. doi: 10.1044/jslhr.4206.1461

A sample 1,328 monolingual English speaking 6-year-old children participated in an articulation assessment and 303 of them also participated in a conversational speech sample. Prevalence of SD for this sample was 3.8%, with higher rates for boys than girls and comorbidity of SLI and SD was 1.3%. At 6-years-old about 11-15% of children with SD had SLI and about 5-8% of children with SLI had SD. This article helps give statistics to show the approximate prevalence of SD in children. This is relevant to our study because knowing the percentage of children with SD reminds us that a percentage of those children will be at higher risk of developing reading disorders later on.

Wagner, R. K., Torgesen, J. K., Rashotte, C. A. (1994). Longitudinal studies of phonological processing and reading. *Journal of Learning Disabilities, 27*, 276-286.

This is a longitudinal study that began with 288 kindergarten students from 6 different elementary schools. Assessments tested phonological abilities (i.e, serial naming, isolated naming, synthesis, analysis, and memory), reading and pre-reading skills, and general verbal skills. Tasks were administered again to these children at the start of first and second grade (ending up with 244 children in the sample.) The study showed that growth rates in each phonological variable were different from each other and fairly stable during early reading instruction; this suggests that the child's abilities are a "cognitive endowment" rather than a true reflection of their knowledge and skills-- they are thought of more as human abilities like intellectual abilities assess on measures of general intelligence. Analytic phonological awareness and rapid serial naming showed as the two strongest predictors of later reading ability. Each phonological variable had different statistical significance influencing first grade reading abilities. Evidence points to poor readers continuing to be be poor readers in later grades. This article supports the idea that phonological processing abilities are correlated to later reading abilities and that a child's abilities in pre-reading stages can be indicative of later reading abilities or difficulties. This helps support the idea that early-identification is necessary and that children with poor phonological processing skills are at risk of developing dyslexia.

APPENDIX B

Parental Permission Form

Parental Permission for a Minor

Introduction

My name is Katy Cabbage. I am a professor from Brigham Young University. I am conducting a research study about how children process speech sounds for speaking and reading. I am inviting your child to take part in the research because (he/she) is in the 2nd or 3rd grades.

Procedures

This is a study about how children process speech sounds for speaking and reading. To participate your child must be a native English speaker. The study will take place at the BYU John Taylor Building in Room 103 at a time convenient for you and your child. The study involves two sessions of activities.

During the *first session*, your child will complete a series of speech, language, and reading tasks that are commonly administered by speech-language pathologists. This session will take about 45-60 minutes.

During the *second session*, your child will complete several listening tasks that involve listening to different types of speech sounds and words. You child will respond by either reporting what they heard or selecting a response on a computer screen, depending on the task. This session will take about 60-90 minutes.

During both sessions, your child will be allowed to take breaks as often as necessary.

It is possible that your child will only be asked to participate in the first session, depending on the needs of the study.

Risks

There is minimal risk associated with this study. It is possible that during participation, your child may become bored with the tasks. We will provide your child with breaks as often as is necessary. You or your child may stop participation at any time.

There is a risk of loss of privacy, which the researcher will reduce by not using any real names or other identifiers in the written report. The researcher will also keep all data in a locked file cabinet in a secure location. Only research staff will have access to the data.

Confidentiality

The research data will be kept in a secure location on password protected and encrypted computers accessible only to research staff. All forms will be stored in a locked filing cabinet accessible only to research staff. All identifying information will be removed. The data will be indefinitely archived on secure password protected computers and accessible only to research staff.

Benefits

There are no direct benefits for your child's participation in this project. You will be provided a summary report of your child's speech, language, and reading skills. Please note that these results will be used for research purposes only. The results will not indicate whether your child does or does not have difficulties that will impact his/her academic experience. If you have concerns regarding your child's skills, you should contact your child's classroom teacher, special education coordinator, or a school administrator at your child's school. We have also attached a list of local providers if you prefer to contact someone outside of your child's school.

Compensation

Your child will be provided small incentives (e.g., stickers, small prizes) throughout the duration of the study to maintain motivation. Your child will receive a $5 gift card at the end of each research session.

Questions about the Research

Please direct any further questions about the study to Katy Cabbage at (801) 422-0507 or kcabbage@byu.edu.

Questions about your child's rights as a study participant or to submit comment or complaints about the study should be directed to the IRB Administrator, Brigham Young University, A-285 ASB, Provo, UT 84602. Call (801) 422-1461 or send emails to irb@byu.edu.

You have been given a copy of this consent form to keep.

Participation

Participation in this research study is voluntary. You are free to decline to have your child participate in this research study. You may withdraw your child's participation at any point without affecting you or your child's relationship with his/her school or Brigham Young University.

I have read, understand, and received a copy of the above consent and of my own free will allow my child to participate in the study.

Child's Name:

Parent Name:_____________ Signature:_________________Date:________

________ Initial here to allow us to keep your information in a secure database to contact you for future studies.

As noted above, we will be audio and video recording your child during participation in this study. Please indicate what uses of this audio and/or video you are willing to permit, by initialing next to the uses you agree to and signing below. This choice is completely up to you. We will only use the audio/video in the ways that you agree to. In any use of the audio/video, you (or your child) will not be identified by name.

______**Audio** and/or_____**Video** samples can be studied by the research team for use in the research project.

______**Audio** and/or_____**Video** samples can be shown at scientific conferences or meetings.

______**Audio** and/or_____**Video** samples can be shown for training in university classes.

I have read the above descriptions and give my express written consent for the use of the videotapes as indicated by my initials above.

Name (Printed):____________________Signature________________________Date:________

APPENDIX C

Child Assent Form

Child Assent (7-14 years old)

What is this research about?

My name is Katy Cabbage. I work at Brigham Young University. I want to tell you about a research study I am doing. A research study is a special way to find the answers to questions. We are trying to learn more about how children think about speech sounds for speaking and reading. You are being asked to join the study because you are in 2^{nd} or 3^{rd} grade.

If you decide you want to be in this study, this is what will happen.
There are two parts to this study. In the first part of the study, you will be asked to do four different activities where we will talk about pictures and stories and you will also do some reading tasks. In the second part of the study, you will listen to silly sounds and silly speech in a computer game and tell me about what you hear. I will explain everything to you when we do it so you will know what to do. At any time, you will also be able to ask questions about anything we are doing.

We will audio and video record the activities we do. It will take us about an hour on two different days for you to participate in this study.

Can anything bad happen to me?

Sometimes the activities might seem boring. If you need to take a break, just tell me and we will take a break.

Can anything good happen to me?

We don't know if being in this study will help you. But you will help us learn about how children think about speech sounds for speaking and reading.

Do I have other choices?

You can choose not to be in this study.

Will anyone know I am in the study?

We won't tell anyone you took part in this study. When we are done with the study, we will write a report about what we learned. We won't use your name in the report.

What happens if I get hurt?

Your parents/legal guardians have been given information on what to do if you get hurt during this study.

What if I do not want to do this?

You don't have to be in this study. It's up to you. If you say yes now, but change your mind later, that's okay too. All you have to do is tell us.

You will get to pick a sticker or small prize after each activity we do. After each session, you will get to choose a $5 gift card for being in this research study. Before you say yes to be in this study, be sure to ask Dr. Cabbage to tell you more about anything that you don't understand. She can also be reached at 161 TLRB at BYU in Provo, UT 84602, (801)422-0507, kcabbage@byu.edu.

If you want to be in this study, please sign and print your name.

Name (Printed):____Signature____Date:_______

APPENDIX D

Parent Questionnaire

Child History Information

CHILD ID:
Child's Name: ____
Birth Date: ____________________ **Gender :** ______________
Mother's Name: ____________________ **Occupation:** ______________
Mother's Highest Level of Education: ______________________________
Father's Name: ____________________ **Occupation:** ______________
Father's Highest Level of Education: ______________________________
Address: ____
____
City: ____________________ **State:** __________ **Zip:** __________
Home Phone: ________________ **Other Phone:** ______________
E-mail: ____
Ages of Siblings: ____

Child's Race	**Mother's Race**	**Father's Race**
☐ American Indian or Alaska Native Native	American Indian or Alaska Native	American Indian or Alaska
☐ Asian	Asian	Asian
☐ African-American or Black	African-American or Black	African-American or Black
☐ Native Hawaiian or Other Pacific Islander	Native Hawaiian or Other Pacific Islander	Native Hawaiian or Other Pacific Islander
☐ Caucasian (White)	Caucasian (White)	Caucasian (White)

Child's Ethnicity	**Mother's Ethnicity**	**Father's Ethnicity**
☐ Hispanic or Latino	Hispanic or Latino	Hispanic or Latino
☐ Not Hispanic or Latino	Not Hispanic or Latino	Not Hispanic or Latino

Child's Elementary School Name: ______________________________
Child's Grade: ____
Child's Teacher: ____
Child's Lunch Status: *Please circle one (optional)*
Regular Reduced Free

How often do you and your child engage in book reading activities? *Please circle one.*
Once/month 2-3 times/month Once/week 2-6 days/week Everyday

Please describe an average book reading activity (e.g. how many books are read; how much time is spent reading; what time of day; how engaged is your child during this activity?)

____
____
____
____

<u>Perinatal History</u>

Weeks of Gestation:
Method of delivery (i.e. Caesarian, forceps, vacuum, other):

Anything notable during delivery? YES/NO
If yes, please describe below:

Medical History (known allergies, known diagnoses, hospitalizations, etc.):

<u>Other Information</u>

When started: (age in months)
First Babble:

Breast feeding: from ____________________ to ______________________
Bottle feeding: from____________________to_______________________
Child Care:
Part-time:
Full-time:

Please answer the following questions.

1. Do you have any concerns about your child's development? YES NO
   If yes, please describe your concerns below:

2. Does your child have a parent or sibling with a reading disability? YES NO
   If yes, please list the parent or sibling and describe the reading disability:

3. Is English the primary language spoken by the child? YES NO
   If no, what is the primary language spoken by the child?

4. Is English the primary language spoken in your home? YES NO
   If no, what is the primary language spoken in your home?

5. Does your child have normal vision (with or without glasses)? YES NO
   If no, please describe visual problems below:

6. Does your child have normal hearing? YES NO
   If no, please describe hearing problems below:

7. Do you feel your child is generally coordinated? Does she or he cut with scissors, jump, and run like other children? YES NO

   If no, please describe coordination problems below:

8. Does your child have any physical or medical problems that might contribute to speech or language development? YES NO

   If yes, please describe below:

9. Is your child currently receiving special education services or instruction?

   YES NO

   Who is providing these services?

10. Has your child ever been enrolled in speech therapy?

    YES NO

    At about what age did speech therapy begin? Is he/she still enrolled in therapy?

    Where did your child receive speech therapy services? (school, clinic, both, etc.)

APPENDIX E

Vocoded Speech Stimuli Sentences

1. Lead this coat home.
2. Blue chairs speak well.
3. Cooks run in brooms.
4. Paint your belt warm.
5. Small lunch wipes sand.
6. Cups kill fat leaves.
7. Dumb shoes will sing.
8. Find girls these clouds.
9. Cats get bad ground.
10. Slow dice buy long.
11. Late forks hit low.
12. Throw his park head.
13. Fan spells large toy.
14. Let their flood hear.
15. Knees talk with mice.
16. Soft rocks taste red.
17. Ducks teach sore camps.
18. Trucks drop sweetdust.
19. Jobs get thick hay.
20. Thin books look soft.
21. Teeth sleep on doors.

22. Cars jump from fish.
23. Soap takes on dogs.
24. Drive my throat late.
25. Suits burn fair trail.
26. Pink chalk bakes phones.
27. Socks pack out ropes.
28. Sad cars want chills.
29. Feet catch bright thieves.
30. Lend them less sleep.
31. Gangs load near sweat.
32. Green hands don’t sink.
33. Wide pens swim high.
34. Hard checks think tall.
35. Late fruit spins lakes.
36. Great shelf needs tape.