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Investigating Speech Perception in Children With Speech Delay, Dyslexia, and Speech Delay and Dyslexia

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ABSTRACT

Investigating Speech Perception in Children With Speech Delay, Dyslexia,
and Speech Delay and Dyslexia

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Perceptual deficits related to phonology in children with speech delay (SD) and children with dyslexia have been identified in separate lines of research. However, there has only been a small number of studies that have investigated the perceptual deficits of children with SD and/or dyslexia in the same study to better understand the overlap of their speech perception abilities. Children with SD have previously shown deficits perceiving speech stimuli that is acoustically sparse, particularly when stimuli contain speech sounds they do not produce correctly. Yet in contrast to children with dyslexia, children with SD are better able to recover linguistic structure from speech stimuli that preserves global acoustic structure in the absence of spectral detail. Therefore, the purpose of this study is to further investigate how children with SD, dyslexia, SD + dyslexia, and typically developing (TD) peers perceive different types of speech. To do this, we used both vocoded speech and sine-wave speech recognition tasks. In this study, 40 children (ages 7-10 years) with SD, dyslexia, SD + dyslexia, and/or typically developing were presented with both sine-wave and vocoded speech recognition tasks to investigate their speech perception.

Findings revealed no differences between groups for both the sine-wave and vocoded speech perception tasks, regardless of SD and/or dyslexia status. Increasing the number of participants or utilizing more sensitive speech perception tasks may provide clinically applicable resources for assessment or intervention. 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, sine-wave speech recognition, vocoded speech recognition

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DESCRIPTION OF THESIS STRUCTURE AND CONTENT

This thesis, *Investigating Speech Perception in Children With Speech Delay, Dyslexia, and Speech Delay + 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 sine-wave speech stimuli words and vocoded speech stimuli sentences in Appendix E.

Introduction

A report published by the American Speech-Language-Hearing Association (ASHA) in 2020 noted that 88.9% of pediatric speech-language pathologists (SLPs) serve children with speech delay (SD). In a variety of studies, researchers have found that children who present with SD early in their life are at an increased risk for experiencing academic difficulties, including reading disability (Farquharson, 2019; Felsenfeld et al., 1994; Hayiou-Thomas et al., 2016; Lewis et al., 2011; Peterson et al., 2009). A profound SD can lead to a reading disability (Peterson et al., 2009), including dyslexia. Children with dyslexia and children with SD may experience deficits in phonological processing or phonemic awareness (Catts et al., 2005; Pennington & Bishop, 2009; Snowling, 2001), but it is unclear the degree to which these deficits are shared among these populations. Thus, the purpose of the present study is to better understand the phonological processing deficit experienced by children with SD, dyslexia, and SD + dyslexia.

Speech Delay

According to Hayiou-Thomas et al. (2016), a speech delay (SD) is defined as a "persistent difficulty with speech sound production that interferes with speech intelligibility or prevents verbal communication that cannot be explained in terms of sensory problems, motoric difficulties or other physical conditions" (p. 197). A child who presents with SD can range in the severity of their specific errors when compared to another child who also has SD. For example, a child who presents with an articulation-based SD may experience difficulty producing one or more phonemes accurately during speech (i.e., "wain" for "rain"). This type of SD is considered to be a mild form of SD when compared to a child who presents with a phonologically-based SD which includes difficulty with the categorization of classes of phonemes during the production of speech. For example, a child may present with a phonological pattern referred to as stopping, which is characterized by the substitution of fricatives with stops; thus, a child might say “dipper” meaning “zipper” or “tum” meaning “thumb.” While children with SD vary in the complexity of their articulation disorders, many respond well to intervention and acquire speech sounds on par with their typically developing peers. For some children with SD, however, speech errors may persist into their school-age years, increasing risk for adverse effects such as of social, emotional, and/or academic challenges (Haiyou et al., 2016; Hitchcock et al., 2015).

Persistent SD was described by Hitchcock et al. (2015) as speech sound errors extending past the ages of eight years of age. The prevalence of children who are eight years old with a persistent SD is estimated at 3.6% (Wren et al., 2016). These individuals usually undergo years of intervention, and yet are unable to make sufficient gains to be discharged from receiving services. Similarly, Hayiou-Thomas et al. (2016) found that children with SD were more likely to experience literacy deficits if speech errors persisted into the primary grades after reading instruction had begun.

Dyslexia

The International Dyslexia Association defines dyslexia as “a specific learning disability that is neurobiological in origin [and is] characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities” (2018). The way that dyslexia is defined is “contested” (Snowling, 2001), which directly affects the way that it is diagnosed. As a result, its prevalence falls within a range of 5% to 20% of the population (Wagner et al., 2020). Children with dyslexia experience particular difficulty mapping sounds onto words, resulting in difficulties with spelling and decoding. This results in academic difficulties, especially in the school-age years when their learning becomes partially dependent on their reading abilities.

According to Snowling (2001), "phonological processing is the core deficit in dyslexia" (p. 11). This extends to deficits in phonemic awareness as well as problems in phonological memory (Catts et al., 2005). Phonological deficits, as well as having a family history of dyslexia, increase the risk for literacy difficulties (Hayiou-Thomas et al., 2016).

Speech Delay and Dyslexia

Speech delay and dyslexia share a broad underlying deficit in that individuals with either or both disorders experience difficulty with some form of phonological processing, but the degree to which these deficits overlap is unclear. Lewis et al. (2011), investigated common genetic influences in reading disorder (RD) or dyslexia and SD. Findings revealed that early SD and later RD may share the endophenotype of phonological processing which is useful in understanding its effect on early SD and later school-age spelling, spoken language, reading, and written expression abilities (Lewis et al., 2011). Similarly, Pennington and Bishop (2009) attempted to better understand language impairment (LI), RD, and SD at three levels of analysis including diagnosis, cognition, and etiology of which phonological processing emerged as the common deficit between all the disorders. In a study that examined deficits in children with SD and co-occurring family history of dyslexia, results showed impairments on measures of phoneme awareness, reading, and spelling when compared to typically developing peers (Hayiou-Thomas et al., 2016). The consistent findings from the literature suggest a common phonological deficit in children with SD and dyslexia, and yet for some children this deficit manifests as a reading impairment and for others as speech production errors. We propose the utility of examining skills that serve as precursors to phonological processing, such as speech perception, to determine whether unique profiles of deficit exist for these different populations of children.

Speech Perception

Speech perception is one of the most basic levels of phonological processing and involves the hearing and processing of speech sounds. It is unique in that it does not require the ability to read or speak and thus, allows researchers to uncover phonological processing abilities in a wide array of individuals, including young children. For decades, researchers have sought to better understand speech perception and its variability across differing listeners. Children develop speech perception abilities early in their life. Initially, children are able to reliably distinguish speech sounds of their native language by 8-10 months of age (Kuhl, 2004). Over time, this speech perception ability continues to refine into adolescence.

Speech Perception and Speech Delay

Researchers past and present have sought to determine whether there is a link between speech perception and disordered articulation and phonology (Lof & Synan, 1997; Menn & Matthie, 1992). Lof and Synan (1997) conducted a systematic review of the literature to investigate the relationship between speech discrimination and speech-sound production errors through analyzing assessment and treatment research from as early as 1931. Mixed results suggested that some children have perceptual difficulties while others do not, likely due to inconsistent testing and subject variables across studies (Lof & Synan, 1997). For example, subjects of the studies varied in age, individual sounds in error, and the severity of errored sounds. In addition, several studies did not specifically assess perception of sounds that were specific to a child's articulation error. As a result of these methodological differences, it was difficult to determine whether there was a true relationship between speech perception and disordered articulation and phonology. Locke (1980) argued a need for consistency across studies to validate measures of speech perception and for these measures to be clinically useful.

Specifically, he encouraged the utilization of perception testing that is relevant to the subject such as assessing only the articulation error sounds. In addition to this, Lof and Synan (1997) recommended an increase in control over subject variable characteristics (i.e., age, specific speech-sound errors, and severity of involvement) in future studies. In summary, although investigators have sought to better understand possible links between speech perception and SD, there is a need for replicable research across studies.

Researchers have sought to identify whether there is a valid speech perception assessment for children with SD. The software system known as the Speech Assessment and Interactive Learning System (SAILS) has been shown to reliably assess and treat preschool and kindergarten-aged children (Rvachew et al., 2004). SAILS presents children with a series of mispronunciation detection tasks wherein they decide via a button press whether an auditorily presented word is produced accurately or not. Given that SAILS has been found effective for young children, Preston et al. (2015) investigated whether SAILS is a clinically viable approach to assess and treat school-aged children with persistent SD. Two cohorts of school-aged children (ages 9;0 to 14;5 [years; months]), those with persistent SD and a control group of age-matched typically developing peers, participated. Results revealed that typically developing children and older children with persistent SD performed equivalently in SAILS. Preston et al. (2015) hypothesized this tool was not sensitive enough for older listeners, further highlighting the need to validate tools and tasks that can adequately assess speech perception in children with persistent SD.

Ongoing research has continued to aim to understand perceptual abilities of school-age children with SD. In a systematic search conducted by Hearnshaw et al. (2019), 73 studies concerning SD and speech perception published between 1931 and 2017 were analyzed. Sixty of the 73 studies that were analyzed reported that some or all children with SDs had difficulties with speech perception. This systematic review revealed that the three most commonly used perception category tasks that identified a majority of children with SDs who have difficulties with speech perception included lexical and/or phonetic judgment tasks, minimal pair word identification, and tasks that required the discrimination of same/different of minimal pair words. Findings from eight decades of research suggest not only a common trend of individuals with SD presenting with difficulty with speech delay, but also potentially reliable assessments for identifying perceptual abilities.

Speech Perception and Dyslexia

Research has shown that individuals with dyslexia also often exhibit deficits in speech perception (Gu & Bi, 2020; Manis et al., 1997; Noordenbos & Serniclaes, 2015; Serniclaes et al., 2004). Dating back to 1997, researchers have uncovered a noted deficit in children with dyslexia, particularly in discriminating between similar sounding phonemes (Manis et al., 1997), even if their speech production skills were intact. This is in contrast to children with SD who typically have particular speech perception deficits for speech sounds they produce in error (Cabbage & Hitchcock, 2022). Perceptual abilities in children with dyslexia have further been explored, leading to theories attempting to explain possible reasons for the perceptual deficit. For example, researchers have posited that children with dyslexia appear to have an *increased* sensitivity to phonemic distinctions that are irrelevant to the language of their environment (Serniclaes et al., 2004) which may contribute to phonological confusion when mapping phonemes onto graphemes during word reading.

Perception of manipulated speech, including amplitude modulation (AM) and sine-wave (SW) speech stimuli, provides insight into the phonological deficits experienced by individuals with dyslexia. Research has shown that children with dyslexia have particular deficits for processing suprasegmental or global acoustic structure, such as onset, rimes, and syllables in words. For example, Goswami et al. (2002) conducted a study to better understand syllable processing in children with dyslexia. Specifically, Goswami et al. (2002) queried whether children with dyslexia were less sensitive to variations/beat detection in AM signals than normally-reading control children. Results indicated that detection of beats in the AM signal were poorer in children with dyslexia when compared to their control peers. Results also showed that children with advanced literacy skills showed adequate detection of AM beats. This finding confirmed the researcher’s speculation that poor AM detection in children with dyslexia is related to their processing deficits at the syllable level. This study further confirms the hypothesis that children with dyslexia process auditory stimuli differently than typical child readers. Similar results concerning speech processing in individuals with dyslexia were identified in Rosner et al. (2003), which focused on SW speech stimuli. In the study, 19 adults with a previous diagnosis of dyslexia and 14 adults without dyslexia were presented with nine sine-wave utterances that included semantic and syntactic cues. Compared to the comprehension of the adults without dyslexia on the SW tasks, adults with dyslexia consistently performed less proficiently on comprehending the SW speech utterances even though the stimuli had normal syntax and semantics. Although different in the stimuli utilized in the aforementioned studies, results from both suggest a speech processing deficit in individuals with dyslexia.

Cabbage et al. (2016) compared the performance of children with dyslexia processing amplitude comodulated sine-wave (AMSW) speech stimuli and SW speech stimuli. All children who participated in this study performed better on the word recognition task involving AMSW speech than the SW stimuli. When unmodulated SW speech was presented, children with dyslexia struggled more to perceive the stimuli. However, when the stimuli were amplitude-comodulated, children with dyslexia performed at the same level as the typically developing children. This suggested that amplitude-comodulation resulted in greater gains in perception for children with dyslexia.

Nittrouer and Lowenstein (2013) also investigated perceptual deficits in children with dyslexia. In their study, 70 children, 41 with dyslexia and 29 typically developing listened to 72 sentences used in previous research (Nittrouer & Lowenstein, 2010). Children heard two types of degraded signals which included four-channel vocoded and SW signals. For both manipulated sentence stimuli, the children with dyslexia, including those participants who did not present with phonological deficits, presented with poorer recognition scores than children without dyslexia. Group differences were larger for the vocoded signals. The older children with dyslexia performed better on the SW sentence stimuli than the younger children with dyslexia. This suggested that while children with dyslexia experience difficulty organizing linguistic sensory input, they learn to do so for SW signals before they are able to for other types of signal structure. Because the participants with dyslexia in this study performed poorer on the vocoded stimuli, the authors of this study speculated that the difficulties that children with dyslexia experience have more to do with their ability to *organize* sensory input on a global level rather than being *sensitive* to acoustic input.

Dyslexia + Speech Delay and Speech Perception

There has only been a small group of studies that have investigated the perceptual deficits of children with SD and/or dyslexia in the same study to better understand the overlap of their speech perception abilities. Comparing the perceptual abilities of children with SD and/or dyslexia provides more insight into the nature of the phonological deficit in both groups.

Cabbage et al. (2016) investigated the speech perception abilities of children between the ages of 7-9 years using SW speech. These children were classified into groups including dyslexia, SD, and typically developing. Each of the children participated in a word recognition task where they listened to two types of impoverished speech which included SW speech and AMSW speech. Stimuli included single-syllable rhyming words that began with either /r/ or /m/. The syllable structure for all words was consonant-vowel (CV) or consonant-vowel-consonant (CVC). To create the stimuli, the investigators determined the center frequencies of the first four formants through visual inspection. Values for each of the formant frequencies were entered into a digital sine-wave generator and the resulting impoverished signal contained only the most basic of acoustic information for each word. To create the AMSW speech, all the SW speech tokens were co-modulated at 80 Hz using a custom-designed modulating software (see Cabbage et al., 2016 for additional details). All children who participated in this study performed better on the word recognition task involving AMSW speech than the SW stimuli. When unmodulated SW speech was presented, children with dyslexia performed more poorly as compared to the other groups of children. However, when the stimuli were amplitude-comodulated, children with dyslexia performed at the same level as the typically developing children. This suggested that amplitude-comodulation resulted in greater gains in perception for children with dyslexia. Children with persistent SD showed no substantial improvements in perception from SW speech to AMSW speech when compared to the performance of peers without SD for the /r/ phoneme but performed equivalent to their TD peers on the /m/ phoneme. This suggested that children with persistent SD have difficulty perceiving words containing their errored sound regardless of the way the stimuli were manipulated whereas children with dyslexia showed a more generalized deficit.

Johnson et al. (2011) investigated the speech perception abilities of a group of children between the ages 10-11 years old using vocoded speech, a form of speech that eliminates spectral detail by averaging frequencies in pre-determined bands or channels. Seventeen of the children had a history of a SD, 16 had a reading disability (RD), 17 had SD + RD, and the other remaining 16 children had typical speech and reading skills. Each child listened to 30 vocoded sentences in a random order where half of the sentences were presented as 8-channel vocoded signals, and half were presented as 4-channel vocoded signals. In both vocoded conditions, children in all three disorder groups (SD, RD, and SD + RD) repeated fewer words correctly when compared to children in the control group. However, children with SD proved to be able to recover linguistically relevant structure more successfully than children in the RD and SD + RD groups, but not as well as children in the control group.

Statement of the Problem

Research involving the investigation of phonological abilities in children with SD or children with dyslexia has shown that both groups experience a deficit in phonological processing (Catts et al., 2005; Farquharson, 2019; Hayiou-Thomas et al., 2016; Lewis et al., 2011; Pennington & Bishop, 2009; Peterson et al., 2009; Snowling, 2001). Previous research suggests that children with SD are more likely to have difficulty perceiving speech stimuli that is acoustically-sparse, such as SW speech, particularly when stimuli contain speech sounds they do not produce correctly (Cabbage et al., 2016). By contrast, other research has demonstrated that children with SD are better able than children with dyslexia to recover linguistic structure from speech stimuli that preserves global acoustic structure (e.g., vocoded speech) in the absence of spectral detail. To date, however, no study has directly compared the perception of these two types of stimuli in children with SD and children with dyslexia. Due to there being a narrow group of studies that have compared the perceptual deficits of children with SD and/or dyslexia (Cabbage et al., 2016; Johnson et al., 2011), there is a need for further research to replicate findings.

Statement of the Purpose

The purpose of this study is to further investigate how children with SD and/or dyslexia perceive different types of speech as compared to their typically developing peers. To do this, we used both vocoded speech and sine-wave speech recognition tasks in this study.

Research Questions

This study will address the following research questions:

1. Do children with SD, dyslexia, SD + dyslexia, and typically developing differ in their perception of sine-wave speech?

   We hypothesize that children with SD and SD + dyslexia will have difficulty perceiving speech stimuli containing sounds produced in error as compared to children with dyslexia or typical development.

2. Do children with SD, dyslexia, SD + dyslexia, and typically developing differ in their perception of vocoded speech?

   We hypothesize that children with dyslexia and SD + dyslexia will have difficulty perceiving vocoded speech as compared to children with SD or typical development.

Method

Participants

Forty children ranging in ages 7;6 to 10;11 and in grades 2-4, participated in this study. The age of the participants was significant because it included children who were old enough to have received reading instruction while also being young enough to still exhibit persistent SD.

The children who participated in this study were recruited via information sent out to local speech-language pathologists in schools and private speech therapy clinics. Recruitment information was also shared with the community through personal invitation and through social media. Each participant and their parents were informed about the study and its procedures prior to participation and were allowed to discontinue at any point if desired. Written consent was acquired from the parents, and child participants provided written as well as verbal consent 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 et al., 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. In addition, the participants needed to exhibit typical cognitive skills as well as hearing within normal limits as indicated 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 four groups: SD, dyslexia, 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 a SD if they exhibited at least one speech sound error across all positions of words, including /r/, on a norm-referenced articulation assessment. Children were classified into the dyslexia group if they scored at the 20^{th} percentile or below in word reading on a norm-referenced reading assessment. Cut-off scores for the classification of dyslexia varies widely across studies ranging from the 7^{th} percentile (Badian et al., 1990) to the

30th percentile (Manis et al., 1996), so we chose the 20th percentile in alignment with the following studies: Baron et al., 2018, Cardillo et al., 2017, and Cowan et al., 2017. Children in the SD + dyslexia group were required to meet the criteria for both the SD and dyslexia group requirements. Typically developing peers were required to produce zero articulation errors on a standardized test of articulation and score at or above the 40th percentile on a standardized reading assessment. In addition, typically developing peers were required to 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 and descriptive results regarding the children's ages and scores.

Table 1

Participant Descriptive Factors by Group

Descriptive factors	Typically Developing (n = 10)	Dyslexia (n = 10)	Speech Delay (n = 10)	Speech Delay + Dyslexia (n = 10)	*F* (max df =)
Age (in months)	102.0 ± 11.24 (84-118)	105.7 ± 11.52 (92-124)	99.0 ± 11.43 (87 – 118)	101.4 ± 8.55 (88 – 118)	.664
RIAS (Nonverbal IQ)	110.20 ± 11.42 (89-127)	115.50 ± 15.21 (92-140)	112.50 ± 12.69 (90-131)	110.00 ± 6.41 (102-119)	.467
CELF-5 (Core Language)	103.70 ± 5.40 (93-110)	101.90 ± 10.40 (76-113)	107.10 ± 9.40 (91-118)	98.00 ± 12.31 (85-123)	1.52
TOWRE INDEX (Age Norms)	107.30 ± 8.99 (93-120)	81.10 ± 9.98 (63-96)	108.40 ± 13.24 (86-124)	77.30 ± 9.98 (62-96)	24.27*
TOWRE INDEX (Grade Norms)	107.20 ± 8.79 (95-121)	80.90 ± 9.11 (68-100)	107.00 ± 11.40 (92-124)	76.50 ± 7.40 (66-90)	31.55*
GFTA-2 (Standard Score)	105.70 ± 1.89 (103-109)	102.90 ± 1.45 (101-105)	76.80 ± 20.61 (40-102)	83.20 ± 18.01 (45-106)	10.87*
CTOPP-2 (Elision)	13.60 ± 3.89 (7-18)	8.40 ± 2.63 (6-15)	12.90 ± 4.68 (7-19)	7.10 ± 3.67 (2-14)	7.28*

Note. Mean ± standard deviation displayed with range in parentheses, by group. RIAS = Reynolds Intellectual Assessment Scales (Reynolds & Kamphaus, 2015); CELF-5 = Clinical Evaluation of Language Fundamentals-Fifth Edition (Wiig et al., 2013); TOWRE-2 = Test of Word Reading Efficiency-Second Edition (Torgesen et al., 2012); GFTA-2 = Goldman-Fristoe Test of Articulation-Second Edition (Goldman & Fristoe, 2000); CTOPP-2 = Comprehensive Test of Phonological Processing–Second Edition *(CTOPP-2*; Wagner et al., 2013).

*$p < .001$.

Measures

Articulation

Each participant's articulation skills were measured using the sounds-in-words subtest of the *Goldman-Fristoe Test of Articulation-2 (GFTA-2*, Goldman & Fristoe, 2000) to determine eligibility for the SD group. A speech-language pathologist or a trained research assistant administered the *GFTA-2* and transcribed each participant's speech for each of the target words using broad transcription with the International Phonetic Alphabet. Two research assistants were required to separately score the tests and consensus scoring was implemented if there were discrepancies between any of the item's scores. Children were considered to have a SD if they produced speech sound errors and were required to have difficulty producing /r/ in all positions of words. Some children produced additional errors considered later developing such as /s/, /θ/ which are common for children with SDs (Smit et al., 1990).

Reading

Participants completed the Sight Word Efficiency and Phonemic Decoding subtests of the *Test of Word Reading Efficiency 2 (TOWRE-2*; Torgesen et al., 2012) to determine reading abilities. For the first subtest, the participants had 45 seconds to read as many real words as they could from the test's provided list of words. For the second subtest, the participants had 45 seconds to read as many nonwords (e.g., ni, bloot, strone, brinbert) as they could from the test's provided list of nonwords. A speech-language pathologist or trained research assistants administered these subtests. Two research assistants were required to separately score 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 < 20th percentile on the composite scores of both subtests.

Non-Verbal Intelligence

Each participant's non-verbal cognitive abilities were confirmed by completing two subtests of the Reynolds Intellectual Assessment Scales (RIAS; Reynolds & Kamphaus, 2015). The subtests included "Odd-Item Out" and "What's Missing." In the "Odd-Item Out" subtest, participants had to indicate which item out of six did not belong. In the "What's Missing" subtest, participants had to indicate what was missing when provided an image of an object or a scene by verbally explaining or pointing. A speech-language pathologist or a trained research assistant administered these subtests. Two research assistants were required to separately score the tests, and consensus scoring was implemented if there were discrepancies between any of the item's scores. The participants were required to receive a standard score of 79 or greater (> -1.5 standard deviations below the mean) on both subtests to remain in the study.

Language

Acknowledging the relationship between language impairment and speech perception, each participant was administered the core language subtests of the *Clinical Evaluation of Language Fundamentals- 5 (CELF-5*; Wiig et al., 2013) that aligned with their age to confirm that language skills were within normal limits. Participants who were eight and younger completed the following subtests: Word Structure, Formulated Sentences, Recalling Sentences, and Sentence Comprehension. In the Word Structure subtest, participants were prompted to finish sentences with grammatically correct forms of words. In the Formulated Sentences subtest, participants were prompted to make sentences that corresponded to a provided picture using specified words. In the Recalling Sentences subtest, participants were prompted to repeat verbally presented sentences. In the Sentence Comprehension subtest, participants were prompted to point to pictures that corresponded to a verbally presented sentence. Participants who were nine years old completed each of the previously listed subtests as well as Word Classes and Semantic Relationships. In the Word Classes subtest, participants were provided with a list of a few words by the test administrator and the participants were required to choose two words that went together best. In the Semantic Relationships subtest, participants were provided a verbal prompt (e.g., a man is bigger than a...), and out of a few options, were asked to choose two correct answers. A speech-language pathologist or a trained research assistant administered each subtest. Two research assistants were required to separately score the tests and consensus scoring was implemented if there were discrepancies between any of the item's scores. The participants were required to score within 1.5 standard deviations of the mean in order to continue with the study.

Phonological Awareness

Participants completed the Elision subtest of *The Comprehensive Test of Phonological Processing – 2nd Edition (CTOPP-2*; Wagner et al., 2013) to measure phonological awareness abilities. This subtest prompted participants to delete syllables or phonemes from words to create new words. Two research assistants were required to separately score the tests and consensus scoring was implemented if there were discrepancies between any of the item's scores. This subtest was informative because both children with SD and children with dyslexia have been identified 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

Two separate sets of stimuli were utilized for the study that included sine-wave speech and vocoded speech.

Sine-Wave Speech

The sine-wave (SW) speech and amplitude-comodulated sine-wave (AMSW) speech stimuli included 36 consonant-vowel-consonant (CVC) or consonant-vowel (CV) rhyming words that began with the initial /r/, /m/, or /w/ phonemes from Cabbage et al. in 2016 (e.g., made, raid, wade). The experimental word stimuli consisted of 12 pairs with the initial phonemes /r/ or /m/ to address hypothesized deficits for children with persistent speech delay (/r/) in contrast to a control phoneme (/m/) which was produced correctly by all children. An additional 12 words, all beginning with the phoneme /w/, were matched to and rhymed with the experimental stimuli to serve as foils. Naturally-produced tokens of each word 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 words 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 CoolEdit 2 K. All words were screened for mispronunciations, peak clipping, and background noise and normalized at -.5 dB (re: 16 bits=96 dB peak). Following this process, one of the remaining tokens of each word was randomly selected for inclusion in this study.

SW and AMSW versions of each word were created following the procedures outlined by Cabbage et al. (2016).

Vocoded Speech

The vocoded speech task stimuli included 36 four-word sentences that were syntactically appropriate yet semantically inappropriate from the study conducted by Nittrouer et al. in 2009 (e.g., Paint your belt warm. Cats get bad ground.) These sentences were also used in the vocoded word recognition task by Johnson et al. (2011) to analyze similarities and differences in phonological representations in children with a history of a SD, RD (reading disability), and SD + RD. Naturally-produced tokens of each word were recorded by an adult female speaker from the western United States with a standard dialect of 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 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 et al., 1995) to create the stimuli. We created both 4-channel and 8-channel vocoded stimuli. All signals were first low-pass filtered with an upper cut-off frequency of 8000 Hz. 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 information. See Figures 1-3 for spectrograms representative of natural speech, 4-channel, and 8-channel stimuli.

Figure 1

Natural Speech Spectrogram

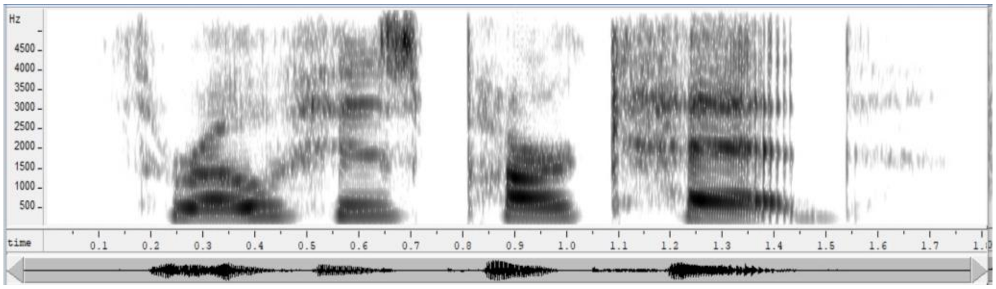
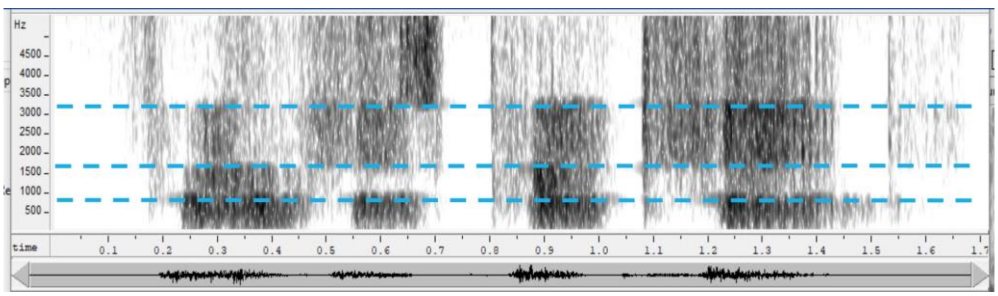


Figure 2

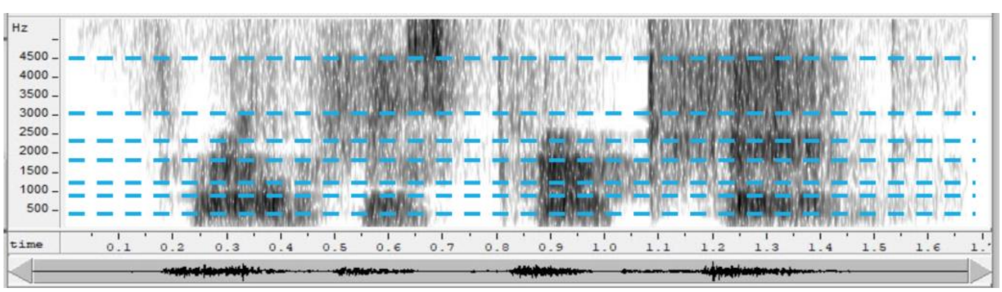
4-Channel Vocoded Speech Spectrogram



Note. Hashed lines indicate boundary frequencies between each band.

Figure 3

8-Channel Vocoded Speech Spectrogram



Note. Hashed lines indicate boundary frequencies between each band.

Procedures

Each child participated in two research sessions. During the first session, the children were administered the previously described assessments to determine eligibility and grouping.

Each of the children also participated in a hearing screening in the first session. If eligible, the children participated in a second session which included a second hearing screening if more than two weeks had transpired since the first session, and additional descriptive measures such as the phonological awareness screen and the speech perception tasks. The testing took place in a child-friendly room and the speech tasks were administered via a computer program on a computer equipped with a Creative SB1700 sound card. The children used closed-ear circumaural headphones (Sennheiser 280 Pro) at a comfortable listening level. The word-recognition tasks required the children to listen to SW speech and AMSW speech. Fictional characters with picture icons were associated with each type of speech: Mort, the alien (sine-wave); and Marty, the robot (amplitude-comodulated sine-wave). The stimuli were 36 consonant-vowel-consonant (CVC) or consonant-vowel (CV) rhyming words that began with the initial /r/, /m/, or /w/ phonemes as used in a previous study (Cabbage et al., 2016).

At the start of the word-recognition tasks, children were given a training item. In the training item, the children heard a word with natural speech and the same word in sine-wave speech. They were given the chance to repeat what they heard, and the administrator also told them the correct word. The training item was not scored. After the training item was complete, the children were told that it was their job to interpret what the character (either Mort or Marty) said by verbally repeating what they heard. Because some children had difficulty producing speech sounds, children also pointed to the first letter of their chosen word on a provided letter strip secured to the table to eliminate ambiguity about the child's intended response. The letter strip contained 12 letters including the target letters, i.e., r, m, w and nine additional letters: b, s, n, p, g, d, l, f, c, and a "not here" option for any alternate letters the child might have wanted to select. The children listened to a word three times, repeated what they heard, and pointed to the first letter of their chosen word. This meant that each child had three exposures of each word before moving on to the next word. The children's responses were transcribed 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.

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 item was 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. This meant that each 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 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.

Data Analysis

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

Results

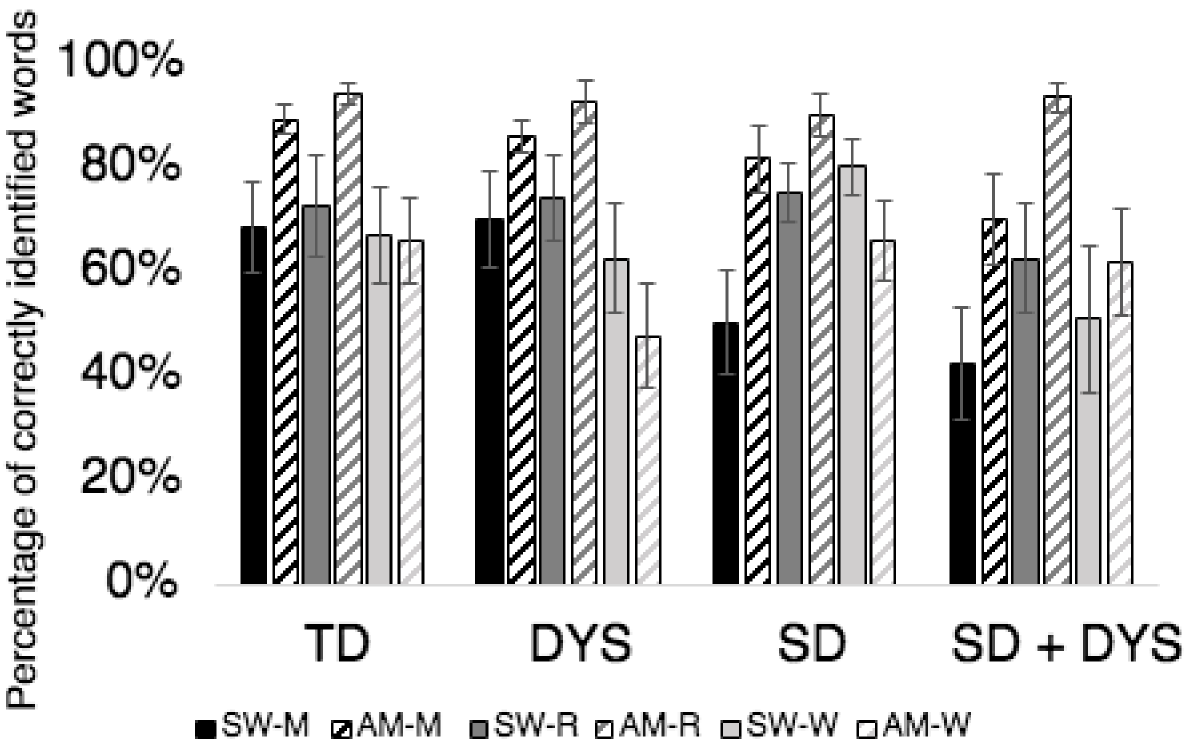
Sine-Wave Speech

In this study, we compared perception across two different speech conditions (SW speech and vocoded speech). Within the sine-wave speech condition, we assessed perception of words that began with /r/, /w/, and /m/. We analyzed the data using a 2 (modulation: sine-wave speech, amplitude-comodulated sine-wave speech) x 2 (phoneme: /r/, /m/, /w/) x 4 (group: dyslexia, SD, dyslexia + SD, typically developing) mixed factorial design repeated-measures ANOVA. Results showed no significant group effect $F(3, 36) = 0.606$, $p = 0.615$ $\eta^2 = 0.048$. Additionally, results revealed a main effect of condition such that all groups had more difficulty perceiving SW speech than the AMSW speech, $F(1, 72) = 63.245$, $p = <0.001$ $\eta^2 = 0.637$.

The condition (SW speech versus AMSW speech) by group interaction was not significant $F(3, 72) = 0.289$, $p = 0.833$ $\eta^2 = 0.024$, suggesting that the groups did not differ in their recognition accuracy across the two modulation conditions. The main effect of phoneme was significant $F(2, 72) = 24.331$, $p = <0.001$ $\eta^2 = 0.403$, and the phoneme by group interaction was also significant $F(6, 72) = 4.559$, $p = <0.001$ $\eta^2 = 0.275$, suggesting that the groups differed in their recognition accuracy for the different phonemes. More specifically, the dyslexia and dyslexia + SD groups had more difficulty with /w/ compared to the TD and SD groups; and the SD and dyslexia + SD groups had more difficulty with /m/ than the other groups. There was a significant interaction between modulation and phoneme $F(2, 72) = 10.233$, $p = <0.001$ $\eta^2 = 0.221$. For all children, the AMSW speech did not improve perception of the /w/ phoneme to the same degree as it did for /m/ and /r/. The three-way interaction between modulation, group, and phoneme was not significant $F(6, 72) = 1.238$, $p = 0.297$ $\eta^2 = 0.094$. See Figure 4 for a graphical display of the data.

Figure 4

Percentage of Correctly Identified Words Correctly Repeated out of 36 Consonant-Vowel-Consonant (CVC) or Consonant-Vowel (CV) Rhyming Words



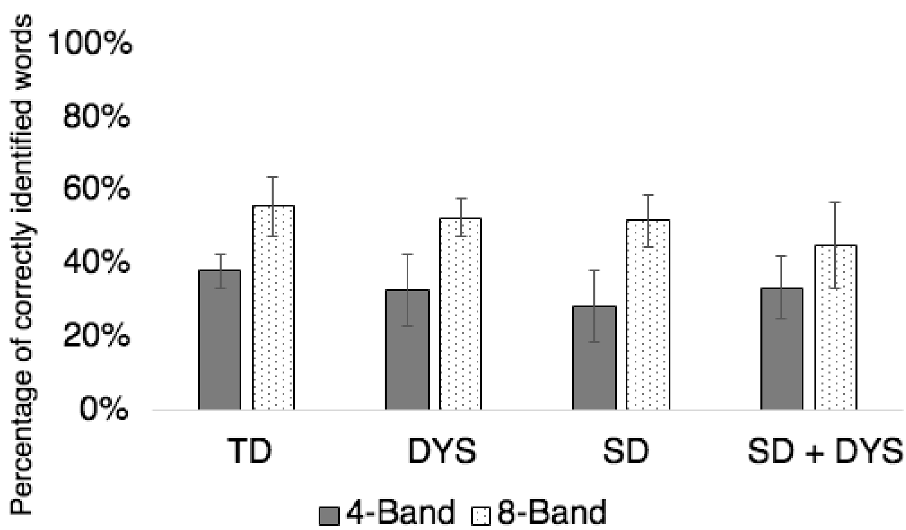
Note. Error bars represent standard error of the mean. TD: typically developing children. DYS: children with dyslexia. SD: children with speech delay. SD/DYS: children with both speech delay and dyslexia.

Vocoded Speech

To analyze the vocoded speech perception tasks, we conducted a 2 (condition: 4-band, 8-band) x 4 (group: dyslexia, speech sound disorder, dyslexia + speech sound disorder, typically developing) repeated measures ANOVA. Results revealed a main effect of condition $F(1, 36) = 162.999$, $p = <0.001$ $\eta^2 = 0.819$, revealing that all children had more difficulty perceiving 4-band speech than 8-band speech. Results also revealed a main effect of group $F(3, 36) = 3.424$, $p = 0.027$ $\eta^2 = 0.222$, suggesting that on average the groups differed in their perception of vocoded sentences. Planned comparisons revealed that SD + dyslexia group performed more poorly than the typically developing children. The other three groups of children (dyslexia, SD, and typically developing) exhibited equivalent speech perception. The two-way interaction between condition and group was not significant $F(3, 36) = 0.255$, $p = 0.857$ $\eta^2 = 0.021$, suggesting that the groups exhibited the same pattern of results across both conditions. See Figure 5 for a graphical display of the data.

Figure 5

Percentage of Correctly Identified Words Correctly Repeated out of 288 Possible



Note. Error bars represent standard error of mean. TD: typically developing children. DYS: children with dyslexia. SD: children with speech delay. SD/DYS: children with speech delay and dyslexia.

Discussion

The aim of this study was to investigate how children with dyslexia, SD and dyslexia + SD perceive different types of speech as compared to their typically developing peers. This study directly compared perception of two types of stimuli in children with SD and children with dyslexia. Specifically, the purpose of the study was to add to evidence that children with SD or SD + dyslexia may have difficulty perceiving sine-wave speech stimuli containing sounds produced in error, and that children with dyslexia and SD + dyslexia may have difficulty perceiving vocoded speech. Ultimately, the purpose of this study was to potentially improve identification of perceptual deficits in children with SD and/or dyslexia to inform effective treatment practices.

For the sine-wave speech perception tasks, there was a main effect of modulation when the children, regardless of group, performed more poorly on the SW speech compared to the AMSW speech. This finding is consistent with previous research. For example, Cabbage et al. (2016) found that all children with dyslexia, SD, and typical development participants experienced an improvement in speech perception with the additional acoustic structure (i.e., AMSW speech). However, the Cabbage et al. (2016) study identified group differences where the current study did not. For example, in the Cabbage et al. (2016) study, the children with SD had comparatively more difficulty with the /r/ phoneme compared to the dyslexia and typically developing groups for the AMSW speech condition. This was unsurprising given that children with SD did not produce the /r/ phoneme accurately. In the current study, groups performed equivalently across all phonemes (e.g., /r/, /w/, /m/). This is an unexpected finding since, similar to the Cabbage et al. (2016) study, children with SD in the current study also did not produce the /r/ phoneme accurately. This unexpected finding may be due to the current study including a fourth group of children with SD + dyslexia where the Cabbage et al. (2016) study only included three groups (SD, dyslexia, and TD), thus reducing the power of the study. In addition, Cabbage et al. (2016) analyzed perception of only /m/ and /r/, whereas the current study included a third phoneme /w/, further reducing statistical power. It is possible that additional comparisons and our small sample size decreased the likelihood of detecting a group effect. Furthermore, due to results being averages across these groups, it is possible that a range of performance in children suggest that some are low performers, and some are high performers. An analysis of individual data may provide insight into within-group variability. Future research should include additional participants and consider analyzing individual trial data to help disentangle this issue.

For the vocoded speech perception tasks, all participants performed better for the 8-band compared to the 4-band vocoded speech. This finding is similarly in line with previous results (Johnson et al., 2011). However, in contrast, results from the current study reveal no group differences. We note that our results do pattern similarly to Johnson et al. (2011) in that the pattern of results across groups was similar but did not reach statistical significance. For example, the typically developing group had the highest accuracy, followed by the SD and then dyslexia groups with the SD group outperforming the children with dyslexia. Our results diverge from Johnson et al. (2011) for children with SD + dyslexia, who did not perform the poorest. Again, it is possible that our low sample size may have masked effects because of the multiple comparisons made, thus there is a need for an increase in number of participants in future research.

Limitations

The sample size of the current study was small and thus impacted the ability to detect group differences. In future research, it will be important to include more participants in each group to improve the power of the study. This will allow the analyses to be more sensitive to detecting differences.

Another limitation concerns the speech stimuli used. The use of sine-wave speech is advantageous because it restricts the linguistic information available; however, it is possible that it is so different from speech that it is not processed like speech (Remez et al., 1981). Theoretical models of speech perception often suggest that differing areas of the brain process auditory information versus speech. Future studies should include speech and non-speech perception tasks to disentangle this issue.

Clinical Implications

Research has shown that children with SD and/or dyslexia experience a deficit in phonological processing, putting them at an increased risk for academic difficulties (Catts et al., 2005; Farquharson, 2019; Hayiou-Thomas et al., 2016; Lewis et al., 2011; Pennington & Bishop, 2009; Peterson et al., 2009; Snowling, 2001). There is a critical need to develop measures that can identify pre-reading children with SD and/or dyslexia to prevent development of negative outcomes (e.g., poor academic performance, difficulty with peer relationships). While the findings from the current study did not appear to expose a differential performance between children with SD and/or dyslexia in the different speech perception tasks, increasing the number of participants or utilizing more sensitive speech perception tasks may provide clinically applicable resources for assessment or intervention. Future research is needed to determine this.

Conclusion

In conclusion, we found that there were no differences between the groups in how they performed for the sine-wave and vocoded speech tasks. We noted a downward ranking in performance between groups on the vocoded speech task with typically developing children performing the best, children with SD following, then children with dyslexia. The SD + dyslexia performance improved in accuracy, thus interrupting the downward trend, and differences were not statistically significant. Since the sample size was small, continued research with an increase in number of participants may provide additional information that may better delineate speech perception skills in children with dyslexia, speech delay, or both.

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Tallal, P., Stark, R. E., Kallman, C., & Mellits, D. (1980). Developmental dysphasia: Relation between acoustic processing deficits and verbal processing. *Neuropsychologia, 18*(3), 273–284.

Torgesen, J., Wagner, R., & Rashotte, C. (2012). *Test of Word Reading Efficiency- Second Edition.* American Guidance Service.

Wagner, R. K., Torgesen, J. K., Rashotte, C. A., & Pearson, N. A. (2013). *Comprehensive Test of Phonological Processing—2nd Edition*. Pro-Ed.

Wagner, R. K., Zirps, F. A., Edwards, A. A., Wood, S. G., Joyner, R. E., Becker, B. J., Liu, G., & Beal, B. (2020). The prevalence of dyslexia: A new approach to its estimation. *Journal of Learning Disabilities*, *53*(5), 354–365. https://doi.org/10.1177/0022219420920377

Wiig, E. H., Semel, E., & Secord, W. A. (2013). *Clinical Evaluation of Language Fundamentals—5th Edition.* Pearson.

Wren, Y., Miller, L. L., Peters, T. J., Emond, A., & Roulstone, S. (2016). Prevalence and predictors of persistent speech sound disorder at eight years old: Findings from a population cohort study. *Journal of Speech, Language, and Hearing Research*, *59*(4), 647–673. https://doi.org/10.1044/2015_jslhr-s-14-0282

APPENDIX A

Annotated Bibliography

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. https://doi.org/10.1016/j.specom.2016.05.002

Objectives: This study sought to identify how children with dyslexia and children with persistent speech delay differ in their perception of words for SW speech and AMSW speech. Specifically, this study sought to identify whether children with persistent SD (specifically /r/) struggle more to perceive phonemes they produce in error.

Methods: 36 children ages 7;6 – 9;6 (years; months) participated in this study. These children were classified into groups including dyslexia, speech sound disorder, and typically developing. Each of the children participated in a word recognition task where they listened to two types of "impoverished speech" (SW speech and AMSW speech). It was hypothesized that children with dyslexia would perform better on the word recognition task for both SW speech and AMSW speech than children with persistent SD. This was a result of also hypothesizing that children with persistent SD would perform poorly on the word recognition task for words that included phonemes they produced in error (/r/).

Results/Conclusions: Findings showed that all children who participated in this study performed better on the word recognition task involving AMSW speech than the SW speech stimuli. When unmodulated SW speech was presented, children with dyslexia struggled more to perceive the stimuli. However, when the stimuli were amplitude-comodulated, children with dyslexia performed at the same level as the typically developing children. This meant that amplitude-comodulation resulted in greater gains in perception for children with dyslexia. Children with persistent SD showed no substantial improvements in perception from SW speech to AMSW speech which may be due to words containing phonemes produced in error (/r/).

Relevance to Current Study: This supports the hypothesis of our study to identify whether children with persistent SD experience difficulty perceiving SW speech stimuli that include phonemes produced in error.

Catts, H. W., Adlof, S. M., Hogan, T. P., & Weismer, S. E. (2005). Are specific language impairment and dyslexia distinct disorders? *Journal of Speech, Language, and Hearing Research*, *48*(6), 1378–1396. https://doi.org/10.1044/1092-4388(2005/096)

Objectives: Researchers sought to identify whether specific language impairment (SLI) and dyslexia are distinct developmental language disorders. This article provided three separate models that compared and contrasted relationships between dyslexia and SLI. Researchers of this study then conducted a thorough analysis of two studies whose purposes were to identify which model represented the relationship between dyslexia and SLI most accurately.

Methods: In study 1, children with SLI and children with dyslexia were selected from a population-based sample of children participating in a longitudinal study of language. This sample involved 527 school-age children. Various measures were administered to identify SLI and dyslexia in the participants. Study 2 examined phonological processing in children with only SLI, only dyslexia, both dyslexia and SLI, and neither dyslexia nor SLI. These participants were a subsample from Study 1.

Results/Conclusions: Results showed that study 1 had a statistically significant overlap between dyslexia and SLI, but the overlap was limited. Only a small percentage of children with SLI in kindergarten met the criteria for dyslexia in the school grades and, similarly, only a small percentage of children with dyslexia in the school grades met the criteria for SLI in kindergarten. This finding was consistent with model 3. Results from Study 2 showed that phonological processing was more closely associated with dyslexia than SLI. This finding was also consistent with model 3. These results support the finding that SLI and dyslexia are distinct disorders. Dyslexia is a developmental language disorder characterized by problems in phonological processing and word reading deficits and SLI is a disorder in oral language involving problems with semantics, syntax, and/or discourse processing.

Relevance to Current Study: This study is relevant to our study as we plan to attempt to better understand the characteristics of dyslexia and the current research surrounding dyslexia.

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 of the United States of America*, *99*(16), 10911–10916. http://www.jstor.org/stable/3059490

Objectives: This study investigated whether children with dyslexia are less sensitive to variations in AM (amplitude modulation) than typically developing children.

Methods: All the participants were followed from ages 4 to 11. At age 11, the children participated in testing.

Results/Conclusions: Findings showed that detection of beats in the AM signal was poorer in children with dyslexia compared to typically developing peers. This finding confirmed the researcher's speculation that poor AM detection in children with dyslexia is related to their processing deficits at the syllable level. Children with advanced literacy skills, on the other hand, showed significant detection of AM beats. This study further confirms the hypothesis that children with dyslexia process auditory stimuli differently than exceptional child readers.

Relevance to Current Study: This study supports the hypothesis of our study. Particularly, it supports the reasoning that the difficulty processing amplitude envelope onsets accurately may constitute deficits in developmental dyslexia. Therefore, the justification for utilizing the vocoded speech task in our study is consistent with this study's proposed theory.

Hayiou-Thomas, M. E., Carroll, J. M., Leavett, R., Hulme, C., & Snowling, M. J. (2016). When does speech sound disorder matter for literacy? the role of disordered speech errors, co-occurring language impairment and family risk of dyslexia. *Journal of Child Psychology and Psychiatry*, *58*(2), 197–205. https://doi.org/10.1111/jcpp.12648

Objectives: The purpose of this study was to examine literacy outcomes in children with early speech sound disorder (SSD) status at 5 and 8 years old.

Methods: There were 245 total participants between the ages of 3 ½ and 9 in the study who were tested 6 times at annual intervals. Participants were categorized to be in one of four groups including family risk (SSD, dyslexia, and/or language impairment) only (FR), language impairment only (LI), family risk and language impairment (FRLI), and typically developing (TD). Progress was examined at three different time points: age 3 ½ (T1), age 5 ½ (T3), and age 8 (T5).

Results/Conclusions: This study found that children who had a SSD at the age of 3 ½ performed more poorly on measures of phoneme awareness, word-level reading, and spelling around the point of school entry and word-level reading, spelling, and reading comprehension at age 8 (3 years later) when compared to their typically developing peers. Similarly, children with a SSD and co-occurring family history of dyslexia showed impairments in measures of phoneme awareness, reading, and spelling when compared to typically developing peers, of which all impairments persisted except for spelling at age 8. Findings from this study that are also consistent with previous evidence suggest that speech difficulties in preschool confer only a slight risk of poor literacy outcomes unless they are accompanied by language difficulties (Pennington & Bishop, 2009). It is also suggested that having a family history of dyslexia is an additional risk factor for literacy difficulties.

Relevance to Current Study: These findings create a case for our study of attempting to further understand the phonological deficits experienced by children with SD and/or dyslexia particularly when the risk of academic difficulties may be associated.

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 & Hearing Research*, *62*(10), 3771–3789. https://doi.org/10.1044/2019_JSLHR-S-18-0519

Objectives: This study aimed to identify whether pre-school-age children and early school-age children with SSDs would have difficulties with speech perception. This was analyzed by conducting a systematic review and meta-analysis of results as well as identifying the methodological features and other research information regarding the speech perception abilities of children with SSDs.

Methods: The systematic search conducted by eight electronic databases to uncover articles included in the final synthesis was 71 (published between 1931 and 2017). Two articles reported two relevant studies totaling 73 studies that were included in the review. Criteria required for the 71 articles to qualify for the meta-analysis included a specific age range and various other diagnostic and research requirements. For example, these articles included subjects who were within the mean age range of 3;0-7;11. This was to make sure that the SSDs of the children were classified as developmental and not residual or persistent articulation errors. In addition, participants needed to present with SSDs and have their perception skills assessed with one or more tasks. Not only were articles that involved subjects who met these criteria included in the meta-analysis, but also children with articulation problems, childhood apraxia of speech (CAS), children with phonological problems, and children with accompanying language disorders whose main communication concern was a SSD were included in the review. 60 of the 73 studies that were analyzed reported that some or all children with SSDs had difficulties with speech perception. Researchers of this systematic review discovered that the three most commonly used perception category tasks that identified a majority of children with SSDs who have difficulties with speech perception included lexical and/or phonetic judgment, minimal pair word identification, and same/different discrimination of minimal pair words.

Results/Conclusions: Results from the meta-analysis, regardless of methodological variabilities of the 73 studies, indicated that some but not all children with SSDs have difficulties with speech perception.

Relevance to Current Study: This is related to the current study because we also plan to further identify whether there are speech perception difficulties in children with SD.

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*(3), 294–314. https://doi.org/10.1016/j.jcomdis.2011.01.001

Objectives: This study analyzed similarities and differences in phonological representations in children with a history of a SSD, reading disability (RD), and SSD + RD. This study examined not only how the children process acoustic cues, but also how they recover linguistically relevant form from the speech signal.

Methods: A group of 10-11 year old children participated in this study. 17 of the children had a history of a SSD, 16 had a reading disability (RD), 17 had SSD + RD, and the other remaining 16 children were the Controls. These children participated in different speech perception tasks including 1) voice onset times (VOT); 2) spectral structure in fricative-vowel syllables; and 3) vocoded sentences. These three speech perception measures explored children's sensitivity to segmental and global levels of speech structure. Vocoded sentences were one of the speech perception tasks used in this study. It was comprised of 30 sentences in a random order where half of the sentences were presented as 8-channel vocoded signals, and half were presented as 4-channel vocoded signals. During the administration of the training portion, children heard the same sentence twice in a row, first in the natural form and then in the processed form. With VOT stimuli, all the children performed similarly. However, children with disorders showed delays in other tasks. Children with poor phonemic awareness not only lack sensitivity to acoustic details but are also less able to recover linguistically relevant forms.

Results/Conclusions: Vocoded sentence results indicated that children in all three experimental groups repeated fewer words correctly in both vocoded conditions than did children in the control group. However, children with SSD proved to be able to integrate the sensory information in these signals to recover linguistically relevant structure better than children in the RD and SSD+RD groups, but not as well as children in the control group. An impactful finding included how children performed on this task if they had poor PA (phonemic awareness) or a history of poor PA. They were not only insensitive to structure in the acoustic speech signal, but they demonstrated insensitivity to a more global level of structure, as well.

Relevance to Current Study: Part of the purpose of our study is to identify if there is a replication of findings similar to the Johnson et al. (2011) study—particularly whether children with dyslexia and SD + dyslexia portray poor performance in being able to recover linguistically relevant structure compared to the SD and typically developing groups.

Lewis, B. A., Avrich, A. A., Freebairn, L. A., Hansen, A. J., Sucheston, L. E., Kuo, I., Taylor, H. G., Iyengar, S. K., & 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*(6), 1628–1643. https://doi.org/10.1044/1092-4388(2011/10-0124)

Objectives: The aim of this study was to identify associations of early childhood SSD (with or without LI) with later language and written language skills. Its purpose was also to show that early childhood SSD, later school-age reading, written expression, and spelling skills are all related in a genetic sense.

Methods: A total of 105 children with SSD (with or without LI) and a total of 256 siblings with and without SSD participated in this study. Children with SSD and their siblings were followed from ages 4-6 years to 7-12 years. Findings confirmed associations between early childhood SSD with later language and written language skills based on oral motor skills, phonological awareness, phonological memory, vocabulary, and speeded naming with later school-age skills of reading, decoding, spelling, written expression, and spoken language. Also, a combination of studies suggested shared genetic influences on these endophenotypes and school-age literacy measures.

Results/Conclusions: Findings suggest that these shared endophenotypes and common genetic influences affect early childhood SSD and later school-age reading, spelling, spoken language, and written expression skills. Children with isolated SSD did not demonstrate reading difficulties in these studies; however, these children had poor spelling skills relative to their reading and language abilities, suggesting a residual spelling weakness. As previously hypothesized, one explanation for these spelling difficulties is that children with histories of SSD have degraded phonological representations.

Relevance to Current Study: The findings from this study support the reasoning of our study in attempting to better understand the connections between SSD and dyslexia.

Lof, G. L., & Synan, S. (1997). Is there a speech discrimination/perception link to disordered articulation and phonology? A review of 80 years of literature. *Contemporary Issues in Communication Sciences and Disorders*, *24*, 63–77.

Objectives: This study's purpose was to review the possible relationship between speech discrimination and speech-sound production errors by analyzing earlier and more current research concerned about treatment and assessment.

Methods: Colleagues first evaluated the validity of research regarding the assessment of perception/discrimination as early as 1931-1980. Evaluation of these studies revealed validity issues, specifically test and subject variables, that were included in these earlier studies. Some of these variables that affected the overall reliability of the discrimination tests included the number of stimulus items, the type of contrasts tested, the meaningfulness of the stimuli (nonsense or unfamiliar words versus real words), the way the stimuli were presented to the subjects, and whether the discrimination was internal or external. In addition, these tests did not specifically assess sounds that were specific to the articulation error. Furthermore, the subjects of the studies varied in their level of severity, individual sounds in error, classified errors, and age. As a result of these discrimination test differences and methodological variants, it was not determined whether there is a relationship between speech discrimination/perception and disordered articulation and phonology. It wasn't until 1980 that Locke published his research regarding 8 criteria, which he thought to be necessary to test speech discrimination/perception validly and to be clinically useful. Part of this research involved encouraging the utilization of discrimination/perception testing that is relevant to the subject such as assessing only the articulation error sounds. In summary, the more recent research regarding assessment concluded that improving the validity and reliability of testing discrimination/perception would increase the chances of coming up with conclusive evidence. Early research regarding treatment recommended clinicians utilize auditory input training for all children with speech-sound errors to improve articulation, whereas later researchers claimed that auditory input training was unnecessary for the improvement of production.

Results/Conclusions: Clinical takeaways include developing a valid assessment that assesses discrimination/perception of speech sounds relevant to the production of the individual and include a way for the individual to respond with internal perceptual representations. Also, if a perceptual difficulty is detected, it may be warranted to include auditory input as part of therapy. Whereas, if there is no perceptual difficulty detected, there may be a detrimental effect on the sound system when auditory input is implemented into therapy. This study was inconclusive in its evidence and proposed a need for further research.

Relevance to Current Study: This is relevant to our study because it examined earlier research and its progression to reveal the connection between speech perception and SSDs.

Nittrouer, S., & Lowenstein, J. H. (2013). Perceptual Organization of speech signals by children with and without dyslexia. *Research in Developmental Disabilities*, *34*(8), 2304–2325. https://doi.org/10.1016/j.ridd.2013.04.018

Objectives: The purpose of this study was to better understand the perceptual deficit that takes place when children with dyslexia experience difficulty organizing sensory stimuli.

Methods: Seventy children (39 boys and 31 girls) between the ages of 8 and 11 with and without dyslexia participated in the study. The control group was matched with the children with dyslexia based on age, gender, and socioeconomic status. Seventy-two (12 for practice and 60 for testing—also used in Nittrouer 2010 study) sentence-length speech sine-wave or 4-channel vocoded analog signals were presented to the participants. The sentences were all five words in length, were syntactically correct and semantically predictable, and followed a subject-predicate structure.

Results/Conclusions: Results showed that for both manipulated sentence stimuli, the children with dyslexia, including those participants who did not present with phonological deficits, presented with poorer recognition scores than children without dyslexia. However, group differences were larger for the vocoded signals. The older children with dyslexia performed better on the sine-wave sentence stimuli than the younger children with dyslexia. Children with dyslexia experience difficulty with being able to organize linguistic sensory input, but they learn to do so for sine-wave signals before they can for other types of signal structures. Because the participants with dyslexia in this study performed poorer on the vocoded stimuli, the authors of this study speculate that the difficulties that children with dyslexia experience have more to do with their ability to organize sensory input rather than being sensitive to the input.

Relevance to Current Study: The findings from this study are relevant to our study as we plan to investigate whether there is a replication of findings—specifically whether children with dyslexia show poorer recognition scores than children without dyslexia.

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*(4), 1245–1253. https://doi.org/10.1037/a0015020

Objectives: Researchers conducted an experiment to measure speech recognition in English-speaking adults, English-speaking children, and Mandarin-speaking adults. This was done using sentences that were syntactically correct, but semantically anomalous. Researchers wanted to discover if participants could recover linguistic forms from two types of acoustic stimuli that eliminated spectro-temporal properties which are associated with the phonetic structure.

Methods: One hundred twenty participants were included in the study. This included 40 adult native English speakers, 40 seven-year-old native English speakers, and 40 adult native Mandarin speakers who were competent second-language speakers of English. All adults were between 18 and 38 years of age, with mean ages of 25 years for the English-speaking adults and 27 years for the Mandarin-speaking adults. Half of the participants in each group listened to the SW (sine wave) stimuli and half listened to the AE (amplitude envelope) stimuli, making a total of six groups of listeners. Stimuli included 36 four-word sentences. All sentences consisted entirely of monosyllabic words, and were syntactically appropriate for English, but were semantically anomalous. Listeners of the AE stimuli heard half of them with 4-channel and the other half with 8-channel.

Results/Conclusions: Findings showed that listeners of the AE stimuli performed better with the eight-channel stimuli than with the four-channel stimuli. Across all AE and SW stimuli results, participants in all three groups performed better with the eight-channel AE stimuli than the SW stimuli. Children were the only participants who showed a contrast in recognition scores when it came to comparing their four-channel AE stimuli performance with SW stimuli. Children who listened to the SW stimuli outperformed the children who listened to the four-channel AE stimuli. Other results suggest that children and adults of the same native language can recover linguistic form from the global spectral structure but are unsuccessful when only amplitude envelopes are preserved.

Relevance to Current Study: This is relevant to our study as we plan to investigate whether children still perform better on the eight-channel AE (vocoded) stimuli than the SW stimuli.

Pennington, B. F., & Bishop, D. V. (2009). Relations among speech, language, and reading disorders. *Annual review of psychology*, *60*, 283–306. https://doi.org/10.1146/annurev.psych.60.110707.163548

Objectives: Researcher conducted a review was to define speech, language, and reading disorders and then analyze these three components utilizing three different levels including diagnostic, cognitive or neuropsychological, and etiological to understand their overlap. This review also identifies which models of comorbidity are considered or rejected based on current evidence. Population samples show that SSD and language impairment (LI) are comorbid and that LI and later reading disorder (RD) are comorbid. Supporting evidence shows that SSD + LI has the greatest risk for later RD. However, there is lacking evidence to support comorbidity between SSD and later RD.

Methods: From the tables included, there is adequate data to support the risk of reading disorder in individuals with a comorbid SSD and LI, but not enough data to support the risk of reading disorder in individuals with SSD and no LI and vice versa. Although there is cognitive overlap between SSD, LI, and RD, there is variation in terms of comorbidity. For example, depending on the presence or absence of rapid serial naming (RSN) deficits in SSD and LI determines whether there is a comorbidity with later RD. Evidence suggests that LI, RD, and SSD are genetically affected.

Results/Conclusions: Results showed that LI, RD, and SSD are complex when attempting to understand them at three levels of analysis such as diagnostic, cognitive, and etiological. The common themed deficit between all three disorders is phonological processing which could be due to auditory perceptual problems. Other deficits analyzed appear to be specific to one of the disorders.

Relevance to Current Study: This study is related to ours as we plan to further investigate the phonological processing deficit in children with SD and/or dyslexia. Specifically, our study's purpose is to identify what parts of a speech signal are important for kids with SD and/or dyslexia to understand what is being perceived.

Peterson, R. L., Pennington, B. F., Shriberg, L. D., & Boada, R. (2009). What influences literacy outcome in children with speech sound disorder? *Journal of Speech, Language, and Hearing Research*, *52*(5), 1175–1188. https://doi.org/10.1044/1092-4388(2009/08-0024)

Objectives: The objective of this study was to identify whether 7 – 9-year-old children who had a preschool SSD would have poorer literacy outcomes compared to controls and higher rates of reading disability (RD).

Methods: 123 children participated in the study of which 86 had a history of a childhood SSD and 37 were the controls (no history of speech or language disorder). These children were initially recruited at ages 5 – 6 and were followed longitudinally.

The literacy of the children with SSD was reported at ages 7 – 9 and was compared with controls. At ages 5 – 6, participants were identified by their speech and language difficulties in one of four groups. These included normalized SSD no LI, persistent SSD no LI, normalized SSD LI, and persistent SSD LI. At ages 5 – 6, participants with SSD as a whole performed worse than controls on three measures that predict later literacy including phonological awareness (PA), letter knowledge, and rapid serial naming (RSN).

Results/Conclusions: Literacy scores of the SSD group were significantly lower than those from the control group, thus concluding that children with a history of speech sound disorder predict literacy difficulties. One-quarter of children with a history of SSD met the criteria for a reading disability. Two-thirds of children with SSD + LI met the criteria for RD. This study supports the reasoning of utilizing speech perception due to it being one of many components of the overall phonological system that comes before speech production and literacy.

Relevance to Current Study: The purpose of our study is to further prove how difficulty in speech perception tasks is correlated with speech sound disorder or dyslexia.

Preston, J. L., Irwin, J. R., & Turcios, J. (2015). Perception of speech sounds in school-aged children with speech sound disorders. *Seminars in Speech & Language, 36*(4), 224–233. https://doi-org.erl.lib.byu.edu/10.1055/s-0035-1562906

Objectives: Researchers of this study identified whether the software system known as the Speech Assessment and Interactive Learning System (SAILS), which has been proven to reliably treat and assess preschool and kindergarten-aged children, is a clinically viable approach to assess and treat school-aged children with residual speech sound disorders.

Methods: Two cohorts of school-aged children participated in the study to identify whether or not the SAILS could identify if school-aged children with residual speech errors (RSE) had speech perception difficulties. The first cohort included two groups of children ages 9;0 to 14;5 (years; months). Within this group, 20 of the children were identified as "typical" with typical /r/ production and who had no history of speech or language disorders. The other 27 students a part of this cohort had residual sound errors (RSE) specifically with the /r/ production. This cohort was administered 20 SAILS items including the following five sounds /f/, / θ/, / ʃ /, /s/, and /r/ with the highest level of difficulty. These tasks required categorical perception for what is known as "goodness judgment" requiring an individual to pay attention to "fine-grained acoustic detail." Results from the groups of this cohort revealed no significant difference. The second cohort included 25 native English-speaking children from upstate New York who all had a history of preschool SSD. These children were followed 3.5 years later to assess literacy, speech, and language where some acquired typical speech sound production and others continued to exhibit difficulties. SAILS was administered to assess the perception of /s/ and /r/ using the highest level of difficulty for each phoneme. Again, results from the groups revealed no significant difference.

Results/Conclusions: Findings showed that SAILS did not prove to be a reliable assessment in detecting differences between the perception of specific phonemes in school-aged typical children and school-aged RSE children.

Relevance to Current Study: This article relates to the current study because it contributes to the overall question of whether school-aged children with SSDs have perceptual difficulties. In addition, it seeks to develop an approach to utilize in assessment and intervention that is sensitive to identifying school-aged children with SSDs who have perceptual difficulties.

Rosner, B. S., Talcott, J. B., Witton, C., Hogg, J. D., Richardson, A. J., Hansen, P. C., & Stein, J. F. (2003). The perception of "sine-wave speech" by adults with developmental dyslexia. *Journal of Speech, Language, and Hearing Research*, *46*(1), 68–79. https://doi.org/10.1044/1092-4388(2003/006)

Objectives: The study determined if adults with developmental dyslexia perform as well as controls when features, including semantic and syntactic cues, are present in a continuous sine-wave.

Methods: 19 adults with previous diagnoses of dyslexia and 14 adults without dyslexia participated in the study. Nine sine-wave utterances were presented to the participants. The participants were able to listen to each sine-wave utterance four times successively and then repeat back what they heard.

Results/Conclusions: Results showed that compared to the comprehension of the adults without dyslexia on the sine-wave tasks, adults with dyslexia consistently performed less proficiently on comprehending the sine-wave speech utterances even though these stimuli had normal syntax and semantics.

Relevance to Current Study: This relates to our study in identifying whether there is a replication of findings about the difficulty experienced by children with dyslexia in accurately perceiving sine-wave speech signals.

Wren, Y., Miller, L. L., Peters, T. J., Emond, A., & Roulstone, S. (2016). Prevalence and predictors of persistent speech sound disorder at eight years old: Findings from a

population cohort study. *Journal of Speech, Language, and Hearing Research*, *59*(4), 647–673. https://doi.org/10.1044/2015_jslhr-s-14-0282

Objectives: The purpose of the study was to understand the prevalence and predictors of persistent speech sound disorder in children who are 8 years of age. This study sought to identify the prevalence and predictors of persistent SSD beyond common clinical distortions such as /s/ and /r/ distortions.

Methods: This study used prospective cohort data from ALSPAC, a transgenerational observational population study of health and development across the lifespan. The participants of this study included children who were 8 years and 6 months old who completed the speech and language session. A total of 7,391 children participated.

Results/Conclusions: Results showed that the prevalence estimate of children who are 8 years old with a persistent SSD was 3.6%. These children were more likely to be boys and from families who did not own their own homes.

Relevance to Current Study: This study builds a case for why understanding speech perception in children with persistent SSD is important by pointing out the prevalence of persistent SSD. The prevalence result is meaningful because it is analyzed in children who are 8 years of age — the same age as some participants in our study.

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

IRB NUMBER: X2020-249
IRB APPROVAL DATE: 07/12/2021
IRB EXPIRATION DATE: 07/26/2022

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:____________

IRB NUMBER: X2020-249

IRB APPROVAL DATE: 07/12/2021

IRB EXPIRATION DATE: 07/26/2022

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

American Indian or Alaska Native

Asian

African-American or Black

Native Hawaiian or Other Pacific Islander

Caucasian (White)

Mother's Race

American Indian or Alaska Native

Asian

African-American or Black

Native Hawaiian or Other Pacific Islander

Caucasian (White)

Father's Race

American Indian or Alaska Native

Asian

African-American or Black

Native Hawaiian or Other Pacific Islander

Caucasian (White)

Child's Ethnicity

Hispanic or Latino

Not Hispanic or Latino

Mother's Ethnicity

Hispanic or Latino

Not Hispanic or Latino

Father's Ethnicity

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?)

____

____

____

____

____

____

Perinatal History

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.):

Other Information

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

Sine-Wave Speech Stimuli Words

1. Made
2. Mail
3. Make
4. Mare
5. Mate
6. May
7. Maze
8. Meal
9. Might
10. Mock
11. Mows
12. Mow
13. Raid
14. Rail
15. Rake
16. Rare
17. Rate
18. Ray
19. Raise
20. Real
21. Right

22. Rock
23. Rose
24. Row
25. Wade
26. Whale
27. Wake
28. Wear
29. Wait
30. Weigh
31. Weighs
32. Wheel
33. White
34. Walk
35. Woes
36. Woe

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 sweet dust.
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.