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Measuring Speech Perception in Children With Speech Sound Disorders Using the Wide Range Acoustic Accuracy Scale

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A thesis submitted to the faculty of
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Master of Science

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ABSTRACT

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The purpose of this study was to measure the speech perception of children with speech sound disorders and compare it to that of adults and typically developing children. A secondary purpose was to determine if an adaptive-tracking tool, the *Wide Range Acoustic Accuracy Scale* (WRAAS) equalized task demands across participants independent of perceptual ability. The participants included 31 adults, 15 typically developing children, and 15 children with speech sound disorders. Children with speech sound disorders all had difficulty producing /r/ correctly. Each participant completed perceptual testing discriminating differences in three syllable contrast pairs: /bɑ/-/wɑ/, /dɑ/-/gɑ/, and /rɑ/-/wɑ/. Results indicated that children with speech sound disorders had significantly poorer perception than the adults for /bɑ/-/wɑ/ and /dɑ/-/gɑ/ and significantly poorer perception than their typically developing peers for the /rɑ/-/wɑ/ contrast. Adults and typically developing children did not differ in their perception of any contrast. Results also indicated that WRAAS equalized the number of trials across all participants irrespective of perceptual ability. We discuss clinical implications of these results and how WRAAS may be used in future research and in clinical work to efficiently and effectively determine perceptual abilities of children with speech sound disorders.

Keywords: speech therapy, speech perception, speech impairment

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DESCRIPTION OF THESIS STRUCTURE AND CONTENT

This thesis, *Measuring Speech Perception in Children with Speech Sound Disorders Using the Wide Range Acoustic Accuracy Scale,* 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 communication disorders 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 consent form in Appendix B, and child assent form in Appendix C.

Introduction

There is a long-standing belief that speech perception plays a role in the production of speech, but the nature of that role has yet to be fully explained (Casserly & Pisoni, 2010; Van Riper & Irwin, 1958). Examples of the interaction between speech perception and production include the effect of delayed auditory feedback on fluency (Yates, 1963), the effect of changing the structure of formant frequencies of a speaker's production on articulation of speech sounds (Lowenstein & Nittrouer, 2019), and the way that different linguistic environments can induce changes in a speaker's articulation (Sancier & Fowler, 1997). Further evidence has demonstrated that in different articulatory contexts the acoustic signal for a particular sound may remain the same, but the motor speech movement of the articulators varies depending on the context (Guenther et al., 1999). Taken together, these examples suggest that placement of articulators to create specific speech sounds may involve at least some degree of auditory-perceptual feedback and is not solely motor based.

The relationship between perception and production holds specific significance within the study of speech sound disorders. Speech sound disorders (SSD) is a broad term referring to children who produce speech errors that are atypical for their age and gender (Smit et al., 1990). Many of the current interventions to correct speech sound production errors focus on the motor aspect of speech - producing the sound in the correct place. But some children, despite learning correct articulatory placement, continue to have difficulty discerning the perceptual accuracy of the production. If, as models of speech production suggest (Guenther & Hickock, 2015; Guenther & Vladusich, 2012), the auditory/perceptual system plays a role in speech production, then it is important to deepen our understanding of the role of speech perception when a child with SSD does not produce a sound correctly.

Speech Perception in Children With Speech Sound Disorders

Several studies have examined speech perception skills in children with SSD and have found mixed results. Many studies find that children with SSD have poorer perception than their typically developing (TD) peers (Cabbage et al., 2016; Hoffman et al., 1985; Rvachew & Jamieson, 1989), but others have not found that to be the case (McNutt et al., 1981; Preston et al., 2015; Smit & Bernthal, 1983). Others find that some, but not all, children with SSD have perceptual deficits (Hearnshaw et al., 2018; Hoffman et al., 1985; Zuk et al., 2018). Some studies have demonstrated that children with SSD show a generalized perceptual deficit (Rvachew et al., 2003; Zuk et al., 2018) whereas others demonstrate that children with SSD only have perceptual deficits for phonemes they don't produce correctly (Cabbage, 2013; Hoffman et al., 1985; Rvachew & Jamieson, 1989). Findings vary across studies but systematic reviews of speech perception in children with SSD have found that, on average, children with speech sound disorders have poorer perception than their typically developing peers (Hearnshaw et al., 2019; Lof & Synan, 1997). Below, we review a sampling of these studies, chosen to demonstrate the range of methods and results within the research of speech perception.

Hoffman et al. (1985) used a speech identification and speech discrimination task to identify speech perception abilities in 22 children with SSD and 13 children with typical speech. All children were between the ages of 6;0 and 6;11. In this study, the researchers focused on the contrast between perception of /r/ and /w/. All children with SSD substituted /w/ for /r/ in all positions, while those who had typical speech did not demonstrate any /r/ substitutions or mispronunciations and were not enrolled in speech services. In order to participate in the experiment, all children had to differentiate between live production as well as recorded production of "ray" vs "way" in 8 out of 10 opportunities to ensure understanding of the given task. Hoffman et al. (1985) created a seven-step acoustic continuum between “ray” and way” systematically changing F1, F2, and F3 frequencies. In an identification task, children with SSD exhibited a flatter identification function than typically developing children, indicating a less distinct phonemic boundary. For both groups, the phonemic boundary fell between stimulus items 3 and 4, but the typically developing children identified the correct phoneme above or below the boundary with 90% accuracy whereas the SSD group achieved 66% and 69% accuracy above and below the boundary, respectively.

In a follow-up discrimination task, Hoffman and colleagues (1985) presented the same children with syllables along the same continuum in Stimulus Pairs 1-4, 2-5, 3-6, and 4-7. Pairs were presented in a game-like format where one syllable was presented twice in a row (AA) and then that same syllable was presented with a contrasting syllable (AB). These pairings were randomized, and the child was asked to indicate which of the syllable pairs was different. The misarticulating children in this experiment correctly identified which of the pairs was different with 57% accuracy on average, a just above chance performance. Those in the typically articulating group correctly discriminated 90% of the pairs. Those in the misarticulating group were also more variable, with some scoring closer to that of the typically articulating group and others closer to chance scores.

Rvachew and Jamieson (1989) also compared the speech perception of children with SSD, TD children, and adults. The adults had a mean age of 27 years (20-50 years) and the children ranged in age from 4;8 – 6;0 (mean age: 5 years 4 months). Rvachew and Jamieson used two identification tasks, one contrasting “seat” – “sheet” and the other contrasting “sick” – “thick.” Seven-step continua were created by systematically varying a specified acoustic parameter between the words in each pair consistent with traditional investigations of categorical perception. For the “seat”– “sheet” continuum, this meant changing the frequency of the major amplitude portion on the spectrum. For the “thick”– “sick” continuum the duration and amplitude of the fricative energy was altered. For example, the energy band for /s/ is concentrated at very high frequencies whereas the energy band for /ʃ/ is a broader band of energy. To create a continuum of stimuli between these endpoints, the authors “systematically manipulated the fricative energy in incremental steps and children were tasked with categorically labeling each stimulus item” (Rvachew & Jamieson, 1989). The participants were shown a picture of the two words and asked to identify which was produced. Results showed that in general children had more variability in their responses than adults. Children with SSD overall had more variability than the other two groups, they also had an overall lower average score. However, with this variability, the range of speech perception varied from some children with SSD who showed perception that was similar to that which was seen in TD children to others who showed markedly poor perception (Rvachew & Jamieson, 1989).

Zuk et al. (2018) used a discrimination task to test speech perception in various groups of children (childhood apraxia of speech, CAS; language impairment; CAS+language impairment; typically developing, and speech delay). All children were between the ages of 4;7 and 17;7 years old. Those with speech delay were characterized as children with “delayed production of age-appropriate speech sounds” (Zuk et al., 2018, p. 584). The study investigated the children’s perceptual discrimination for two syllables (/dɑ/ and /gɑ/) using a continuum of stimuli that varied from /dɑ/ to /gɑ/, systematically manipulating a single acoustic parameter (i.e., F3 onset frequency). Findings showed that only the children with CAS+language impairment and children with speech delay had difficulty with this contrast. Notably, all children, even those with CAS and SD, were able to produce /d/ and /g/ in their speech. Thus, this study demonstrated that some children with SSD have difficulty perceiving some perceptual contrasts, even if they don't have errors for these phonemes in their speech production. While the focus of this experiment was on children with CAS, the comparisons between groups highlighted the variability that occurs within the subgroups of children with SSD and those with language impairment.

In contrast, Preston et al. (2015) found that children with SSD did not show a difference in speech perception compared to TD children. Using the Speech Assessment and Interactive Learning System (SAILS), these researchers tested children ages 9;0 to 14;5 who were split into those with residual speech errors (RSE; specifically for /r/) and those with typically developing speech. In the SAILS program children are presented with 10 recorded productions of a word from multiple speakers in a computer game format, some producing the word correctly and some misarticulating a particular sound. In a forced choice goodness judgement task, the children are asked to point to a picture of the word if the production is correct and to point to an X if its incorrect (Preston et al., 2015; see Rvachew, 1994 for full description of the task). The speech perception between these two groups was not significantly different. The researchers hypothesized that this unexpected result may have been due to the fact that SAILS was initially designed to assess and normed on younger children and is not sensitive enough to differentiate between speech perception abilities for older children (Preston et al., 2015; Rvachew et al., 2004).

The variability of findings across studies of speech perception in children with SSD is supported by the evidence from multiple other studies (Hearnshaw et al., 2018; Lowenstein & Nittrouer, 2019; Rvachew et al., 2003); speech perception deficits exist within the group of children with SSD, but with such a large amount of variability it is difficult to determine which children are most likely to have speech perception deficits (Zuk el al., 2018). Therefore, a clearer view of the specifics of speech perception deficits in children with SSD is needed.

Task Demands of Perceptual Experiments for Children

The varied findings above may be attributable to individual variation in speech perception for different children with SSD. It also may be, however, that methodological challenges associated with testing speech perception in children may be contributing to the disparate findings. Locke (1980) argued the importance of ″preventing nonperceptual errors from masquerading as perceptual errors" (pg. 436-437). For example, lengthy perceptual experiments may be fatiguing for children and/or children′s attention may wane because of the repetitive nature of most perceptual tasks. Locke (1980) suggested the importance of providing multiple trials on every production-relevant item to account for trials where a child′s attention may have drifted. He also acknowledged, however, that perceptual tasks must have a short enough duration and be within a child′s capacities, including not requiring lengthy pretraining of the task.

In typical speech perception experiments, to determine a reliable discrimination threshold, each stimulus item is presented multiple times to ensure accurate measures and account for lapses in attention. This can result in the presentation of a large number of trials, which may be challenging for some children. For example, Rvachew and Jamieson (1989) reported their task demands as follows:

> The tape contained several blocks of trials arranged in the following order (the number of trials per block is shown in parentheses): Practice Pair 1 (10), Practice Pair 2 (10), continuum (28), Practice Pair 1 (10), continuum (28), Practice Pair 2 (10), End Point Pair

1 (10), End Point Pair 2 (10), End Point Pair 3 (10), End Point Pair 4 (10), Practice Pair 1 (10), End Point Pair 4 (10), End Point Pair 3 (10), End Point Pair 2 (10), End Point Pair 1 (10), Practice Pair 2 (10), continuum (28), Practice Pair 1 (10), continuum (28). The order of the stimuli was randomized within each block. The interstimulus interval within a block was 4 s, and the interval between blocks was approximately 10 s (p. 195).

Thus, in total, children were presented with 262 trials to determine their perceptual abilities. The authors did not indicate whether children were provided with breaks. While this number of trials may accurately determine speech perception abilities, expecting children to complete 250+ trials is not practical clinically because of the time and effort required of the child and the clinician in order to complete the speech perception evaluation. The balance between providing enough trials to get an accurate measure of speech perception and presenting an optimal number of trials that will not fatigue children has been a methodological concern for many years. Hoffman and colleagues (1985) managed this conundrum by limiting their perceptual continua to 7 steps and presenting select pairs of stimuli from the continua in a 2-alternative forced-choice discrimination task. This resulted in children being given a total of 70 trials, not including the training pre-trial that involved 8-23 presentations for those with SSD. While 70 trials may be manageable, this task evaluated perception along a 7-step continuum between the two syllables. Adding additional steps to the continuum would allow more fine-grained perceptual measurements of speech perception but would also add ten more trials to be presented with each new step along the continuum.

Other studies demonstrate similar difficulties with the number of tasks presented. An evaluation of Rvachew's SAILS perception task (Rvachew, 1994) or similar tasks modeled after it, researchers have conducted perceptual experiments requiring that 70, 100, or 192 samples of words be presented to participants (Hearnshaw et al., 2018; Preston et al., 2015; Rvachew et al., 2003). Lowenstein and Nittroeur (2019) presented children and adults with two blocks of 120 CVCVCV non-words, equaling a total of 240 words. Shuster (1998) presented children with 100 recorded words that children had to categorize as correct/incorrect. While these studies demonstrate a large range, the majority require 100 or more trials in order to determine speech perception abilities. This may challenge the attention of the children completing the tasks as well as be unlikely for clinical use.

Researchers and clinicians alike would benefit from efficient but reliable ways to determine speech perception skills in children. Parameter estimation by sequential tracking (PEST), an adaptive method that individualizes stimulus presentation, significantly reduces the number of trials required to find a specified discrimination threshold (Taylor & Creelman, 1967). The PEST algorithm uses probability estimation to adjust stimulus presentation so that listeners do not hear multiple repetitions of stimulus items they are likely to respond to with very high or very low accuracy. The effect is that the bulk of stimulus trials are centered near the individual listener's perceptual threshold, resulting in very few "wasted" trials on stimulus items that are well above or well below the threshold. The PEST algorithm has been used in psychological research for decades and was first utilized in speech perception research more recently (Cabbage, 2013; Carrell et al., 1999; Hitchcock et al., 2020; Kraus et al., 1996; Zuk et al., 2018).

Kraus et al. (1996) first used the PEST algorithm in connection to speech perception to test and compare speech perception differences for children between 6;0 and 15;0 with and without learning disabilities. The study compared discrimination of the syllable contrast pairs /bɑ/-/wɑ/ and /dɑ/-/gɑ/. As with other speech perception experiments, the investigators created a continuum of stimuli for each syllable pair by adjusting a single acoustic parameter. The /bɑ/-

/wɑ/ continuum varied in the duration of the formant transition; the /dɑ/-/gɑ/ continuum varied by the spectral content of the formant transition. Stimuli were presented in pairs, one of which presented a standard stimulus from one end of the continuum, the other pair presented the standard stimulus and a second stimulus from somewhere along the continuum. Children identified which pair contained the differing stimuli. Consistent with PEST, the first comparison stimulus item was half the distance between the endpoints of the continuum. If the child responded correctly, the next stimulus item presented was half the distance closer to the standard stimulus item. If the child responded incorrectly, the distance between the comparison stimulus and the standard was *increased* on the next trial. The PEST algorithm continued in an iterative process until the program converged on the Just Noticeable Difference (JND). Results indicated that there was a significant difference in the speech perception, or auditory discrimination as it is described in this study, between the two groups (Kraus et al., 1996).

Cabbage (2013) used the same paradigm to determine differences in speech perception abilities between TD children, children with dyslexia, children with SSD, and children with both SSD and dyslexia. Results of this study extended the findings of Kraus et al. (1996), revealing that TD children showed better perceptual sensitivity for /bɑ/-/wɑ/ and /dɑ/-/gɑ/ syllable contrasts as compared to children with dyslexia and children with SSD/dyslexia. Children with SSD only, however, performed similarly to their TD peers in these contrasts. Cabbage (2013) tested an additional syllable contrast, /rɑ/-/wɑ/, to determine whether children with SSD, none of whom produced the /r/ phoneme, showed a perceptual deficit for this specific contrast. As predicted, group differences between the TD children and children with SSD revealed that children with SSD showed poorer perception for the /rɑ/-/wɑ/ contrast. Zuk et al. (2018) used the same paradigm to examine speech perception of /dɑ/-/gɑ/ for children with childhood apraxia of speech (CAS), a subtype of speech sound disorder that involves motor programming deficits (Shriberg et al., 1997). Zuk and colleagues included children with CAS without language impairment, CAS with language impairment, and speech delay, "characterized by delayed production of age-appropriate speech sounds" (Zuk et al., 2018). Findings demonstrated that some (CAS with language impairment, children with speech delay) but not all (CAS without language impairment) children with speech and language deficits had poor perception for this contrast.

More recently, by embedding the same PEST algorithm into a child-friendly computer software program, Hitchcock et al. (2020) administered the *Wide Range Acoustic Accuracy Scale* (WRAAS) to assess the speech perception abilities of adults, TD children, and children with SSD. They found that adults and children with SSD differed in their perception of all three syllable contrasts (/bɑ/-/wɑ/, /dɑ/-/gɑ/, /rɑ/-/wɑ/), and that TD children and children with SSD differed only on the /rɑ/-/wɑ/ contrast, which was the sound the children with SSD misarticulated. Taken together, these studies suggest the PEST algorithm, including the most recent platform for its presentation, WRAAS, consistently finds that children with SSD show poor perception for a speech sound they do not produce correctly.

These studies demonstrate that use of the PEST algorithm is feasible for children with and without SSD. The algorithm was designed to reduce the number of trials children are required to complete while still determining speech perception abilities. However, the number of trials children complete has not been explicitly reported or analyzed in previous studies. Due to the dynamic nature of PEST within the WRAAS program, the number of trials presented is not the same for each person who completes the task. This could potentially be detrimental to use of

WRAAS in speech perception assessment if the number of trials presented to a listener is significantly different based on perceptual ability.

Statement of the Purpose

The primary purpose of the current study is to determine whether children with SSD exhibit poorer speech perception in the sounds that they misarticulate compared to both typically developing (TD) children and adults. Based on previous research, we expect that the children with SSD will, as a group, perceive sounds more poorly, specifically the sounds that they are not currently producing correctly (Hoffman et al., 1985; Preston et al., 2015; Rvachew & Jamieson, 1989; Zuk et al., 2018). A secondary purpose of this study is to determine whether listeners experience similar task demands (e.g., number of trials) when their perception skills are measured using WRAAS, a computer program that utilizes the PEST algorithm.

Research Questions

This study aims to answer the following research questions:

1. How does perception of various syllable contrasts compare among adults, TD children, and children with SSD and does this change when comparing the syllables containing phonemes the children with SSD can produce vs. those they cannot produce?
2. What is the relationship between task demands (e.g., reaction time, number of trials) and perceptual skill in adults, TD children, and children with SSD?

Method

The Institutional Review Board at Brigham Young University granted approval for the recruitment of human subjects and the execution of this study. Sixty-one participants were recruited for participation. We recruited typically developing adults and children through emails, flyers, and word of mouth. Children with SSD were recruited from local school-based and private practice speech-language pathologists. Informed consent forms were read and signed by the parent prior to the beginning of the first session. Children provided written assent to participate. Consent forms were then collected by the researcher with a copy provided to the parent upon request.

Participants

Participants were recruited from the communities surrounding Brigham Young University in Provo, Utah and Montclair State University in Montclair, New Jersey. Participants consisted of 31 adults, 15 TD children, and 15 children with SSD. All children were between the ages of 7;8 and 13;11years old and the adult were between the ages of 20 and 54 years old. All participants were monolingual English speaking, passed a hearing screening (1000, 2000, and 4000 Hz at 20 dB HL) and passed an oral mechanism exam that indicated normal oral structures and function and ruled out the presence of dysarthria or childhood apraxia of speech for children with SSD. Adults self-reported and parents of TD children reported no history of speech or language deficits, or history of attention deficit (hyperactive) disorder (ADD/ADHD), cognitive disorders and/or other neurobehavioral disorders. Per parent report, individuals in the TD children group were performing at or above grade level academically.

Each of the children with SSD exhibited rhotic errors and were not excluded from the study if they exhibited other speech sound deficits in addition to the rhotic errors. The stimulability of the rhotic sounds was assessed by eliciting imitation of /r/ in isolation and in syllable-initial, intervocalic, and syllable-final position in the vowel contexts /ɑ, i, u/ (Miccio, 2002). In addition, each child with SSD scored 1.5 SDs below the mean on the *Goldman-Fristoe Test of Articulation-3* (*GFTA-3*; Goldman & Fristoe, 2015). The Reynolds Intellectual

Assessment Scale 2 (*RIAS-2;* Reynolds & Kamphaus, 2015) was administered to ensure cognitive skills within normal limits (greater than a standard score of 78). A passing score on the *Clinical Evaluation of Language Fundamentals - Screening Test -5* (*CELF-5 Screening Test*; Wiig, Secord, & Semel, 2013) or a Core Language Score with 1.5 SDs below the mean on the *Clinical Evaluation of Language Fundamentals - 5* (*CELF-5*, Wiig, Semel, & Secord, 2013) indicated typical language abilities.

Task

The *Wide-Range Acoustic Accuracy Scale* (WRAAS), a computer based perceptual assessment program, was used to measure the listeners' ability to discriminate stimulus items from selected syllable-pair continua (i.e., /bɑ/-/wɑ/, /dɑ/-/gɑ/, /rɑ/-/wɑ/), each differing by a single acoustic parameter. The purpose of the WRAAS is to use the PEST algorithm (Taylor & Creelman, 1967) to find the Just Noticeable Difference (JND) in the perception of the presented stimuli. The JND is defined as the distance when the listener can successfully discriminate two stimuli with 71% accuracy. This is accomplished by presenting a reference pair of stimuli which repeats a standard stimulus and an experimental pair of stimuli containing the standard stimulus and a second stimulus item taken from a continuum. Similar to Kraus et al. (1996), in the WRAAS program, the first comparison stimulus item was the farthest distance between the endpoints of the continuum. If the child responded correctly, the next stimulus item presented was half the distance closer to the standard stimulus item. If the child responded incorrectly, the distance between the comparison stimulus and the standard was *increased* on the next trial. An example of this pattern is demonstrated in Figure 1. WRAAS continued in an iterative process until the program converged on the JND. The WRAAS records the JND as the Convergence Level (CL), the specific step along the respective continuum at which the JND is determined.

Stimuli

The stimuli for this task were created using a Klatt software synthesizer (Klatt, 1980) and used previously (Cabbage, 2013; Hitchcock et al., 2020). Spectral representations for each syllable pair are shown in Figure 2. The first presented stimulus pair was /bɑ/-/wɑ/. This pair contained 81 steps along its continuum, each sound differing in the transition duration from 25 msec to 105 msec in 1 msec steps. The second presented pair was /dɑ/-/gɑ/. This pair differed in the F3 onset frequency, ranging from 1800 Hz to 2700 Hz, differing in 20 Hz steps along the continuum. This pair contained 46 differing stimuli. The final stimulus pair presented was /rɑ/-/wɑ/. This pair differed in the F3-F2 distance, ranging from 1500 Hz to 2500 Hz in 25 Hz steps. There were 41 steps along the continuum for this pair. Aside from the acoustic parameters mentioned above, all other acoustic measurements remained the same between each syllable pair. Each continuum was pilot tested with child subjects in order to avoid floor and ceiling effects.

Each CV pair was chosen specifically to provide an overarching view of the speech perception abilities for each group. The /bɑ/-/wɑ/ stimulus pair was selected as a control pair for the WRAAS task, as it was not expected any child would have difficulty with this pair due to its early development in perception and production for all children (Nittrouer et al., 2013). The /dɑ/-/gɑ/ pair was chosen because of its use in previous work in children with SSD and other disabilities (Cabbage, 2013; Kraus et al., 1996; Zuk et al., 2018). This also helped address whether there was a more generalized perceptual deficit (did children with SSD struggle with more than just the phoneme they didn't produce correctly?) and /rɑ/-/wɑ/ was chosen because it was a specific production error that children with SSD did not produce correctly - this tested a direct perception-production link.

Figure 1

Discrimination Data From a Pilot Participant for /ba/-/wa/

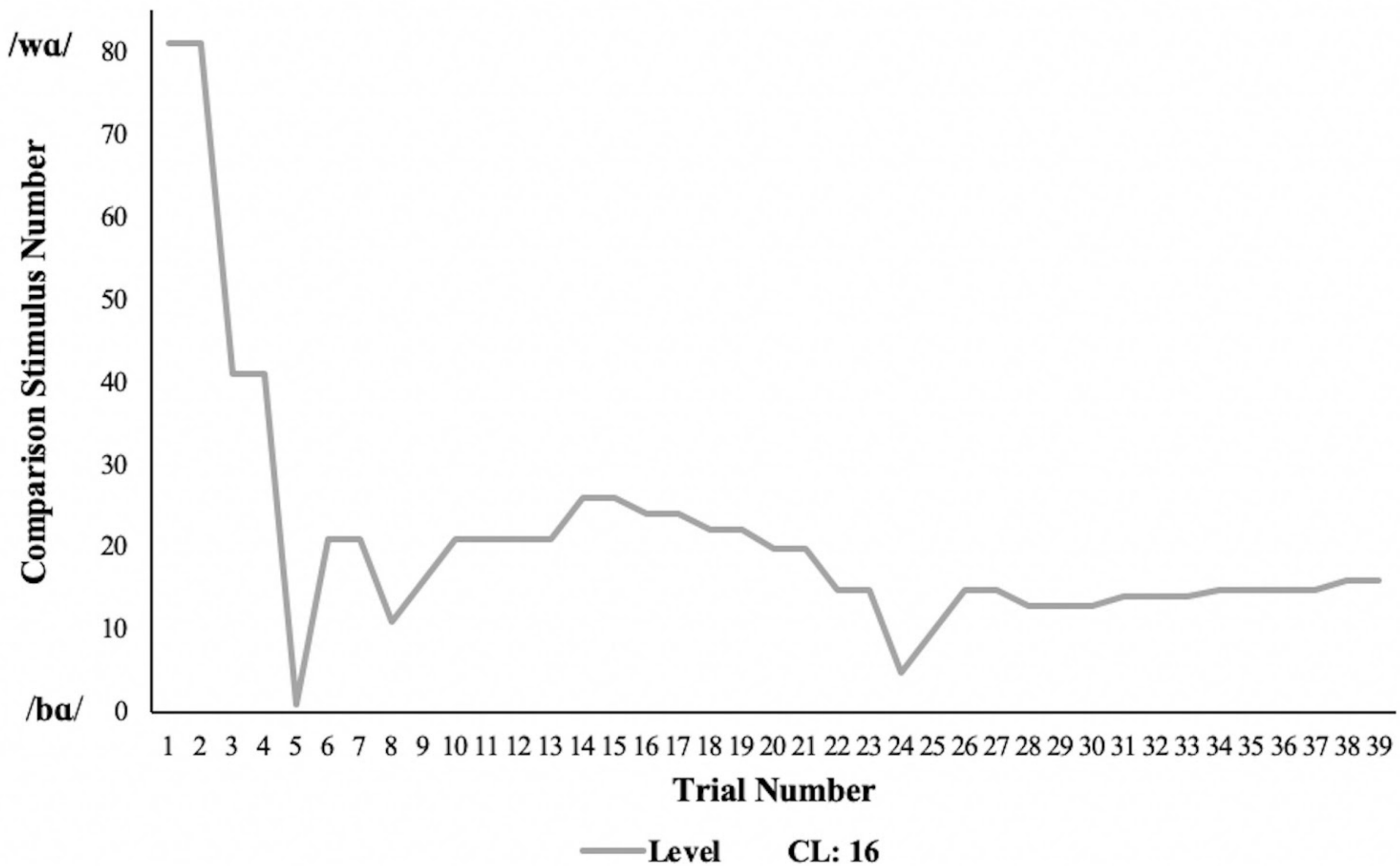
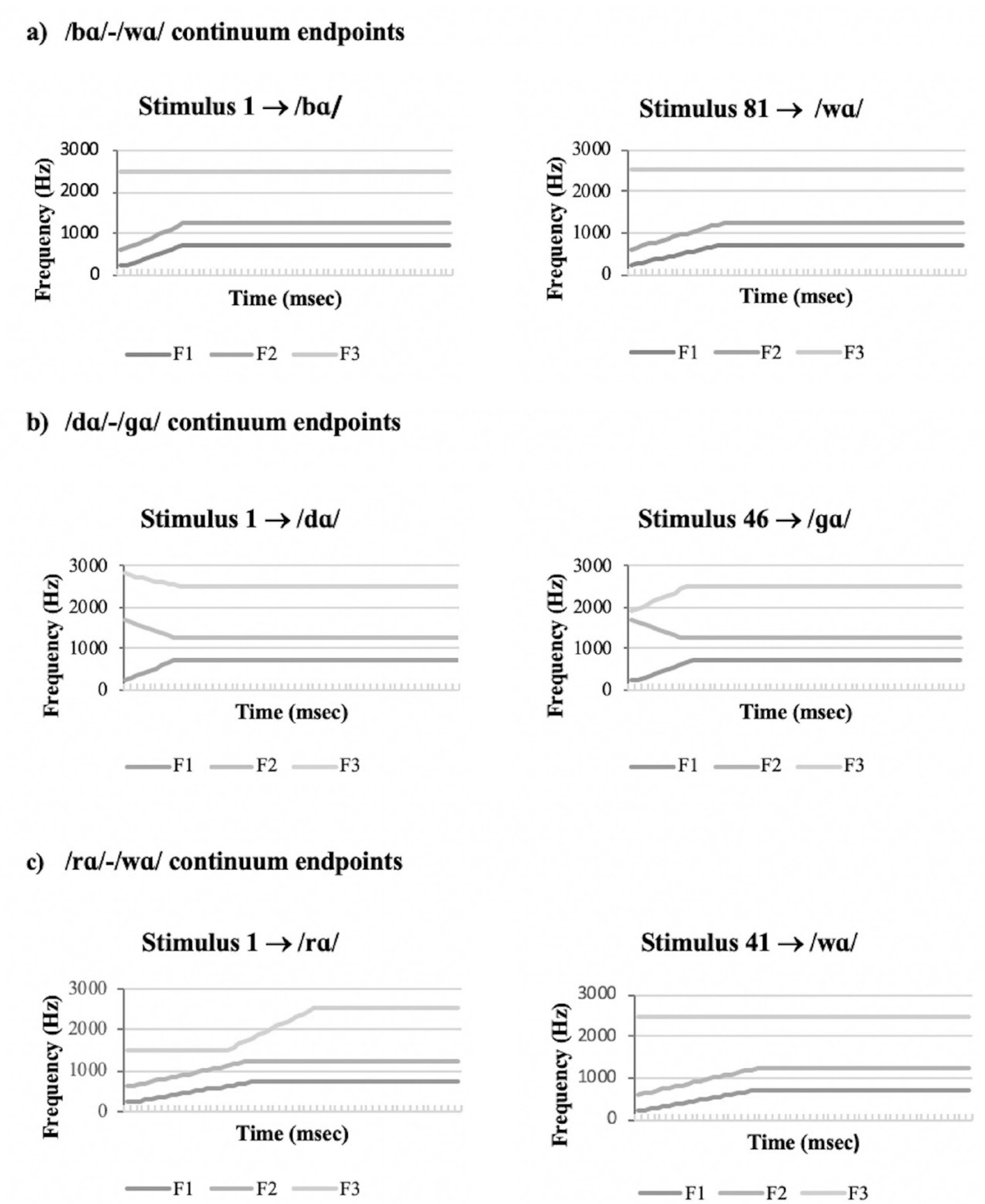


Figure 2

Visual Representation of Each Stimuli Continuum Endpoints



Note. a) /bɑ/-/wɑ/; b) /dɑ/-/gɑ/; c)/rɑ/-/wɑ/

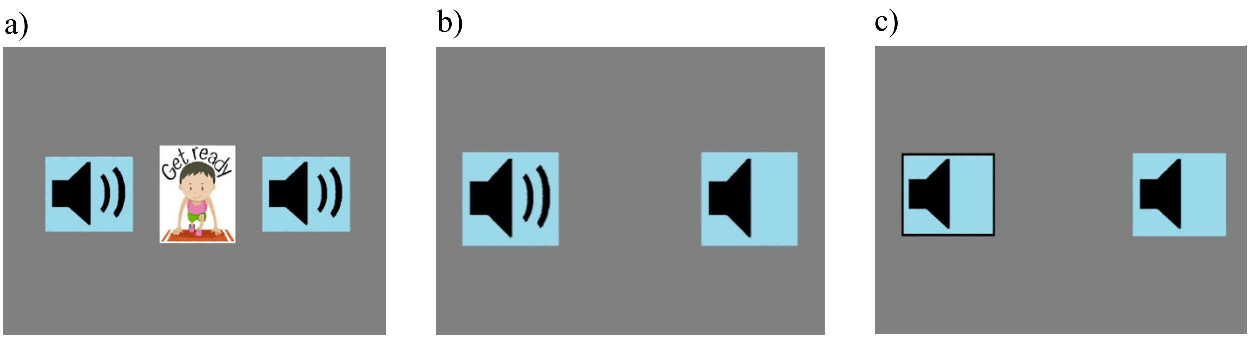
Procedures

Each participant in the two groups of children completed two sessions which included baseline testing of speech and language as well as completing the WRAAS task. Total testing time ranged from 60-90 minutes. The participants in the TD adult group completed a single session in which they participated in a hearing screening and the WRAAS task. Data collection occurred in a quiet room (sound booth, quiet room in lab, or quiet room in child's home) with a maximum of two weeks between sessions. The discrimination stimuli were presented on a Dell Latitude E6500 using a Creative SB1700 Sound Card and Sennheisr HD280 Pro closed, circumaural headphones. The calibration process was standardized across sessions. The stimuli were calibrated to 72 dB SPL with all stimuli having the same amplitude. On the computers, volume was set to a consistent level, but participants were allowed to adjust the volume to a comfortable loudness level.

Each participant began with a sample stimulus continuum, /bɑ/-/pɑ/ for training to ensure understanding of the task. A graphics interface tailored towards school-aged children was created in order to make the program engaging for the participants (shown in Figure 3). For each pair of stimuli presented, including the practice stimuli, the participant was presented with instructions on the computer screen. The stimuli were then presented auditorily in two sets of pairs (shown in Figure 3). One pair presented two of the exact same syllable. The other pair presented one set syllable and one syllable from any point along the continuum. The order of the presented stimulus pairs was randomized with each presentation in order to avoid learning effects. The listener indicated which presented pair sounded different through pressing a button on a two-button response box. The correct pair was then indicated irrespective of the listener's choice. The acoustic difference between the stimuli for each new presentation was based upon the accuracy of the participant's former response, increasing or decreasing the steps along the continuum until the patient reached 71% accuracy, or the CL. Thus, CL for /ba/-/wa// refers to the difference in milliseconds, for /da/-/ga/ the difference in Hz (F3 onset frequency), and for /ra/-/wa/ the difference in Hz (height in the third formant frequency). The presentation of the stimuli was counterbalanced to avoid order effects. Data were collected throughout the administration of the task and then transferred into an Excel spreadsheet for analysis.

Figure 3

Computer Image Sequence of Each Trial



Note. a) The screen before the syllables are presented. b) The screen when the first pair of syllables was presented; this indicates the first sound as the sounds are on the left. c) The screen when the participant has picked the first choice, the square indicates which of the syllable pairs the participants has chosen.

Research Design

This study was conducted as a between group comparison. As this study is meant to describe and compare the speech perception between children with and without SSD as well as typically developing adults, this design fits the requirements of the study.

The independent variables within this study were the age and speech abilities/history of each participant and the specific stimuli that were presented. The primary dependent variables were *convergence level* (CL), average *reaction time*, and the *number of trials* it took for the participant to reach the convergence level.

Results

The primary purpose of this study was to measure the speech perception of children with SSD and compare it to the speech perception of TD children and adults. The secondary purpose of this study was to determine the relationship between task demands and perception level in all three groups to determine whether the WRAAS task equalizes effort when measuring and comparing speech perception abilities. Hypotheses based on previous research were: 1) that the CLs of children with SSD would significantly differ from adults on all CV syllable contrast pairs, but only differ from TD children in the sounds they misarticulated (/rɑ/-/wɑ/) and 2) that the task demands, as measured by number of trials required to reach the CL and average reaction time would be similar for all three groups.

Perception (CL)

Summary Statistics

A summary of convergence level findings grouped by syllable contrast pair (/bɑ/-/wɑ/, /dɑ/-/gɑ/, /rɑ/-/wɑ/) and population (adult, TD children, children with SSD) is provided in Table 1. Box plots representing the shape, variability, and center of each distribution are shown in Figure 4. The box plots showed asymmetry evidenced by outliers in the CL scores per group, suggestive of nonnormality of the distributions. Values of the interquartile range (IQR) across the /bɑ/-/wɑ/ and /dɑ/-/gɑ/ syllable contrasts were largest for children with SSD, followed by TD children and adults, respectively. These IQR values indicate larger within-group variability for children with SSD relative to TD children and adults. The /rɑ/-/wɑ/ syllable contrast showed the largest IQR for children with SSD, adults, and TD children, respectively.

Normality in the distributions of CL scores by group was assessed using the Shapiro-Wilk test for normality and Kolmogorov-Smirnov goodness of fit test (see Table 2). Distribution of CL scores per group for the /bɑ/-/wɑ/ contrast were skewed for all groups, for adults and TD children for the /dɑ/-/gɑ/ contrast, and for TD children for the /rɑ/-/wɑ/ contrast. This provides evidence of nonnormality in six of nine distributions, prompting the use of the Mann-Whitney *U* test for statistical comparison of group differences.

Table 1

Summary Statistics for Convergence Level (CL) Grouped by Syllable Contrast Pair and Group

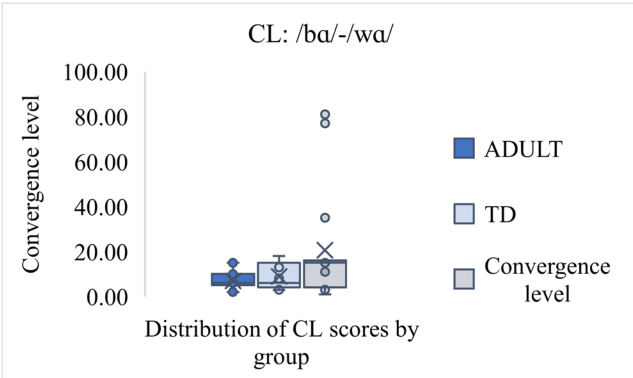
		/bɑ/-/wɑ/			/dɑ/-/gɑ/			/rɑ/-/wɑ/		
Variable		Adults	TD	SSD	Adults	TD	SSD	Adults	TD	SSD
N		31	15	15	31	15	15	31	15	15
Mean		6.90	8.93	20.60	11.68	14.93	20.40	14.84	12.20	21.27
Std. Error of Mean		0.65	1.36	6.49	1.63	3.43	3.47	1.48	1.89	3.21
Median		6.00	6.00	15.00	8.00	9.00	18.00	15.00	11.00	22.00
Mode		6.00	6.00*	15.00	8.00	3.00*	6.00*	2.00*	7.00*	36.00
Std. Deviation		3.59	5.23	25.13	9.06	13.27	13.42	8.21	7.32	12.41
Range		13.00	15.00	80.00	35.00	41.00	42.00	37.00	31.00	37.00
Minimum		2.00	3.00	1.00	2.00	3.00	3.00	2.00	3.00	1.00
Maximum		15.00	18.00	81.00	37.00	44.00	45.00	39.00	34.00	38.00
Sum		214	134	309	362	224	306	460	183	319
	25	5.00	4.00	4.00	6.00	6.00	8.00	10.00	8.00	11.00
Percentiles	50	6.00	6.00	15.00	8.00	9.00	18.00	15.00	11.00	22.00
	75	10.00	15.00	16.00	14.00	20.00	33.00	20.00	15.00	36.00
IQR		5.00	11.00	12.00	8.00	14.00	25.00	10.00	7.00	25.00

Note. CL = convergence level; TD = typically developing children; SSD = children with speech sound disorders; IQR = interquartile range; *more than one mode

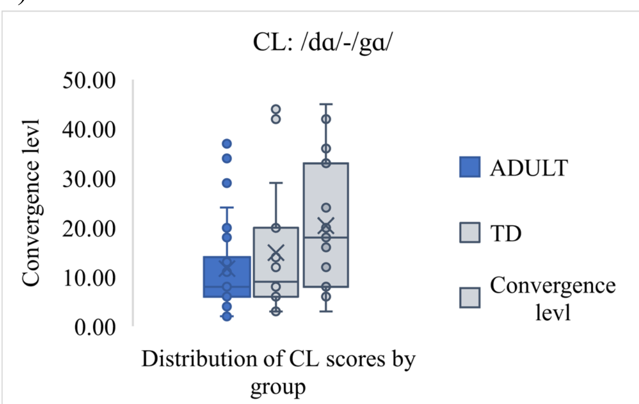
Figure 4

Boxplots for Convergence Level (CL) by Group

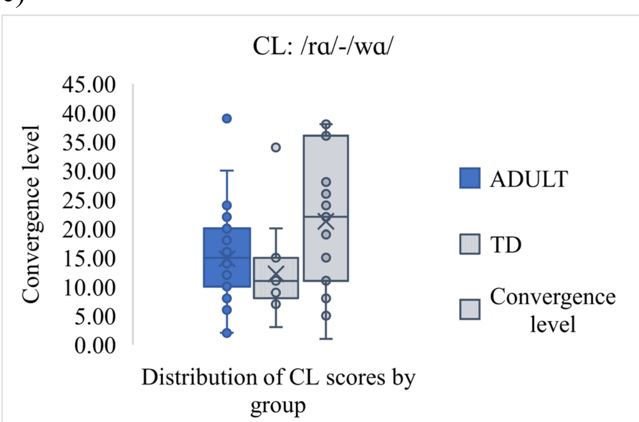
a)



b)



c)



Note. a) /bɑ/-/wɑ/; b) /dɑ/-/gɑ/; c) /rɑ/-/wɑ/; CL = convergence level; TD = typically developing children; SSD = children with speech sound disorders

Table 2

Test of Normality for Convergence Level (CL)

Stimuli		Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	*df*	Sig.	Statistic	*df*	Sig.
/bɑ/-/wɑ/	A	0.309	31	0.000	0.870	31	0.001
	TD	0.245	15	0.016	0.864	15	0.028
	SSD	0.373	15	0.000	0.681	15	0.000
/dɑ/-/gɑ/	A	0.238	31	0.000	0.824	31	0.000
	TD	0.261	15	0.007	0.795	15	0.003
	SSD	0.128	15	0.200	0.932	15	0.292
/rɑ/-/wɑ/	A	0.092	31	0.200	0.956	31	0.221
	TD	0.244	15	0.016	0.811	15	0.005
	SSD	0.149	15	0.200	0.939	15	0.366

Note. CL = convergence level; A = adults; TD = typically developing children; SSD = children with speech sound disorders

Syllable Contrast Comparisons

A Mann-Whitney *U* test was run in order to determine potential differences in perception as measured by the CL score for each syllable contrast pair and group. This revealed a statistically significant difference between adults and children with SSD for /bɑ/-/wɑ/ and /dɑ/-/gɑ/ as well as TD children and children with SSD for /rɑ/-/wɑ/. These findings are reported in Table 3. We will review each of the comparisons below.

Table 3

Mann-Whitney U Test Results Comparison of Convergence Level (CL) by Syllable Contrast and Group

		Mann-Whitney *U*						Effect Size
Stimuli	Pairwise comparison	Mean Rank			*U* Value	z score	*p*	Hedges' *g*
		A	TD	SSD				
/bɑ/-/wɑ/	A-TD	22.10	26.40	N/A	189.0	-1.035	0.301	0.49
	A-SSD	20.52	N/A	29.67	140.0	-2.190	0.029	0.94
	TD-SSD	N/A	13.77	17.23	86.5	-1.088	0.276	0.64
/dɑ/-/gɑ/	A-TD	22.44	25.70	N/A	199.5	-0.777	0.437	0.31
	A-SSD	20.50	N/A	29.70	139.5	-2.187	0.029	0.82
	TD-SSD	N/A	13.47	17.53	82.0	-1.268	0.205	0.41
/rɑ/-/wɑ/	A-TD	25.35	19.67	N/A	175.0	-1.350	0.177	0.33
	A-SSD	21.21	N/A	28.23	161.5	-1.666	0.096	0.66
	TD-SSD	N/A	12.10	18.90	61.5	-2.119	0.034	0.89

Note. CL = convergence level; A = adults; TD = typically developing children; SSD = children with speech sound disorders

Visual inspection of the CL score distributions for /bɑ/-/wɑ/ revealed only CL scores between adults (mean rank = 20.52) and children with SSD (mean rank = 29.67), $U = 140.0$, $z = -2.190$, $p = 0.029$, were significantly different for the syllable contrast /bɑ/-/wɑ/. That is, children with SSD showed poorer discrimination than adults for this contrast. All other comparisons between the CL scores for /bɑ/-/wɑ/ between groups (Adults vs. TD, TD vs SSD) were not significantly different (all *p*s > .05).

Distribution of the CL scores for /dɑ/-/gɑ/ were similar for adults compared to TD children, but not for children with SSD compared to the other two groups as assessed by visual inspection. Results of the Mann-Whitney *U* test revealed that CL scores between adults (mean rank = 20.50) and children with SSD (mean rank = 29.70), $U = 139.5$, $z = -2.187$, $p = 0.029$ were significantly different, again demonstrating that children with SSD, as a group, showed poorer discrimination than adults for this contrast. All other comparisons between groups (Adults vs TD, TD vs SSD) for /dɑ/-/gɑ/ were not significantly different (all *p*s > .05).

Distribution of CL scores for /rɑ/-/wɑ/ as assessed by visual inspection revealed few similarities across groups. Unlike the previous two syllable pairs, the Mann-Whitney *U* test for /rɑ/-/wɑ/ indicated that only the CL scores between TD children (mean rank = 12.10) and children with SSD differed (mean rank = 18.90), $U = 61.5$, $z = -2.119$, $p = 0.034$) demonstrating that children with SSD showed poorer discrimination than the TD children. All other comparisons (Adults vs. TD, Adults vs. SSD) for /rɑ/-/wɑ/ were not significantly different (all p*s* > .05).

Effect Size

Table 3 shows the effect sizes for all CL distributions. Hedges' *g* calculations, used because of the different sample sizes between groups, revealed medium effect sizes for the /bɑ/-/wɑ/ contrast when comparing the distribution of CL scores for adults versus TD children as well as TD children and children with SSD. The comparison between adults and children with SSD revealed a large effect size. A similar pattern occurred in the effect sizes for the CV syllable contrast /dɑ/-/gɑ/; however, the effect sizes for the comparison of adults vs. TD children and TD children vs children with SSD were small instead of moderate. The effect size was again large for the comparison of adults and children with SSD. The effect size for CV syllable contrast /rɑ/–/wɑ/ was small when comparing CL scores between adults versus TD children, medium between adults versus children with SSD, and large between TD children vs. children with SSD.

Average Reaction Time

Summary Statistics

A summary of the average reaction time by syllable contrast and pair group is provided in Table 4. Box plots representing the shape, variability, and center of each distribution are shown in Figure 5.

Normality in the distributions of reaction time by population was assessed using the Shapiro-Wilk test for normality and Kolmogorov-Smirnov goodness of fit test (see Table 5). Distribution of reaction time per group for /bɑ/-/wɑ/ was skewed for adults and TD children, but not for children with SSD. They were also skewed for TD children in both the /dɑ/-/gɑ/ and /rɑ/-/wɑ/ syllable contrasts. This provides evidence of nonnormality in four of nine distributions, prompting the use of the Mann-Whitney *U* test for statistical comparison of group differences.

Table 4

Summary Statistics for Average Reaction Time Grouped by Syllable Contrast Pair and Group

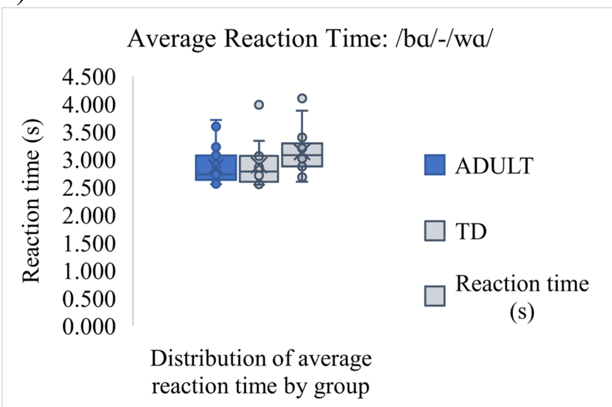
		/bɑ/-/wɑ/			/dɑ/-/gɑ/			/rɑ/-/wɑ/		
Variable		Adults	TD	SSD	Adults	TD	SSD	Adults	TD	SSD
N		31	15	15	31	15	15	31	15	15
Mean		2.86	2.89	3.13	2.79	2.94	3.15	2.84	2.98	3.22
Std. Error of Mean		0.05	0.10	0.11	0.05	0.13	0.11	0.05	0.13	0.01
Median		2.72	2.78	3.07	2.76	2.85	3.04	2.77	2.86	3.15
Mode		2.54*	2.54*	2.59*	2.39*	2.54*	2.64*	2.41*	2.48*	2.90*
Std. Deviation		0.31	0.38	0.42	0.25	0.51	0.43	0.27	0.52	0.26
Range		1.16	1.44	1.51	1.10	2.12	1.35	0.99	2.17	0.74
Minimum		2.55	2.54	2.59	2.39	2.54	2.64	2.41	2.48	2.90
Maximum		3.70	3.98	4.10	3.49	4.66	3.99	3.40	4.66	3.63
Sum		88.77	43.38	46.97	86.62	44.16	47.20	88.01	44.71	48.37
Percentiles	25	2.63	2.59	2.87	2.64	2.64	2.78	2.63	2.74	2.94
	50	2.72	2.78	3.07	2.76	2.85	3.04	2.77	2.86	3.15
	75	3.07	3.06	3.29	2.94	3.01	3.45	3.12	3.02	3.43
IQR		0.44	0.47	0.42	0.18	0.37	0.67	0.49	0.28	0.49

Note. TD = typically developing children; SSD = children with speech sound disorders; IQR = interquartile range; *more than one mode

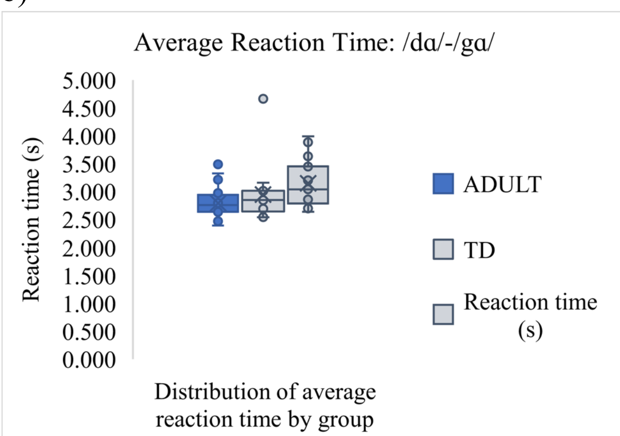
Figure 5

Boxplots for Average Reaction Time by Group

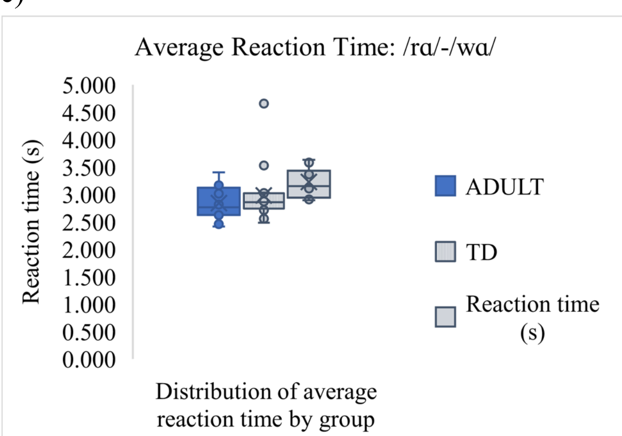
a)



b)



c)



Note. a) /bɑ/-/wɑ/; b) dɑ/-/gɑ/; c) /rɑ/-/wɑ/; TD = typically developing children;

SSD = children with speech sound disorders

Table 5

Test of Normality for Average Reaction Time

		Kolmogorov-Smirnov			Shapiro-Wilk		
Stimuli		Statistic	*df*	Sig.	Statistic	*df*	Sig.
/bɑ/-/wɑ/	A	0.196	31	0.004	0.861	31	0.001
	TD	0.183	15	0.187	0.821	15	0.007
	SSD	0.156	15	0.200	0.908	15	0.125
/dɑ/-/gɑ/	A	0.104	31	0.200	0.954	31	0.196
	TD	0.287	15	0.002	0.631	15	0.000
	SSD	0.180	15	0.200	0.912	15	0.147
/rɑ/-/wɑ/	A	0.123	31	0.200	0.947	31	0.130
	TD	0.324	15	0.000	0.676	15	0.000
	SSD	0.171	15	0.200	0.911	15	0.139

Note. A = adults; TD = typically developing children; SSD = children with speech sound disorders

Syllable Contrast Comparisons

The findings of the Mann-Whitney *U* tests, calculated to determine group differences in average reaction time required to complete each trial, revealed statistically significant differences between adults and children with SSD in all syllable contrast pairs (/bɑ/-/wɑ/: $p = 0.017$; /dɑ/-/gɑ/: $p = 0.005$; /rɑ/-/wɑ/: $p = 0.001$, such that children with SSD had longer average reaction times than adults. There was a statistically significant difference between children with SSD and TD children in the /rɑ/-/wɑ/ syllable contrast only ($p = 0.002$), demonstrating that children with SSD took, on average, longer to respond than their TD peers (see Table 6). There was no difference in average reaction time between children with SSD and TD children for /bɑ/-/wɑ/ ($p = 0.440$) or /dɑ/-/gɑ/ ($p = 0.078$).

Table 6

Mann-Whitney U Test Results Comparison of Average Reaction Time by Group

		Mann-Whitney *U*						Effect Size
Stimuli	Pairwise comparison	Mean Rank			*U* Value	z score	*p*	Hedges' *g*
		A	TD	SSD				
/bɑ/-/wɑ/	A-TD	23.48	23.53	N/A	232.0	-0.012	0.991	0.09
	A-SSD	20.23	N/A	30.27	131.0	-2.378	0.017	0.77
	TD-SSD	N/A	12.27	18.73	64.0	-2.012	0.440	0.60
/dɑ/-/gɑ/	A-TD	21.97	26.67	N/A	185.0	-1.113	0.266	0.42
	A-SSD	19.61	N/A	31.53	112.0	-2.824	0.005	1.13
	TD-SSD	N/A	12.67	18.33	70.0	-1.763	0.078	0.45
/rɑ/-/wɑ/	A-TD	22.32	25.93	N/A	196.0	-0.855	0.392	0.38
	A-SSD	18.39	N/A	34.07	74.0	-3.714	0.000	1.42
	TD-SSD	N/A	10.60	20.40	39.0	-3.049	0.002	0.58

Note. A = adults; TD = typically developing children; SSD = children with speech sound disorders

Effect Size

The effect sizes for the reaction time are reported in Table 6. All effect sizes were calculated using Hedges' *g* due to the different sample sizes between each group. These calculations revealed small effect sizes for the syllable contrast /bɑ/-/wɑ/ when comparing adults and TD children, and medium effect sizes when comparing children with SSD with both adults and TD children. With the /dɑ/-/gɑ/ syllable contrast, Hedges' *g* revealed small effect sizes when comparing adults with TD children and TD children with children with SSD. The comparison of the reaction time between adults and children with SSD revealed a large effect size. In the /rɑ/-/wɑ/ syllable contrast, Hedges' *g* revealed a small effect size between adults and TD children, a large effect size between adults and children with SSD and a medium effect size between TD children and children with SSD.

Correlations

A Pearson's product moment correlation was run to determine correlations between the CL and the reaction time specific to each CV syllable contrast pair as well as the correlations between each reaction time (see Table 7). When calculated with the data from each group combined, the analysis revealed significant correlations between reaction time and CL for both the /bɑ/-/wɑ/ and /dɑ/-/gɑ/ syllable contrasts, indicating that if a participant demonstrated poorer perception (higher CL score) they also took more time on average to complete each trial. The data from all groups together also revealed statistically significant correlations across all reaction times (all ps < 0.00), indicating that when someone took a longer or shorter amount of time to respond to each trial on one syllable contrast, they were likely to demonstrate similar reaction times on the other syllable contrasts.

When groups were split between adults (Table 8), TD children (Table 9), and children with SSD (Table 10) the analysis of adults revealed no significant correlations between CL and reaction time, however all RT continued to have a significant correlation (ps < 0.00). This pattern continues in TD children, with the exception of a significant correlation between the /rɑ/-/wɑ/ CL and the /rɑ/-/wɑ/ reaction time ($p = 0.01$). In children with SSD, there was no significant correlation between CL and reaction time for any of the syllable contrast pairs. When comparing reaction times, /bɑ/-/wɑ/ to /dɑ/-/gɑ/ ($p = 0.002$) and /bɑ/-/wɑ/ to /rɑ/-/wɑ/ ($p = 0.044$) were statistically significant, but /dɑ/-/gɑ/ to /rɑ/-/wɑ/ ($p = 0.059$) was not.

Table 7

Pearson's Product Moment Correlation for Average Reaction Time and Convergence Level (CL) for All Groups Combined

		/bɑ/-/wɑ/ CL	/bɑ/-/wɑ/ RT	/dɑ/-/gɑ/ CL	/dɑ/-/gɑ/ RT	/rɑ/-/wɑ/ CL	/rɑ/-/wɑ/ RT
/bɑ/-/wɑ/ CL	Pearson Correlation	1.000					
	Sig. (2-tailed)						
/bɑ/-/wɑ/ RT	Pearson Correlation	0.336	1.000				
	Sig. (2-tailed)	0.008					
/dɑ/-/gɑ/ CL	Pearson Correlation	0.283	0.209	1.000			
	Sig. (2-tailed)	0.027	0.106				
/dɑ/-/gɑ/ RT	Pearson Correlation	0.283	0.797	0.074	1.000		
	Sig. (2-tailed)	0.027	0.000	0.570			
/rɑ/-/wɑ/ CL	Pearson Correlation	0.354	0.180	0.213	0.210	1.000	
	Sig. (2-tailed)	0.005	0.166	0.100	0.104		
/rɑ/-/wɑ/ RT	Pearson Correlation	0.400	0.714	0.184	0.779	0.368	1.000
	Sig. (2-tailed)	0.001	0.000	0.155	0.000	0.004	

Note. RT = average reaction time

Table 8

Pearson's Product Moment Correlation for Average Reaction Time and Convergence Level (CL) for Adults

		/bɑ/-/wɑ/ CL	/bɑ/-/wɑ/ RT	/dɑ/-/gɑ/ CL	/dɑ/-/gɑ/ RT	/rɑ/-/wɑ/ CL	/rɑ/-/wɑ/ RT
/bɑ/-/wɑ/ CL	Pearson Correlation	1.000					
	Sig. (2-tailed)						
/bɑ/-/wɑ/ RT	Pearson Correlation	0.099	1.000				
	Sig. (2-tailed)	0.596					
/dɑ/-/gɑ/ CL	Pearson Correlation	-0.019	0.131	1.000			
	Sig. (2-tailed)	0.917	0.484				
/dɑ/-/gɑ/ RT	Pearson Correlation	0.355	0.695	-0.282	1.000		
	Sig. (2-tailed)	0.050	0.000	0.124			
/rɑ/-/wɑ/ CL	Pearson Correlation	0.196	-0.066	0.015	-0.017	1.000	
	Sig. (2-tailed)	0.290	0.722	0.934	0.927		
/rɑ/-/wɑ/ RT	Pearson Correlation	0.164	0.627	-0.075	0.602	-0.110	1.000
	Sig. (2-tailed)	0.378	0.000	0.689	0.000	0.556	

Note. RT = average reaction time

Table 9

Pearson's Product Moment Correlation for Average Reaction Time and Convergence Level (CL) for TD Children

		/bɑ/-/wɑ/ CL	/bɑ/-/wɑ/ RT	/dɑ/-/gɑ/ CL	/dɑ/-/gɑ/ RT	/rɑ/-/wɑ/ CL	/rɑ/-/wɑ/ RT
/bɑ/-/wɑ/ CL	Pearson Correlation	1.000					
	Sig. (2-tailed)						
/bɑ/-/wɑ/ RT	Pearson Correlation	0.327	1.000				
	Sig. (2-tailed)	0.235					
/dɑ/-/gɑ/ CL	Pearson Correlation	0.288	0.169	1.000			
	Sig. (2-tailed)	0.299	0.546				
/dɑ/-/gɑ/ RT	Pearson Correlation	0.343	0.936	0.221	1.000		
	Sig. (2-tailed)	0.211	0.000	0.428			
/rɑ/-/wɑ/ CL	Pearson Correlation	0.466	0.649	0.383	0.751	1.000	
	Sig. (2-tailed)	0.080	0.009	0.159	0.001		
/rɑ/-/wɑ/ RT	Pearson Correlation	0.436	0.900	0.237	0.950	0.753	1.000
	Sig. (2-tailed)	0.104	0.000	0.394	0.000	0.001	

Note. RT = average reaction time; TD = typically developing.

Table 10

Pearson's Product Moment Correlation for Average Reaction Time and Convergence Level (CL) for Children With SSD

		/bɑ/-/wɑ/ CL	/bɑ/-/wɑ/ RT	/dɑ/-/gɑ/ CL	/dɑ/-/gɑ/ RT	/rɑ/-/wɑ/ CL	/rɑ/-/wɑ/ RT
/bɑ/-/wɑ/ CL	Pearson Correlation	1.000					
	Sig. (2-tailed)						
/bɑ/-/wɑ/ RT	Pearson Correlation	0.349	1.000				
	Sig. (2-tailed)	0.202					
/dɑ/-/gɑ/ CL	Pearson Correlation	0.275	0.097	1.000			
	Sig. (2-tailed)	0.320	0.731				
/dɑ/-/gɑ/ RT	Pearson Correlation	0.152	0.735	-0.151	1.000		
	Sig. (2-tailed)	0.590	0.002	0.591			
/rɑ/-/wɑ/ CL	Pearson Correlation	0.322	-0.038	0.148	-0.147	1.000	
	Sig. (2-tailed)	0.242	0.893	0.599	0.600		
/rɑ/-/wɑ/ RT	Pearson Correlation	0.554	0.536	-0.072	0.498	0.500	1.000
	Sig. (2-tailed)	0.032	0.044	0.800	0.059	0.058	

Note. RT = average reaction time; SSD = speech sound disorders.

Number of Trials

Summary Statistics

A summary of findings by syllable contrast and pair group is provided in Table 11. Box plots representing the shape, variability, and center of each distribution are shown in Figure 6.

Normality in the distributions of reaction time by group was assessed using the Shapiro-Wilk test for normality and the Kolmogorov-Smirnov goodness of fit test (see Table 12). Distribution of number of trials per group was skewed for children with SSD in both the /dɑ/-/gɑ/ and /rɑ/-/wɑ/ syllable contrasts. All other distributions were normal. This provides evidence of nonnormality in two of the nine distributions, prompting the use of a Mann Whitney *U* test for statistical comparison of group differences.

Table 11

Summary Statistics for Number of Trials Grouped by Syllable Contrast Pair and Group

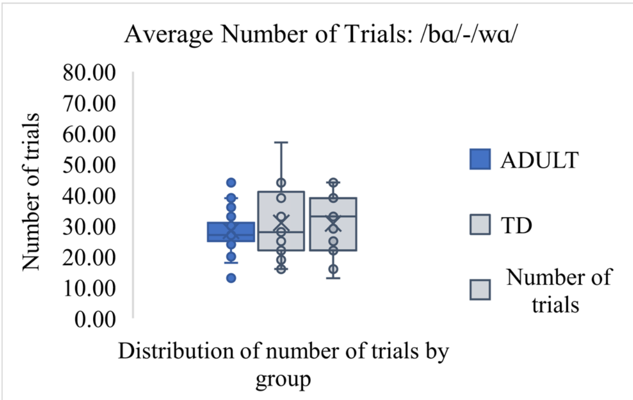
		/bɑ/-/wɑ/			/dɑ/-/gɑ/			/rɑ/-/wɑ/		
Variable		Adults	TD	SSD	Adults	TD	SSD	Adults	TD	SSD
N		31	15	15	31	15	15	31	15	15
Mean		28.35	31.00	30.89	27.06	23.73	26.13	25.74	29.60	29.67
Std. Error of Mean		1.32	3.17	2.63	2.26	2.87	3.13	1.84	3.09	4.50
Median		27.00	28.00	33.00	25.00	21.00	22.00	25.00	29.00	25.00
Mode		25.00*	16.00*	44.00	11.00*	13.00	15.00	16.00	18.00	13.00*
Std. Deviation		7.33	12.28	10.20	12.58	11.18	12.14	10.22	11.95	17.44
Range		32.00	41.00	31.00	46.00	37.00	18.00	36.00	42.00	61.00
Minimum		13.00	16.00	13.00	9.00	8.00	15.00	11.00	13.00	13.00
Maximum		45.00	57.00	44.00	55.00	45.00	53.00	47.00	55.00	74.00
Sum		879.00	465.00	462.00	839.00	356.00	392.00	798.00	444.00	445.00
Percentiles	25	25.00	22.00	22.00	18.00	13.00	15.00	16.00	18.00	15.00
	50	27.00	28.00	33.00	25.00	21.00	22.00	25.00	29.00	25.00
	75	31.00	41.00	39.00	33.00	30.00	36.00	34.00	38.00	43.00
IQR		6.00	19.00	17.00	15.00	17.00	21.00	18.00	20.00	28.00

Note. TD = typically developing children; SSD = children with speech sound disorders; IQR = interquartile range; *more than one mode

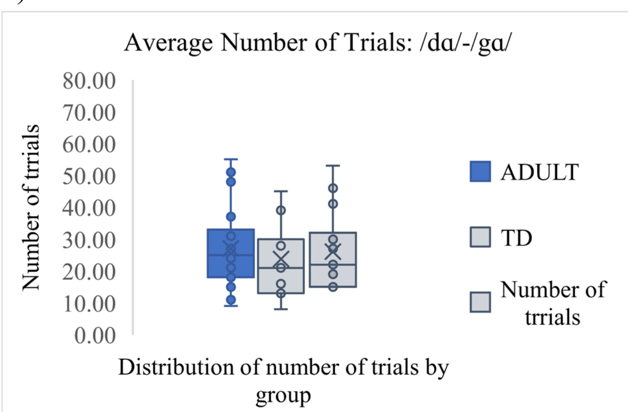
Figure 6

Boxplots for Number of Trials by Group

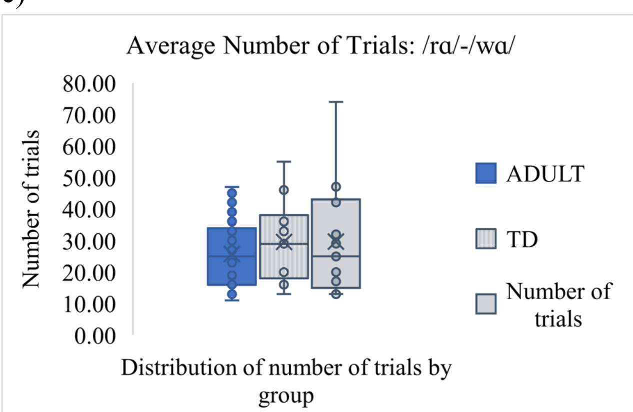
a)



b)



c)



Note. a) /bɑ/-/wɑ/; b /dɑ/-/gɑ/; c) /rɑ/-/wɑ/; TD = typically developing children; SSD = children with speech sound disorders

Table 12

Test of Normality for Number of Trials

		Kolmogorov-Smirnov			Shapiro-Wilk		
Stimuli		Statistic	*df*	Sig.	Statistic	*df*	Sig.
	A	0.133	31	0.171	0.960	31	0.284
/bɑ/-/wɑ/	TD	0.154	15	0.200	0.936	15	0.332
	SSD	0.123	15	0.200	0.937	15	0.348
	A	0.108	31	0.200	0.935	31	0.059
/dɑ/-/gɑ/	TD	0.130	15	0.200	0.937	15	0.342
	SSD	0.202	15	0.101	0.856	15	0.021
	A	0.163	31	0.036	0.945	31	0.112
/rɑ/-/wɑ/	TD	0.138	15	0.200	0.951	15	0.538
	SSD	0.177	15	0.200	0.859	15	0.024

Note. A = adults; TD = typically developing children; SSD = children with speech sound disorders

Syllable Contrast Comparisons

The findings of the Mann-Whitney *U* tests, calculated to determine potential differences in amount of effort necessary to complete the task as measured by number of trials required to determine CL score per CV syllable contrast pair and group, revealed no statistically significant differences between groups for each CV syllable contrast pair, as shown in Table 13 (all *p*s > .05).

Table 13

Mann-Whitney U Test Results Comparison of Number of Trials by Population

Mann-Whitney *U*								Effect Size
Stimuli	Pairwise comparison	Mean Rank			*U* Value	z score	*p*	Hedges' *g*
		A	TD	SSD				
/bɑ/-/wɑ/	A-TD	23.08	24.37	N/A	219.5	-0.305	0.760	0.29
	A-SSD	22.42	N/A	25.73	199.0	-0.787	0.431	0.30
	TD-SSD	N/A	15.30	15.70	109.5	-0.125	0.901	0.01
/dɑ/-/gɑ/	A-TD	24.53	21.37	N/A	200.5	-0.750	0.453	0.27
	A-SSD	23.97	N/A	22.53	218.0	-0.340	0.734	0.07
	TD-SSD	N/A	14.43	16.57	96.5	-0.665	0.506	0.21
/rɑ/-/wɑ/	A-TD	22.10	26.40	N/A	189.0	-1.021	0.307	0.38
	A-SSD	23.03	N/A	24.47	218.0	-0.340	0.734	0.30
	TD-SSD	N/A	16.30	14.70	100.5	-0.498	0.618	0.01

Note. A = adults; TD = typically developing children; SSD = children with speech sound disorders

Correlations

A Pearson's product moment correlation was run to determine any potential correlations between the CL and the number of trials specific to each CV syllable contrast pair. The correlations were run first with all of the data together, and then separated into different groups (see Tables 14-17). In the data as a whole, the only significant correlation occurred between the /rɑ/-/wɑ/ CL scores and the /rɑ/-/wɑ/ trials ($p = 0.038$). This correlation occurs in a negative direction, indicating that as the CL scores increase, the number of trials necessary to determine the CL decreases. This indicates that fewer trials were evident for participants with poorer perception on this contrast.

When the correlations were split into separate groups (adults, TD children, and children with SSD), a moderate negative correlation was found for the /rɑ/-/wɑ/ syllable contrast pair in children with SSD ($p = .004$).

Table 14

Pearson's Product Moment Correlation for Number of Trials and Convergence Level (CL) for All Populations

		/bɑ/-/wɑ/ CL	/bɑ/-/wɑ/ trials	/dɑ/-/gɑ/ CL	/dɑ/-/gɑ/ trials	/rɑ/-/wɑ/ CL	/rɑ/-/wɑ/ trials
/bɑ/-/wɑ/ CL	Pearson Correlation	1.000					
	Sig. (2-tailed)						
/bɑ/-/wɑ/ trials	Pearson Correlation	-0.119	1.000				
	Sig. (2-tailed)	0.360					
/dɑ/-/gɑ/ CL	Pearson Correlation	0.283	0.227	1.000			
	Sig. (2-tailed)	0.027	0.079				
/dɑ/-/gɑ/ trials	Pearson Correlation	-0.073	0.135	-0.240	1.000		
	Sig. (2-tailed)	0.575	0.301	0.062			
/rɑ/-/wɑ/ CL	Pearson Correlation	0.354	0.135	0.213	0.114	1.000	
	Sig. (2-tailed)	0.005	0.301	0.100	0.383		
/rɑ/-/wɑ/ trials	Pearson Correlation	-0.094	0.027	-0.074	0.091	-0.266	1.000
	Sig. (2-tailed)	0.470	0.837	0.572	0.488	0.038	

Table 15

Pearson's Product Moment Correlation for Number of Trials and Convergence Level (CL) for Adults

		/bɑ/-/wɑ/ CL	/bɑ/-/wɑ/ trials	/dɑ/-/gɑ/ CL	/dɑ/-/gɑ/ trials	/rɑ/-/wɑ/ CL	/rɑ/-/wɑ/ trials
/bɑ/-/wɑ/ CL	Pearson Correlation	1.000					
	Sig. (2-tailed)						
/bɑ/-/wɑ/ trials	Pearson Correlation	-0.323	1.000				
	Sig. (2-tailed)	0.077					
/dɑ/-/gɑ/ CL	Pearson Correlation	-0.019	-0.268	1.000			
	Sig. (2-tailed)	0.917	0.145				
/dɑ/-/gɑ/ trials	Pearson Correlation	0.087	-0.053	-0.298	1.000		
	Sig. (2-tailed)	0.641	0.777	0.103			
/rɑ/-/wɑ/ CL	Pearson Correlation	0.196	0.247	0.015	0.143	1.000	
	Sig. (2-tailed)	0.290	0.181	0.934	0.442		
/rɑ/-/wɑ/ trials	Pearson Correlation	-0.221	0.060	-0.157	-0.049	0.033	1.000
	Sig. (2-tailed)	0.231	0.747	0.399	0.793	0.861	

Table 16

Pearson's Product Moment Correlation for Number of Trials and Convergence Level (CL) for TD Children

		/bɑ/-/wɑ/ CL	/bɑ/-/wɑ/ trials	/dɑ/-/gɑ/ CL	/dɑ/-/gɑ/ trials	/rɑ/-/wɑ/ CL	/rɑ/-/wɑ/ trials
/bɑ/-/wɑ/ CL	Pearson Correlation	1.000					
	Sig. (2-tailed)						
/bɑ/-/wɑ/ trials	Pearson Correlation	-0.282	1.000				
	Sig. (2-tailed)	0.308					
/dɑ/-/gɑ/ CL	Pearson Correlation	0.288	0.592	1.000			
	Sig. (2-tailed)	0.299	0.020				
/dɑ/-/gɑ/ trials	Pearson Correlation	0.208	-0.394	-0.380	1.000		
	Sig. (2-tailed)	0.458	0.146	0.162			
/rɑ/-/wɑ/ CL	Pearson Correlation	0.466	0.044	0.383	-0.019	1.000	
	Sig. (2-tailed)	0.080	0.877	0.159	0.945		
/rɑ/-/wɑ/ trials	Pearson Correlation	-0.112	0.399	0.047	0.178	-0.034	1.000
	Sig. (2-tailed)	0.691	0.141	0.868	0.526	0.904	

Note. TD = typically developing

Table 17

Pearson's Product Moment Correlation for Number of Trials and convergence level (CL) for Children With SSD

		/bɑ/-/wɑ/ CL	/bɑ/-/wɑ/ trials	/dɑ/-/gɑ/ CL	/dɑ/-/gɑ/ trials	/rɑ/-/wɑ/ CL	/rɑ/-/wɑ/ trials
/bɑ/-/wɑ/ CL	Pearson Correlation	1.000					
	Sig. (2-tailed)						
/bɑ/-/wɑ/ trials	Pearson Correlation	-0.198	1.000				
	Sig. (2-tailed)	0.480					
/dɑ/-/gɑ/ CL	Pearson Correlation	0.275	0.236	1.000			
	Sig. (2-tailed)	0.320	0.396				
/dɑ/-/gɑ/ trials	Pearson Correlation	-0.229	-0.545	-0.053	1.000		
	Sig. (2-tailed)	0.412	0.036	0.851			
/rɑ/-/wɑ/ CL	Pearson Correlation	0.322	0.097	0.148	0.127	1.000	
	Sig. (2-tailed)	0.242	0.731	0.599	0.651		
/rɑ/-/wɑ/ trials	Pearson Correlation	-0.183	-0.367	-0.208	0.273	-0.697	1.000
	Sig. (2-tailed)	0.513	0.178	0.456	0.324	0.004	

Note. SSD = speech sound disorders

Discussion

The primary purpose of this study was to investigate the speech perception abilities of adults, TD children, and children with SSD and compare these abilities across groups. Speech perception was assessed using the WRAAS task, a tool that individualizes stimulus presentation to each participant based on his or her responses. This discrimination task utilizes an adaptive tracking algorithm (PEST; Taylor & Creelman, 1967) designed to determine perceptual abilities efficiently and effectively.

Perceptual Abilities

Perceptual skills were assessed using WRAAS. Mann Whitney U tests revealed three statistically significant differences between groups and when comparing CL for each CV syllable contrast pair. These included the comparison between adults and children with SSD on the /bɑ/-/wɑ/ and /dɑ/-/gɑ/ syllable contrasts, and between TD children and children with SSD on the /rɑ/-/wɑ/ syllable contrast. We noted that there were outliers in the SSD group for the /bɑ/-/wɑ/ syllable contrast pair. Future work may remove outliers to determine whether these participants inappropriately skew the results. It was not unexpected that children would differ from adults in speech perception as it is expected that speech perception is a skill that becomes more refined as children age (Hazan & Barrett, 2000; Nittrouer & Miller, 1997a, 1997b). However, the only statistically significant difference between adults and children was with the children with SSD, and on the two syllable contrasts that did not involve the speech errors that the children with SSD produced. Based on previous research, it was expected that the children with SSD would differ from adults on all CV syllable contrast pairs (Hitchcock et al., 2020). One possible explanation for this unexpected result is the disparity in sample size between the adults (n=31) and the children with SSD (n=15). This difference in sample sizes may have exceeded what is appropriate for the Mann Whitney U test.

While the comparison of CL scores between adults and children with SSD for the /rɑ/-/wɑ/ contrast was unexpected, the comparison between TD children and children with SSD for this same contrast matched what was hypothesized. Namely, the perception abilities between these two groups of children, as measured by CL scores, was significantly different in addition to having a large effect size. These results confirm what has been found in previous studies: children with SSD, on average, have poorer perception than their same-aged peers on the sounds they produce incorrectly (Cabbage, 2013; Hoffman et al., 1985). Clinically, this may explain the difficulty children with SSD have in their ability to identify their errored phonemes in speech production. This may also have negative effects in therapy and generalization of these sounds into their everyday speech if they have difficulty perceiving the correct production.

While the variability of CL scores within each group was not statistically analyzed, it is notable that a visual inspection of the standard deviations of CL across groups appeared to be quite different. Particularly with the /rɑ/-/wɑ/ syllable contrast (adult SD = 8.21; TD SD = 7.32; SSD SD = 12.41). Numerically, the SSD group had a larger standard deviation than the other two groups, indicating more variability in the speech perception abilities of the children with SSD compared to the adults and TD children. This may suggest that while some children with SSD have near typical perception, others have lower levels of speech perception. This variability matches what has been found in other studies as well (Hearnshaw et al., 2019; Rvachew & Jamieson, 1989). It is possible that the variability within children with SSD could be indicative of other factors. For example, children with poor perceptual skills may have a more difficult time acquiring the sound they perceive poorly while those with better perceptual skills may be able to move more quickly though therapy. It may also be indicative of children who began to receive therapy at an older age, and their perceptual abilities are a result, instead of a cause, of saying a sound in a particular way for so long because of the hypothesized bidirectional relationship between perception and production (Casserly & Pisoni, 2010). Further investigation is warranted to determine the characteristics of subgroups of children with SSD with varying perceptual skills and the impact these subgroups may have on understanding assessment and treatment of speech sound disorders.

Effort

A secondary purpose of this study was to determine if the WRAAS task equalized effort across populations and perceptual skill. In the case of the WRAAS task, we used the variables of average reaction time and the number of trials needed to determine the CL for each participant in each syllable contrast pair as dependent measures to examine effort amongst participants. Determining level of effort and differences in level of effort is important because if this task requires more effort in one population compared to another this would indicate that the different populations are performing different tasks. For example, if a child with poor perception takes longer to respond, requires more trials, or both to determine CL, then she would need to attend to the task for a longer amount of time. This would mean that the task was requiring more attention and effort than it would for a child or adult with a lower CL/better perception (Locke, 1980). Time to complete this task would then become a confounding variable and the scores may not be comparable.

A Mann Whitney *U* test revealed no statistically significant differences between any of the groups in number of trials required to determine CL. The Pearson's product moment correlation revealed one single significant correlation between the /rɑ/-/wɑ/ CL and the /rɑ/-/wɑ/ trials when all of the groups were combined. When separated by group, this trend only continued in the children with SSD. This correlation was negative. That is, for these participants, the WRAAS task required a smaller number of trials for the syllable contrasts that they did not perceive as well. This would indicate that the amount of effort in this task is lessened or equivalent for participants with better perceptual skill.

While the results from number of trials indicate an equalization of effort, the results from the reaction time do demonstrate some differences between groups. Results from the Mann

Whitney *U* test revealed statistically significant differences between adults and children with SSD for all syllable contrast pairs, and a statistically significant difference between TD children and children with SSD on the /rɑ/-/wɑ/ syllable contrast pair, all of these comparisons also had medium to large effect sizes. These differences match with what was found in the group comparison for CL scores in all but the adults and children with SSD on the /rɑ/-/wɑ/ syllable contrast which was not found to be statistically significant.

These results may indicate a connection between perceptual skills and processing speed, meaning that for those who have a wider range as to what is correct for a particular sound (i.e., the children with SSD have a higher point of JND between /w/ and /r/ compared to TD children and adults), it also may take more time to perceive the differences between those sounds. This is supported by results from Cabbage (2013), who found that children with SSD are less efficient and less automatic in their neural processes during phoneme categorization. This processing speed may affect all perception, indicative of the correlation between the reaction time between each syllable contrast pair. This significant correlation was evident for at least two of the syllable contrast pairs for each separated group, and for all pairs when the groups were all combined. This may indicate that with a larger sample size this perceptual trend would continue in each population but is not evident in the current data because of potential outliers confounding the correlational data.

These differences in reaction time could indicate that children with SSD appear to expend more effort when completing this task compared to the adults and their TD peers. In future research, adding up the total of all reaction times to determine the overall amount of time required to complete the task may provide a more specific determiner of total combined effort necessary to complete the task.

Limitations

Some limitations of this study have already been addressed, namely the relatively small and disproportionate sample sizes. It is difficult to compare and determine generalizable group differences with these smaller sample sizes. In addition, the disparity between the number of adults and the number of children in both groups is at the limits of what is recommended for a Mann Whitney *U* test (Lehmann, 2006). A second limitation was the groups not being gender matched. The majority of the adults and TD children were female while the majority of the children in the SSD group were male. This is not surprising as a diagnosis of SSD is more common in males than females (Campbell et al., 2003; Pennington & Bishop, 2009). However, if the groups were to be gender matched in the future, this could solve any concerns over disparities between speech perceptions between the two genders. These limitations can be addressed in future studies by using more participants and equalizing the number of participants between groups as well as gender matching the participants between groups.

Furthermore, the adult and TD children's groups did not receive formal language testing. Although typical language abilities were reported in both groups by the parents on the part of the children, and by observation of the current abilities of the adults, many of whom were undergraduate students in language-based majors at universities, without a formal language test, we cannot definitively report and compare language abilities between each of the groups. Controlling for language ability is important, given the known relationship between language skill and perceptual skill (Leonard et al., 1992; Tallal et al., 1980). This can be addressed in a future study by performing the same language assessment on all child participants and using an adult language assessment to determine language abilities in the adult group.

The setting for data collection was not held constant across participants. Some completed the task in a sound booth, while others completed it in a quiet setting at their home. While this decision was made with the intent to use WRAAS as it would be used in a clinical setting, this difference in settings could be a potential confounding variable. Those in a sound booth may have been able to perceive the differences between the syllable contrast pairs at a smaller JND compared to those who were not because of the elimination of incidental ambient noise.

Finally, the WRAAS task employs synthetic speech. While the use of synthetic speech allows for discrete control of acoustic variables in the stimuli, it lacks the naturalness of speech and may not demonstrate the participants' speech perception abilities in more natural, conversational or word-based contexts. Work is currently underway to control acoustic parameters within natural speech tokens for use in the WRAAS task.

Implications for Future Research

One of the next steps in this line of research would be to more closely analyze children with SSD. Although we limited the age and SSD diagnosis of children included here (e.g., exclusion of children with CAS), it is possible that children with SSD differed in other ways that were not captured in this study. This could include factors such as time spent in speech therapy or the number and type of speech sound errors. Due to the variability of perceptual skills in children with SSD, this could potentially determine if there are other factors that might explain the apparent variability in speech perception in children with SSD. For example, if children who have a hard time producing /r/ correctly after multiple years of therapy have lower perceptual abilities than others, this could explain why, and provide the justification for a new treatment approach, such as acoustic biofeedback or ultrasound.

Another step that will be important in further research is using a person's own voice instead of synthesized speech for the syllables. This could include recording the child, or adult, saying at least one of the syllables (i.e., /wa/) and then manipulating the consonant to follow the steps along a continuum similar to what has already been done with the WRAAS program. This would be useful because in speech therapy because children need to learn how to monitor their own speech production and identify which sounds are correct and which are incorrect. Without this ability, it would be difficult for children to generalize a corrected sound into their typical speech as they would not be able to initially identify if they are producing the sound correctly and would most likely continue with the sound placement that had been their habit up until that point.

This would expand the research of Shuster (1998). Shuster recorded the speech of 26 children (7;1-13;11) who produced /r/ incorrectly and broke them into two groups based on length of time in therapy. She presented each child with multiple recordings of their and another child's incorrect productions of a word as well as corrected productions and asked them to judge the correctness of each utterance and whether or not it was their own. All children in both groups had the most difficulty judging whether an incorrect utterance was correct or not. This indicates that these children have too broad of a range for what they consider correct production for the sounds that they produce incorrectly (Shuster, 1998). This could mean that in therapy, they would have difficulty knowing when their own speech was correct, which would make it difficult to generalize a corrected sound outside of therapy when there is not someone there to tell them when a sound is produced correctly or not. Due to length of task and difficulty with acoustically manipulating the children's incorrect utterances to sound correct, there have not been many opportunities to expand this line of research. Using the WRAAS task with recorded speech would allow for further research to be done without requiring as many recordings or perceptual trials from the children participating in the study. This could help to determine how children with SSD perceive their own speech in terms of correctness of the phoneme.

Implications for Practitioners

As research with the WRAAS task and speech perception goes forward, it has two connected clinical implications. First, in the future WRAAS may be a clinical tool that clinicians could use to determine whether poor speech perception is a contributing factor in a child's poor production of speech sounds. As is evidenced by the variation in the speech perception abilities of children with SSD, it appears that some children have difficulty with perceiving the differences between the phonemes they produce poorly, and some do not. With a task such as WRAAS used by clinicians, they could determine which children have difficulty with perception. This could then inform treatment as it would help clinicians to have more information about the underlying difficulty and know if teaching perception/auditory discrimination or using some other form of biofeedback that bypasses the auditory perceptual system would be helpful for the child to produce the phonemes correctly (Preston et al., 2020). For example, ultrasound biofeedback helps children to visualize where their tongue is while speaking (Preston et al., 2020). This provides a way for children to see and compare where their tongue is compared to where it should be to produce the sound correctly. This treatment approach has proved successful in increasing accuracy of sounds with children with SSD who have a range of perceptual abilities with their mispronounced sounds (Preston et al., 2020). Studies have also shown that training perceptual skills and auditory discrimination can be effective in increasing the speech production of children with SSD (Rvachew, 1994; Rvachew et al., 2004). Use of WRAAS in clinical settings would allow clinicians to quickly determine which children may benefit more from these additional forms of treatment.

Conclusions

The primary aim of this study was to compare the speech perception abilities of adults, TD children, and children with SSD. It was hypothesized that the children with SSD would perform more poorly on the syllables that they had difficulty producing (/rɑ/-/wɑ/). This hypothesis was partially confirmed as children with SSD performed significantly more poorly on this syllable contrast as compared to TD children. They did not perform significantly differently from adults on these syllables; however, this may be due to differences in sample size between the two groups. A secondary purpose of this study was to determine if WRAAS equalized the effort across each group and/or for individuals with differing levels of perceptual skill. Findings revealed that, on average, participants required relatively the same number of trials to determine CL, regardless of group status (e.g., adult, TD, SSD) or perception skill. The only significant correlation was between the CL and number of trials for /rɑ/-/wɑ/ and in a negative direction, indicating that those with lower perceptual ability for this contrast required fewer trials to determine CL. In contrast, the average reaction time was significantly different between adults and TD children on all syllable contrast pairs and between children with SSD and TD children on /rɑ/-/wɑ/. This, in addition to correlations between CL and average reaction time, as well as reaction times between syllables indicates that those with a poorer perceptual ability may also have slower processing skills. Further research is required to determine if this has a negative effect on the effort required to complete perceptual testing.

The WRAAS task may be used by researchers and clinicians. It has the potential to allow for an effective and efficient test of perceptual ability that will allow further research into the nature of speech perception skills among children with SSD as well as other groups. Future work should explore how it may be used by clinicians in the future to determine how to best differentiate treatment approaches for children with SSD.

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APPENDIX A

Annotated Bibliography

Casserly, E. D. & Pisoni, D. B. (2010). Speech perception and production. *WIREs Cognitive Science, 1*(5), 629-647. https://doi.org/10.1002/wcs.63

Objective: In this article, Casserly and Pisoni discuss the theories and concepts in speech perception research and speech production research. They then examine some of the recent steps being taken in research that combines the study of both of these aspects of speech.

Relevance to the current study: This is a theory-based paper that explores the theory of how speech perception and speech production are related. This is important because the current study assesses speech perception with the assumption that children who mis-articulate, or produce sounds, may also have difficulty with the perception of these same sounds.

Hearnshaw, S., Baker, E., & Munro, N. (2018). The speech perception skills of children with and without speech sound disorder. *Journal of Communication Disorders, 71*, 61-71. https://doi.org/10.1016/j.jcomdis.2017.12.004

Objective: This study examines the speech perception skills of children with and without SSD who speak Australian-English.

Methods: Twenty-five children participated in this study, 12 with SSD and 13 TD. The children with SSD were identified by scoring below the 16th percentile on the *Diagnostic Evaluation of Articulation and Phonology (DEAP)*. Both groups of children scored within normal limits on hearing and receptive and expressive language. The assessment tasks in this study were modeled after the tasks in Rvachew's *Speech*

Assessment and Interactive Learning System (SAILS) program. Recordings of various Australian English speakers (both with typically developing speech and with SSD) were recorded saying a list of words highlighting the sounds /k, ɹ, ʃ, s/. The children in the study were presented with these recordings, 12 different productions of each word, and then asked to indicate whether the word was correct or not. The IBM SPSS statistics software was then used to analyze the data.

Results: Results indicated that some children with SSD performed significantly more poorly than TD children, while some children with SSD performed similarly to TD children. Post-hoc pairwise comparisons between each phoneme tested indicated that both /ɹ/ and /s/ were perceived significantly less accurately than /k/ across groups, but other than that all other comparisons between phonemes were non-significant.

Conclusion: Results from this study support much of the research that has occurred indicating that some children with SSD perform significantly poorer on speech perception tasks than TD peers. Results also indicated that some phonemes, specifically /ɹ/ and /s/ may be perceptually more difficult for all children, regardless of SSD diagnosis.

Relevance to current study: This study, like the current study, examines speech perception across groups as well as across specific phonemes. However, this study uses more of a judgement-based task while the current study focuses on discrimination tasks.

Hearnshaw, S., Baker, E., & Munro, N. (2019). Speech perception skills of children with speech sound disorders: A systematic review and meta-analysis. *Journal of Speech, Language, and Hearing Research, 62*(10)*,* 3771-3789. https://doi.org/10.1044/2019_JSLHR-S-18-0519

Objective: The aim of this study was to conduct a systematic review of peer-reviewed research on speech perception skills of children with speech sound disorders. The aim was also to perform a meta-analysis of the findings from a number of these studies.

Methods: The authors found over 15,000 articles through electronic database searching as well as manual searching of reference lists. They included studies that examined the speech perception skills of children with SSDs, which included children with phonological disorders, articulation disorders, or childhood apraxia of speech. The mean age of the children in the study needed to be between 3;0 and 6;11 in order to ensure that the children in the study presented with a developmental SSD as opposed to a persistent or residual articulation error. After extensive screening according to the inclusion criteria, 71 articles were included in the review (two of which reported on two relevant studies, bringing the number of studies up to 73). Data from these articles was entered into a predesigned excel sheet. The authors designed and used a new rating scale, the Speech Perception Assessment Methodological Reporting Rating Scale, in order to rate each of the studies. A meta-analysis was also conducted to compare effect sizes from methodologically similar studies.

Results: Sixty out of the 73 studies reported that some or all children with SSDs had difficulties with speech perception. Of these 60, 36 suggested this is only the case for some children with SSDs, and/or only with specific phonemes, and/or only on specific tasks/in specific testing conditions. In four studies, children had difficulty perceiving their own speech, but not the speech of typically developing adults. The studies used a variety of different types of perceptions tasks: judgement tasks (lexical or phonetic), identification tasks, discrimination tasks, indication tasks, and comprehension of high to low intelligibility tasks. The meta-analysis was focused on studies using lexical and/or phonetic judgement tasks and each of the eight studies indicated poorer speech perception in children with SSDs.

Conclusion: Analysis of the studies in this review indicate that speech perception is worse in children with SSDs. Further research needs to be done on the specifics of the speech perception, whether it is only in some children with SSDs, if it affects certain types of SSDs, i.e., phonological disorders, articulation disorders, CAS, and if it just affects particular phonemes.

Relevance to the current study: This study, like the previous one, explored and synthesized the existing research that relates to the current study: exploring the relationship between speech perception and children with SSDs. One thing the current study explores that the other studies have not is what speech perception looks like in adults as well as typically developing children in order to understand the range of possibility within speech perception.

Hitchcock, E., Cabbage, K., Swartz, M., & Carrell, T. (2020). Measuring speech perception using the Wide Range Acoustic Accuracy Scale: Preliminary findings. *Perspectives of the ASHA Special Interest Groups, 5*(4), 1098-1112. https://doi.org/10.1044/2020_PERSP-20-00037

Objective: This study examined the effectiveness of measuring speech perception in three population groups: typical adult listeners, typically developing children, and children with speech sound disorders. It examined the differences between the perception in these three groups.

Methods: Participants consisted of 24 adults, 15 typically developing (TD) children, and 15 children with speech sound disorders (SSD). The children with SSD received a number of assessments to ensure that their language and intellectual abilities were within normal limits. The requirements for these children to be considered as having a SSD was to receive a score of 1.5 or lower standard deviations on the *Goldman-Fristoe Test of Articulation - 2* and they had to have a rhotic error, but were not excluded if other speech errors were present. Researchers used the *Wide Range Acoustic Accuracy Scale* (WRAAS) system to assess the perceptual differences for three consonant pairs: /bɑ/-/wɑ/, /dɑ/-/gɑ/-, and /rɑ/-/wɑ/. Participants completed one to two sessions where they listened to each of these sounds along a continuum and indicated if they heard a difference in the sounds. This was done until the participant reached the convergence level, which is when they are correct about the differences between the phonemes 71% of the time.

Results: Results indicated that there was a statistical significance between adults and children with SSD on the /bɑ/-/wɑ/, /dɑ/-/gɑ/, and /rɑ/-/wɑ/ continuums. There was a statistical significance as well between TD children and children with SSD on the /rɑ/-/wɑ/ continuum. Children with SSD also presented with the most variability in their speech perception.

Conclusion: These results indicate that TD children do not vary significantly from adults, although TD children do demonstrate more variability in their perception. This could indicate that over time, perception begins to become more refined. Since TD children only significantly differed from children with SSD on the /rɑ/-/wɑ/ continuum, this could indicate that the greatest difference in speech perception of children is with the sounds that are specifically in error in the children with SSD.

Relevance to the current study: This study explores interpersonal speech perception in a variety of groups. This same method to test speech perception will be used in the current study. The current study will also use the information about speech perception found in this study and refine it by specifically examining the speech perception of children with CAS and comparing it to children with SSD.

Hoffman, P. R., Daniloff, R. G., Bengoa, D. & Schuckers, G. H. (1985). Misarticulating and normally articulating children's identification and discrimination of synthetic [r] and [w]. *Journal of Speech and Hearing Disorders, 50*(1)*,* 46-53. https://doi.org/10.1044/jshd.5001.46

Objective: This study sought to determine if "older" children (aged 6;0-6;11) who had a continued /w/ for /r/ substitution past a developmentally appropriate age could determine categorize ambiguous stimuli as belonging to the /r/ or /r/ categorization based on their points along a continuum.

Methods: Twenty-two children between the ages of 6;0 and 6;11 were chosen for this study, based on their misarticulation of /r/ for /w/ in word initial, medial, and final positions as well as consonant clusters. Thirteen children with typical speech in the same age group were chosen for the control. All children were then asked to complete a task indicating if an experimenter said "ray" or "way" in order to ascertain that they could complete the experimental task and identify "live voice productions of /r/ and /w/". The researchers used seven synthetic CV syllables, synthesized to be presented along a gradual continuum with "ray" at one end and "way" at the other. Stimuli changed in F1, F2, and F3 frequencies in order to achieve the continuum. Stimulus were tested for three step continuum stimulus pairs (1-4, 2-5, 3-6, and 4-7), presented in pairs where one pair differs, and one does not. The children were asked to identify which of the pairs were different.

Results: The misarticulating children were less consistent in their identification than the typically speaking children. After a look at each individual child's responses, researchers discovered that the TD children all had a boundary for the difference between /w/ and /r/ that was within two stimuli (3 and 4). Six of the misarticulating children had patterns of discrimination similar to that of the typical children. Of these six, two had a stimulus boundary that was wider than typical children, indicating some confusion as to the discrimination of these two sounds. Three of the misarticulating children had a "single /w/ region and multiple /r/ regions". Eleven did not show a "complete division between the two phonemic spaces" and the remaining two performed only at chance level for all stimuli.

Conclusion: The researchers determined a number of conclusions from these results. First, while misarticulating children were able to discriminate between the two syllables in live voice production, many of them exhibited difficulty with a synthetic voice production. They also found that the misarticulating children demonstrated a less discrete categorization of the acoustic space between /r/ and /w/, with multiple stimuli as the boundary instead of just one. Finally, that discrimination performance was poorer in the misarticulating children compared to their TD peers and the range of categorization ability was more spread out then the TD peers.

Relevance to the current study: This study took an approach similar to the current study with the discrimination of /r/ and /w/, however this demonstrates some of the benefits of the current study's WRAAS task, based on the PEST algorithm because it requires less trials and less time in order to determine the participants' discrimination abilities.

Kraus, N., McGee, T. J., Carrel, T. D., Zecker, S. G., Nicol, T. G. & Koch, D. B. (1996). Auditory neurophysiologic responses and discrimination deficits in children with learning problems. *Journal of Science, 273*(5277)*,* 971-973. https://doi.org/10.1126/science.273.5277.971

Objective: This is a comprehensive study meant to compare the speech perception ability, standardized measures of learning and academic achievement, and neurophysiology between typically developing children and those with learning problems.

Methods: 181 children between the ages of 6 and 15 participated in this study. They were divided into 90 "normal children" (no history of learning or attention difficulties) and 91 children with a diagnosis of learning disability (LD) or attention deficit disorder (ADD). Children were then presented with the /bɑ/-/wɑ/ continuum and the /dɑ/-/gɑ/ continuum using the Parameter Estimation by Sequential Tracking (PEST) paradigm. The PEST paradigm was used to obtain a JND for each pair of stimuli for each participant. The mismatch negativity (MMN) neurophysiological response was then tested in 42 of the children who all perceived /bɑ/-/wɑ/ well, and were age matched and split into perception abilities of /dɑ/-/gɑ/.

Results: There was no correlation between JND and intelligence. The difference between groups was smaller for the /bɑ/-/wɑ/ continuum then the /dɑ/-/gɑ/ continuum. The normal children performed better for both groups of stimuli, and all children performed more poorly on the /da/-ga/ stimulus. Researchers also found that good discrimination of /dɑ/-/gɑ/ is related to strong MMN responses and poor discrimination of the syllables is related to poor MMN responses.

Conclusion: These results of the auditory discrimination tasks as well as MMN indicate that the auditory discrimination abilities of these children with ADD and other learning disabilities is not dependent on voluntary response or attention. Some of the difficulties in this population of children occur even before conscious perception. They also found that there was variability in this population in regard to auditory discrimination.

Relevance to the current study: This study uses a preliminary version of the WRAAS task, which is used in the current study. It was the first study to use the PEST algorithm, which was a preliminary form of the WRAAS task, to test auditory discrimination in children.

Locke, J. L. (1980). The inference of speech perception in the phonologically disordered child. Part I: A rationale, some criteria, the conventional tests. J*ournal of Speech and Hearing Disorders, 45*(4), 431-444. https://doi.org/10.1044/jshd.4504.431

Objective: Locke explores the use and effectiveness of tests of speech perception and puts forth certain requirements that would make discrimination tasks effective. He also compares these criteria to certain perception tasks that already exist in order to determine their effectiveness

Assessment Criteria: Assessment procedure should 1) examine the child's perception of replaced sounds in relation to replacing sounds 2) observe the same phonemes in identical phonetic environments in production and perception 3) permit a comparison of the child's performance on target and replacing sounds with discrimination of target and perceptually similar control sounds 4) be based on a comparison of an adult's surface form and the child's representation 5) present repeated opportunities for the child to reveal his/her perceptual decisions 6) prevent nonperceptual errors from masquerading as perceptual errors 7) require a response easily within a young child's conceptual capacities and repertoire of responses and 8) allow a determination of the direction of misperception.

Relevance to the current study: The current study uses a discrimination task to test perception, and this task was designed in a way that is meant to address many of the criteria and concerns that Locke presents in this paper in order to ensure that this task is accurate in determining children's speech perception.

Lof, G. F. & Synan, S. T. (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*(Spring), 57-71. https://doi.org/10.1044/cicsd_24_S_57

Objective: The aim of this study was to present the studies from 70+ years of speech discrimination/perception research in both assessments and treatment in order to discover if, based on these various studies, a relationship exists between speech perception and speech sound disorders.

Methods: The authors split the review of the research into two categories: assessment and treatment. From there they further split the analysis into before and after 1980, because the Locke article, published that year, changed many clinicians' and researchers' understanding of speech perception tasks. The data from the articles was reviewed in order to compare results.

Results: Overall, results from this review indicate that while there are many studies that claim that no relationship exists, the majority of the studies found a correlation between poor speech perception and poor speech production.

Conclusion: Conclusions drawn from this systematic review indicate that for a speech perception assessment to be valid, it must assess the sounds that are produced in error and must actually evaluate children's internal perceptual understanding of a sound or word.

Relevance to the current study: This study explores the history of the research basis for the history of the question this study attempts to answer: Is there a difference in the speech perception of typical children/adults and children with speech sound disorder? It gives the history of the various ways that assessments have been used to try and answer this question, which is specifically relevant to this study and how it is looking at the relevance and validity of using the WRAAS task to answer the speech perception question.

Lowenstein, J. H. & Nittrouer, S. (2019). Perception-production links in children's speech. *Journal of Speech, Language, and Hearing Research, 62*(4), 853-867. https://doi.org/10.1044/2018_JSLHR-S-18-0178

Objective: This study examined potential links between perception and production in children with normal hearing who hear both a typical audio recording and a vocoded audio recording.

Methods: Ten 5-year-old children participated in this study. Each child had normal hearing, typical language development, and was a native speaker of English. Each child was presented with 120 three syllable, audio-recorded non-words, both in unprocessed form and in vocoded form, and asked to repeat what they heard. Vocoded form means the audio was changed to more closely resemble what an individual with a cochlear implant would hear. The consonants and vowels from each child's utterances were then analyzed using measures such as VOT, spectral moments, and F1 and F2 and compared between the unprocessed and the vocoded presentations of speech.

Results: Based on the measures mentioned above, the researchers discovered that children were producing /s/ and /ʃ/with different overall spectral weight across conditions, but the fricative place did not vary between the vocoded and the unprocessed condition. There was a significant tendency toward vowel centralization with the repetition of vocoded speech. There was also a greater level of variability in the vowels from repeated vocoded speech. In stops, VOT productions were slightly more variable in the vocoded condition.

Conclusion: While there were changes of the type expected when the participants repeated the vocoded speech, the deficits in speech production were not to the same level of the deficits that are observed in the speech of children with cochlear implants. This could indicate that some of the problems in the speech of children with cochlear implants could be due to "impoverished experience".

Relevance to the current study: This study demonstrates that at least in part, ongoing perception of a sound affects how that sound is produced. This is relevant to the current study because it explores the perception of speech in typical adults in order to understand the variability of perception that exists in individuals with typical speech.

Preston, J. L., Hitchcock, E. R., & Leece, M. C. (2020). Auditory perception and ultrasound biofeedback treatment outcomes for children with residual /ɹ/ distortions: A randomized controlled trial. *Journal of Speech, Language, and Hearing Research, 63*(2)*,* 444-455. https://doi.org/10.1044/2019_JSLHR-19-00060

Objective: This study evaluated the effectiveness of ultrasound treatment with perceptual training compared to stand-alone ultrasound treatment in children with residual /ɹ/ errors. This study also evaluated whether or not pre-treatment perceptual acuity affected the post treatment improvements in /ɹ/ production.

Methods: Participants were between 8 and 16 years of age. They were required to test typically on tests of language and cognitive/intellectual functioning and receive a score of 7th percentile or lower on the *Goldman-Fristoe Test of Articulation - 2.* Participants also completed a perception test before participating in intervention. Thirty-six participants were then randomly split into two groups: those receiving ultrasound visual feedback (UVF) and those receiving perception training plus ultrasound visual feedback (P + UVF). Participants received 14 sessions of treatment from speech language pathologists. They received this treatment in the production of /ɹ/ in various positions in a syllable. Participants in the P+UVF group received pre-practice that emphasized category goodness judgement as opposed to the articulatory training received in the UVF group. The P+UVF group was also asked to rate the accuracy of their own productions during treatment. In order to test the effectiveness of treatment, each participants' productions of /ɹ/ in various syllabic positions were taken before treatment, midway through treatment, within one week after the final treatment session and at a 2 month follow up.

Results: There was no significant difference between the mean improvements of both treatment groups. There was a significant negative correlation between pre-treatment perceptual acuity and change in /ɹ/ production, suggesting that sharper perceptual boundaries led to a greater improvement in production of /ɹ/. This did not significantly differ between groups. There was also no significant change in perceptual acuity in either group, even though perceptual awareness was a target of the P+UVF group.

Conclusion: Both treatments used in this study, UVF and P+UVF, resulted in improvements in the production of children with residual /ɹ/ errors. Level of response to either treatment did correlate with the level of the participants perception, with those who had a sharper perception of /ɹ/ improving more than those who did not. Further research may explore different kinds of speech perception training at different levels in order to further explore if a focus on speech perception during treatment could improve the production of /ɹ/ in children with residual speech errors.

Relevance to the current study: This study explored the effects of speech perception training, as well as the effects of speech perception acuity on treatment outcomes. This highlights the importance of this study in understanding the specific characteristics of speech perception compared to those with and without speech sound errors, and those with specific types of speech sound disorders such as CAS.

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

Objectives: This study was in two parts. One investigated whether children with residual speech errors (RSEs) differed from children with typical speech in the Speech Assessment and Interactive Learning System (SAILS) program. The second part investigated, using the same program, whether children who have speech errors that have resolved detect misarticulations better than children whose speech difficulties have persisted.

Methods: Part 1 - Two groups of children, those with typical speech and those with RSE were administered SAILS using 20 items for 5 different sounds, including /r/. Part 2 - 25 Native English-speaking children with speech sound disorders were tested for speech sound errors during preschool, and then again about 3.5 years later. Some of the children no longer had a speech sound disorder, while others had errors that persisted. These children were administered 20 tokens each of /s/ and /r/ in the SAILS to determine speech perception abilities.

Results: Part 1 - Children with RSE did not score significantly lower on the SAILS compared to those with typical speech. However, 1 of 20 children in the typical speech group "did not score above chance level on /r/, whereas 6 of 27 children in the RSE group did not score above the chance level." This is not statistically significant but could be an indicator that some children with RSE have difficulty with perception while others do not. Part 2 - Correlation between /r/ production and /r/ perception was not statistically significant, and the trend that did occur was opposite the anticipated direction, with children with more accurate /r/ productions performing more poorly on the SAILS. The correlation between /s/ production and /s/ perception was also not statistically significant, but the trend did go in the anticipated direction.

Conclusion: Results from both parts of the study indicated that while SAILS scores are significantly associated with speech sound production abilities in preschool/kindergarten aged children, the same is not true of school-aged children. These findings could be due to the possibility that deficits in preschool/kindergarten children are more severe than those in school-aged children or that SAILS is not sufficiently sensitive to detect perception difficulties in school-aged children. With this latter possibility, judging errors in their own speech might be more challenging and differentiating for children with RSE.

Relevance to the current study: This study compares the sound perceptions of children in varying categories (typical speech, RSE, remediated speech) with other's productions. The current study will take adult's own productions and altered productions to determine what is typical in the perception of adults with typical speech in preparation for further studies of children with speech sound disorders.

Rvachew, S. (1994). Speech perception training can facilitate sound production learning. *Journal of Speech and Hearing Research, 37*(2)*,* 347-357. https://doi.org/10.1044/jshr.3702.347

Objective: The objective of this study was to provide evidence that speech perception training can facilitate the intervention of children with articulation or phonological disorders. In this study the misarticulation of /ʃ/ was the focus of the treatment.

Methods: There were 21 participants in this study, all had normal hearing and oral structure and function, and no known etiological conditions. They were all diagnosed with a significant phonological delay and not stimulable for the /ʃ/ sound. Six sets of stimuli were created, including minimal pairs and misarticulated words paired with their correct articulation. These words were recorded from children with phonological delays as well as normal adult and child speakers. Each child attended a pre-test session, six treatment sessions, and a post-test session. Each child received 60 perception training trials and 60 production training trials. The children were divided into three groups, and the second and third groups received a single set of stimuli (group 2 received shoe-moo, and group 3 received cat-Pete) while the first group received two minimal pair stimul and then a set of stimuli that involved various distortions of /ʃ/ in a word and it's typically produced counterpart. They were asked to point to the word that was the target word, or the one that was pronounced correctly, depending on the stimuli.

Results: The differences between groups on pre- and post-treatment speech perception was significantly different. Children in groups 1 and 2 progressed significantly further in the production training (scored on levels 1-9 with indicating mastery at isolated phoneme and 9 indicating carryover into conversation). Only one child in group 3 produced a correct /ʃ/ sound while 6 children each in groups 1 and 2 produced a correct /ʃ/. Overall, the children did not progress past the imitating words phase of treatment regardless of group.

Conclusion: The results indicate that a computer-based speech perception task provided with speech production training can help some children in their speech production. The "some" is placed in the sentence because previous studies indicated that the children who had difficulties with both the production and perception of a sound were the ones who benefited from speech perception training.

Relevance to the current study: This study further explores the relationship between speech perception and speech production and indicates that training speech perception paired with training speech production can augment the acquisition of difficult phonemes for children with SSD. However, this study is exploring perception at an identification task word level, and the current study is exploring perception at a discrimination-task single CV syllable level.

Rvachew, S. & Jamieson, D. G. (1989). Perception of voiceless fricatives by children with a functional articulation disorder. *Journal of Speech and Hearing Disorders, 54*(2), 193-208. https://doi.org/10.1044/jshd.5402.193

Objective: This study examined the relationship of speech perception and speech production in children who had fricative errors and distortions. This was done through two experiments, the first compared the speech perception of TD children and children with SSD with the phonemes /s/ and /ʃ/ and the second compared similarly divided groups with speech perception of the phonemes /s/ and /θ/.

Methods: The first experiment consisted of three groups: adults, TD children and children with an articulation disorder (all children were 5 years old). All of the participants were monolingual English speaking and passed a hearing screening. Some of the children in the TD group misarticulated some phonemes, but these were considered age appropriate. Three sets of stimuli were given to the participants. One as a practice, one included a seven-set continuum with the words “seat” and “sheet” on either end, and one included the end points of “seat” and “sheet” with varying levels of amplitude and duration manipulated. Children were presented with two pictures and asked to point to which was indicated by the stimulus. The second experiment included similar groupings and requirements for the participants. The process and procedures of this experiment followed similar patterns, but with the words “sick” and “thick” instead of “seat” and “sheet”.

Results: Results indicate that adults and TD children performed similarly within their groups, but there was more variability in the SSD children for the “seat” “sheet” continuum. MANOVA indicated that there were significant differences between the scores of each group (adult to TD child, TD child to SSD child, and adult to SSD child). All children were more strongly biased towards answering “seat” at the “sheet” end of the continuum than adults. Seven of the 12 children with SSD were unable to differentiate between the stimuli. When amplitude and duration were changed for the stimuli, no significant differences occurred. For the “sick”- “thick” continuum, none of the SSD children were able to identify the stimuli appropriately. Much like the previous experiment, three were significant between group differences in each group pairing and both groups of children were more biased towards /s/ word responses. When the duration of the /θ/ was reduced, the researchers observed poorer performance. This is in contrast to the /ʃ/ reduced duration, which did not change performance.

Conclusion: Findings indicate that children with articulation disorders perform more poorly on speech perception tasks compared to TD children. There also tends to be more variability among the children with articulation disorders, with some performing similarly to TD children, and some unable to distinguish between two phonemes. The results also indicate that the speech discrimination is more likely to be worse with the sounds that children are already misarticulating in comparison to a broad speech perception deficit across all speech sounds.

Relevance to current study: This study groups participants similarly to the current study which looks at the speech perception of adults, TD children, and children with SSD. It also explores speech perception on a continuum, speech discrimination level. However, the current study explores the perception of nonsense syllables, over the single syllable words used in this study.

Rvachew, S., Nowak, M., Cloutier, G. (2004). Effect of phonemic perception training on the speech production and phonological awareness skills of children with expressive phonological delay. *American Journal of Speech-Language Pathology, 13*(3)*,* 250-263. https://doi.org/10.1044/1058-0360(2004/026)

Objective: This study explored the use of a perceptual approach to intervention in the treatment of a phonological delay.

Methods: Thirty-four children were randomly assigned to a treatment or control group. All of the children in this study had a significant phonological disorder, as evidenced by a score of 1st to 6th percentile on the GFTA-2, many had delayed expressive syntax and all had normal receptive language and hearing except for one child who scored lower for receptive language. SLPs who administered treatment and assessments were all blind to the children's group placement. Children received pre and post treatment assessments and normal therapy in addition to the control and experiment treatment. Speech perception, PCC, and phonological awareness were both tested pre and post treatment. Children's productions of specific phonemes - /ŋ, k, g, v, ʃ, tʃ, dʒ, ð, θ, s, z, l, r/ referred to as PCC-difficult were specifically recorded. The intervention was a computer program based on the SAILS assessment, but with a teaching aspect. The control group received a narrative intervention with computerized books.

Results: After controlling for pre-treatment levels, the children in the experimental group made significantly greater gains in their phoneme perception and articulation accuracy. Averaged across the PCC-difficult phonemes, children in the experimental groups showed a 20% increase in correct phoneme production, and children in the control group showed a 9% increase in correct phoneme production. Both groups improved in phonological awareness. There was no significant difference in improvements between the groups. However, phonological awareness and phoneme perception did correlate.

Conclusion: The result of this study indicates that a computer-based intervention program targeting phonemic perception, when paired with normal speech therapy sessions, improves the effectiveness of articulation-based speech therapy. This program does not have the same effect on phonological awareness.

Relevance to the current study: The current study is exploring the speech perception of children with SSD in order to eventually go down the path of discovering if intervention focused on speech perception can augment articulation therapy. This study indicates success with this particular group of children.

Rvachew, S., Ohberg, A., Grawburg, M., & Heyding, J. (2003). Phonological awareness and phonemic perception in 4-year-old children with delayed expressive phonology skills. *American Journal of Speech-Language Pathology, 12*(4), 469-471. https://doi.org/10.1044/1058-0360(2003/092)

Objective: This study examined the differences between the phonological awareness skills in four-year-old children with delayed expressive phonology and four-year-old children with normally developing phonological skills. Four-year-old children were chosen because if a difference can be detected this early then it could help with the detection and subsequent intervention of preschool aged children with phonological disorders.

Methods: Participants consisted of 13 children who presented with a moderate to severe expressive phonology delay (PD; less than 12th percentile on GFTA-2) and 13 children with normal expressive phonology (PN; greater than 20th percentile on GFTA-2), all between the ages of 4;0 and 4;11. Four of the participants in the PD group had lower MLU scores, but other than that, participants were matched for language, SES community, and age. All had normal hearing and oral structure and function. Children were assessed for expressive phonology using the GFTA-2, receptive vocabulary using the PPVT-III, phonological awareness using a modified version of the Bird et al. phonological awareness test, speech perception using the SAILS program, and early literacy using an early literacy assessment. A speech sample was also collected using the picture book *Carl Goes Shopping* and then the speech samples were analyzed through SALT.

Results: In an analysis and comparison of the results of the various assessments, the researchers found that there was a significant difference in the phonological awareness between groups, the PN group scoring higher on the assessment, with a large effect size. The children in the PN group also had phonemic perception abilities that were significantly higher than the PD group with a large effect size. No differences in literacy were found between the groups. The two outliers were in the PD group, with one child in the PD group not able to name any letters, and another child being the only one to read some words.

Conclusion: Results indicate that children with an expressive phonological delay often also have deficits in phonological awareness and speech perception in the absence of a language delay or disorder. However, these two measures are not considered equivalent, and SLPs must consider both when assessing a child with a phonological delay.

Relevance to the current study: This study further proves the connections between phonological disorders and other deficits such as speech perception and phonological awareness. The current study continues to add to the description of speech perception in children with a SSD in order to use this knowledge to aid in the diagnosis and intervention of these children, who may also be at risk for literacy difficulties as well with the speech production deficit.

Rvachew, S., Rafaat, S., & Martin, M. (1999). Stimulability, speech perception skills, and the treatment of phonological disorders. *American Journal of Speech-Language Pathology, 8*(1)*,* 33-43. https://doi.org/10.1044/1058-0360.0801.33

Objective: This article summarizes two descriptive studies in which two variables - stimulability and speech perception - are related to treatment progress.

Methods: (Study 1) - Ten children were divided into four groups. Every child but one performed moderately or severely poorly on a test of articulation. All children received normal expressive and receptive language scores on a standardized test. Children attended a pre-treatment and post-treatment session as well as nine treatment sessions. A treatment session consisted of the SLP targeting one phonological process (processes were targeted for three sessions and then switched, three processes total were targeted). Decisions for the processes were decided based on group needs. Each treatment session included auditory bombardment, story time, drawing practice pictures, play activities to drill correct sound productions, and review of individual progress with parents. Pre and post treatment sessions included assessments on speech production, speech perception, and stimulability. (Study 2): Thirteen children participated in this study. The characteristics of the participants in this study are the same as those in Study 1. Each participant attended a pre- and post- treatment assessment session as well as three individual sessions and six group sessions. The same procedures were followed for this group of participants as with the previously mentioned study with the exclusion of three individual sessions in lieu of three of the groups' sessions. The three individual sessions contained focused stimulability training.

Results: In study 1 no changes in sound production accuracy occurred for sounds that a child was unstimulable for in the pre-treatment testing. Poor speech perception in the pre-treatment assessment was also a predictor of little to no speech production accuracy gains. Overall, in this study, speech production gains were small, for this reason the researchers conducted a second study the following year. In the second study with the modifications, greater gains in production accuracy were achieved in the non-stimulable and low speech perception sounds compared to the results in study 1. Overall, the speech sound accuracy increased by 53% percent in comparison to the 34% in study 1.

Conclusion: Results of these studies indicate that stimulability and speech perception both play a role in the acquisition of speech sounds during therapy. Sounds that are more stimulable are acquired more easily, and stimulable sounds that can be perceived easier predict positive treatment outcomes as well. Further research is needed to understand how this knowledge should affect treatment.

Relevance to the current study: This study demonstrates that speech perception is a good predictor of success in therapy. The current study is exploring the specifics of speech perception in children with SSD in order for further research to use this knowledge to decide if children should receive speech perception training to add to speech production training.

Shuster, L. I. (1998). The perception of correctly and incorrectly produced /r/. *Journal of Speech, Language and Hearing Research, 41*(4), 941-950. https://doi.org/10.1044/jslhr.4104.941

Objective: This study determined if children who misarticulate /r/ can accurately judge their own corrected and incorrect utterances as well as that of others. It also explored the comparisons between the children who have received therapy for two years and the children who are just beginning treatment.

Methods: Twenty-six children who were unable to produce /r/ correctly participated in this study and split into two groups. Group one had been in treatment for /r/ in the public schools for less than a month. Group two had had treatment for /r/ for at least two years and were still unable to produce /r/ consistently correctly for single word utterances. Of those in group two, 6 of the 13 were no longer receiving treatment. The children in each group produced 45 words containing /r/ or /ɝ/ in multiple contexts. These productions were transcribed. Twenty-five of the 45 words were then altered using linear predictive coding (LPC) so that the /r/ or /ɝ/ sounded correct to experienced listeners. Tapes were then prepared with two presentations of 25 corrected words for one speaker, 25 incorrect productions from the same speaker, and then the same number of words corrected and incorrect from another speaker. One to two weeks after the initial recording the children were called back to listen to their respective tapes. Each child was informed that they were going to listen to recordings of words with /r/, some with their own recording and some from another speaker. They were also told that some of their productions of /r/ had been corrected. Each child was given the option to mark “me” or “not me” and “correct” or “incorrect” for each word spoken. Most of the children from group one were then audio tape recorded at the end of the school year using the same materials during the initial recording to determine whether they had acquired correct production.

Results: Analysis of results using a three-factor variance of analysis (ANOVA) indicated that the two groups did not perform significantly differently when judging correctness. Subjects did perform significantly more poorly in judging the correctness of their own incorrect utterances than in judging their own and the other’s child’s corrected utterances. The children were also better able to judge the identity of the speaker when the utterance was incorrect than when it was correct. Judgements about the identity of the speaker were more accurate when the speaker was the other child. In regard to reliability, subjects were more consistent in judging the correctness of the correct utterances than in judging the correctness of the incorrect utterances.

Conclusion: Based on these results, all of the subjects performed significantly poorer in judging their own incorrect utterances as incorrect than judging their own and another’s corrected utterances. Shuster inferred that this means that the subjects’ underlying representation of /r/ is too broad, including at least some of their own

incorrect utterances as well as their own and another's corrected utterances. Although not significant, the results also demonstrated that the subjects had slightly more difficulty judging the incorrectness of their own incorrect utterances. Also, despite the two years of treatment, group 2 did not perform any better in the perception of their own incorrect utterances compared to group 1. This may indicate that in teaching a child to produce /r/ it may be helpful to teach the child how to discriminate between his or her own productions of /r/.

Relevance to the current study: The current study examines an adult's own correct and incorrect utterances of /r/ in an adult who produces /r/ typically. This study examines this perception difference in children who do not produce /r/ typically.

Taylor, M., & Creelman, C. D. (1967). PEST: Efficient estimates on probability functions. *The Journal of the Acoustical Society of America, 41*(4A), 782-787. https://doi.org/10.1121/1.1910407

Objective: This study elaborated on PEST (Parameter Estimation by Sequential Tracking). In this paper it is explained in the context of psychoacoustic research, although the authors mention that it can be used in a number of different fields. The authors explain that PEST uses maximal trivial by trial deletions in order to find the specific variable that is needed for whichever study is occurring.

Relevance to the current study: PEST is the preliminary method used to create the Wide Range Acoustic Accuracy Scale (WRAAS) that is used in this study in order to find the convergence level for each set of stimuli.

Zuk, J., Iuzzini-Seigel, J., Cabbage, K., Green, J. R., & Hogan, T. P. (2018). Poor speech perception is not a core deficit of childhood apraxia of speech: Preliminary findings.

Journal of Speech, Language, and Hearing Research, 61(3), 583-592. https://doi.org/10.1044/2017_JSLHR-S-16-0106

Objective: This study evaluated the speech perception between children with CAS and no co-occurring language impairment, children with CAS and language impairment, children with language impairment only, children with speech delay, and typically developing children. The aim of the study was to examine if children with CAS have inherent difficulty with speech perception, or if the difficulty with speech perception is more connected to the language impairment that often co-occurs in those with CAS.

Methods: Forty-seven children participated in the study and were grouped into the categories mentioned above based on scores from the Sounds-in-Words subtest of the Goldman-Fristoe Test of Articulation 2 (GFTA-2) and the core subtests in the Clinical Evaluation of Language Fundamentals - Fourth Edition (CELF-4). Using a parameter estimation by sequential tracking (PEST) software program, children were presented with two sets of syllables, one with two equal forms of /da/ presented, and one with /da/ presented and then /ga/ somewhere along the continuum. The /ga/ syllable began at the farthest end of the continuum, but as the task continued, the differences between the syllables became smaller, making the differentiation task more difficult until the convergence level or Just Noticeable Difference (JND) was found.

Results: Post hoc group comparisons indicated that the group with CAS and no language impairment did not significantly differ from TD children. Both of these groups showed significantly better discrimination compared to children with speech delay and CAS with language impairment. The children with language impairment did not significantly differ from the typically developing group or the groups with CAS (with and without language impairment). This could be due to a substantial in group variability in the group of children with language impairment. This variability also existed in the group of children with speech delay.

Conclusions: The results from this study indicated that the speech perception of children with CAS and no language impairment did not differ from the expected speech perception of same aged peers. This preliminarily indicates that difficulties with speech perception is not a core feature or an underlying cause of children with CAS.

Relevance to the current study: This study uses PEST, a preliminary program to the WRAAS task used in the current study. Using this program, the study focused on describing the speech perception of different groups of children with varying combinations of speech delay and language impairment. This is connected to the greater task that this current study is also involved in identifying and describing speech perception in various groups of children and adults in order to understand how speech perception may play a role in identification and intervention of speech sound disorders.

APPENDIX B

Parental Consent 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 7-13 years old.

Procedures

This is a study about how children hear and process different speech sounds. To participate your child must be a native English speaker. The study will take place at the BYU John Taylor Building in Room 109 at a time convenient for you and your child. The study involves two sessions of activities.

In the first part of the study, which will last about 90 minutes, your child will complete the following tasks:

1. Complete a hearing screening. If your child does not pass this screening, we will notify you verbally and via written report to advise you of the results. We will also provide contact information for local audiologists that can provide further hearing evaluation services.
2. Allow us to look inside your child's mouth to assess his/her tongue, roof of his mouth, and lips for structural and functional abnormalities.
3. Participate in tests to screen your child's language and speech skills.
4. Listen to practice speech sound items on the computer using headphones.
5. Listen to speech sounds on the computer using headphones.

In the second part of the study, which will last about 45 minutes, you will complete the following tasks:

1. Listen to practice speech sounds items on the computer using headphones.
2. Listen to speech sounds on the computer using headphones.

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

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 any written reports or journal articles related to this research. 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.

IRB NUMBER: IRB2020-117
IRB APPROVAL DATE: 05/26/2020
IRB EXPIRATION DATE: 05/25/2021

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.

Information gained from this research will help us better understand how children with varied speech skills organize and process speech sound sounds during listening tasks. Moreover, this research will verify the appropriateness of using this task to measure speech perception in children.

Compensation

Your child will be provided small incentives (e.g., stickers, small prizes) throughout the duration of the study to maintain motivation. At the conclusion of each session, your child will receive $15.

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.**

AUDIO/VIDEO RELEASE

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

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

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

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

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

Name (Printed): ______________________ **Signature**__________________________ **Date**:_____________

IRB NUMBER: IRB2020-117
IRB APPROVAL DATE: 05/26/2020
IRB EXPIRATION DATE: 05/25/2021

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 hear and process different speech sounds.

If you decide you want to be in this study, we will ask you to come for two sessions that will occur about two weeks apart.

In the first part of the study, which will last about 90 minutes, you will complete the following tasks:

1. Complete a hearing screening.
2. Allow us to look inside your mouth to see your tongue, roof of your mouth, and lips.
3. Participate in tests to screen your language and speech skills.
4. Listen to practice speech sound items on the computer using headphones.
5. Listen to speech sounds on the computer using headphones.

In the second part of the study, which will last about 45 minutes, you will complete the following tasks:

1. Listen to practice speech sounds items on the computer using headphones.
2. Listen to speech sounds on the computer using headphones.

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 receive $15 for being in this research study. Before you say yes to be in this study, be sure to ask Professor 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:**_____________