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Perception of speech sounds in school-age children with speech sound disorders

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Abstract

Children with speech sound disorders may perceive speech differently than children with typical speech development. The nature of these speech differences is reviewed with an emphasis on assessing phoneme-specific perception for speech sounds that are produced in error. Category goodness judgment, or the ability to judge accurate and inaccurate tokens of speech sounds, plays an important role in phonological development. The software Speech Assessment and Interactive Learning System (Rvachew, 1994), which has been effectively used to assess preschoolers' ability to perform goodness judgments, is explored for school-age children with residual speech errors (RSE). However, data suggest that this particular task may not be sensitive to perceptual differences in school-age children. The need for the development of clinical tools for assessment of speech perception in school-age children with RSE is highlighted, and clinical suggestions are provided.

Keywords

speech sound disorder; speech perception; assessment

The ability to perceive fine-grained phonetic detail in the speech signal is foundational to the development of speech production. Children with speech sound disorder (SSD), who by definition have clinically significant difficulty producing the sounds of their native language, are commonly observed to show differences in speech perception. Perception of acoustic detail is important because it is eventually mapped to phonological and motoric representations governing speech production. This information is clinically relevant, as perception may be targeted in speech therapy to facilitate accurate production of speech sounds[1,2]. This article reviews known differences in auditory speech perception in children with SSD and explores options for assessment of speech perception for school-age children.

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There is evidence that some children with SSD have a broad perceptual deficit in processing both speech and non-speech auditory stimuli. For example, they may show differences in the ability to detect auditory gaps in noise, or in the ability to sustain attention on tasks that require identification of a specific auditory stimulus.[3] Differences in auditory evoked responses to both speech (syllables) and nonspeech stimuli (clicks) have also been reported in some individuals with SSD, although the sensitivity and specificity from these measures are poor.[4] Recent studies of functional brain activity have revealed differences in neural activation in school-age children with SSD when perceiving and processing spoken syllables and words.[4–6] Additionally, children with persisting speech sound errors have structural brain differences (i.e., greater gray matter volume) bilaterally in the superior temporal gyrus,[7] which is known to be associated with acoustic representations for speech sounds.[8] These underlying neural differences appear to manifest as a lack of sensitivity to acoustic detail, which may impede the development of well-defined acoustic representations for speech sounds.[9]

As neuroimaging techniques are clinically impractical, it is important to determine if clinical measures of speech perception can sensitively identify perceptual differences in school-age children with SSD. Speech perception differences in SSD can include problems with sound discrimination, categorical perception, and goodness judgments of phonetically acceptable and unacceptable productions of words based on the speaker's native language and dialect.[10–17]

Speech sound discrimination tasks necessitate attention to fine-grained acoustic differences between tokens. Such tasks require children to recognize differences between phonetically similar items, such as recognizing that /re/ and /we/ are different while identifying /re/ and /re/ as the same. Several studies have reported that children with SSD are less accurate than children with typical speech on discrimination tasks that require perception of both within-category and between-category distinctions.[11,17] For example, Hoffman and colleagues[18] created seven synthetic speech tokens with formant structure that varied along a continuum from /r/ to /w/. When presented with pairs of two tokens, children were required to determine if they were the same or different. Six-year-old children who misarticulated /r/ were less accurate at this task than age-matched children who could produce /r/ accurately.

Categorical perception tasks typically require the child to classify synthetic speech tokens into phoneme categories. Synthetic speech tokens are digitally generated sounds, syllables, or words; this allows for systematic control over acoustic features (e.g., formant patterns, spectral noise). Endpoint tokens are created for two phoneme categories that are phonetically similar (e.g., /w/ and /r/) and these endpoints should be reliably identified across speakers of the language. Synthetic speech continua typically involve additional tokens that are acoustically mid-way between the endpoints. For example, on a "rake"-"wake" continuum, some tokens should be consistently identified as "rake" and some as "wake," while some midpoint tokens will sometimes be identified as "rake" and sometimes as "wake" because they have acoustic properties that approach a boundary between the phonemes.

Children with SSD typically tend to be less reliable in phonemic categorization of endpoint tokens (i.e., clear "rake" and "wake" tokens), and they do not show distinct phonemic boundaries. Figure 1 shows an example from clear "rake" and "wake" tokens, plus seven tokens in between. Each token was rated eight separate times by the listener, presented in random order. The percent of times the token was identified as "rake" is plotted for each token. Stimuli were validated in a prior study,[19] and a typical response pattern from an adult is shown at the top of Figure 1. The first three tokens are classified as "rake" 100% of the time. The last four tokens are classified as "rake" 0% of the time. Two items in the middle are sometimes identified as "rake" and sometimes as "wake", suggesting that these tokens are near the category boundary. Data from a 9-year-old male with /r/ distortions is shown at the bottom of the figure. It is clear that even tokens toward the ends of the continuum are not consistently identified as "rake" or "wake"; for example, token 2, which the adult classified as "rake" 100% of the time, is identified as "rake" only 75% of the time by the child with residual errors affecting /r/. Token 7, which the adult identified as "rake" 0% of the time, was classified as "rake" by the child 50% of the time. The shallow slope indicates that there is not a sharp boundary between the two categories (i.e., there are several tokens that are not consistently identified as either "rake" or "wake"). Studies have shown that children with typical speech reliably distinguish endpoint /w/ and /r/ tokens and show sharp boundaries between the two categories, whereas children who misarticulate /r/ do not consistently categorize endpoint tokens and have category boundaries between /w/ and /r/ that are less well defined.[18,20]

Goodness judgment tasks require error detection; that is, children determine if a token is phonetically acceptable or unacceptable for a given category. Goodness judgments require not only categorical perception, but also attention to fine-grained acoustic detail. For example, it is important to recognize that substitutions and distortions of the /r/ phoneme in "red" are not acceptable, but productions with a good rhotic quality are acceptable. Several studies indicate that children with SSD have difficulty identifying correct and incorrect tokens of words both in their own speech and in the speech of others.[15,22–24] These deficits in perception may be linked with phonological awareness difficulties observed in some children with SSD.[9,25–27] For example, the ability to perceive phonetically similar and different acoustic targets is necessary to be able to detect words that rhyme and words that do not.[25, 28]

Studies have revealed that perceptual differences are most commonly associated with the specific sounds that are in error in a child's productions.[16,29, 30] For example, Shuster[23] evaluated children's ability to perform category goodness judgment for correct and misarticulated /r/ from recordings of their own speech and from the speech of other children. Children with residual /r/ errors were better at judging correct utterances as correct than at judging incorrect utterances as incorrect; that is, they tended to have broad phoneme categories and would rate both good and poor tokens as acceptable. Moreover, children with /r/ errors were also better at judging the accuracy of other children's productions than at judging the accuracy of their own.[23]

Relationship to treatment. Effective clinical assessment of speech perception problems can have direct implications for treatment. Children must be able to identify acceptable and unacceptable productions in order to master a sound, since error detection is necessary for self-monitoring and self-correction.[33] Specific treatment procedures have been developed that focus on speech perception. Van Riper's "ear training" approach requires children to discriminate between correct and incorrect tokens and identify proper productions (usually spoken by the clinician); this has been part of traditional articulation therapy for many decades.[31,32] Other common clinical techniques for enhancing children's attention to phonetic detail include modeling, focused auditory stimulation, auditory bombardment, phonological recasting, and minimal pair discrimination.[34–41] With respect to treatment response, it has been reported that children who exhibit both production and perception problems on a particular phoneme may improve their speech sound errors with training in category goodness judgment for that target.[42] Therefore, being able to identify and/or treat problems related to perception of category goodness is clinically beneficial.

Jamieson and Rvachew[21] created a training program in which synthetic speech tokens were used to teach children with SSD to identify when the target /s/ was heard and when a non-target sound was heard (e.g., synthetic /θ/ or /ʃ/). Children who were initially poor at identifying acceptable and unacceptable /s/ tokens improved in both their perception and their production of /s/ when this training was implemented. This task required category goodness judgment and demonstrated the utility of this approach for facilitating improvements in perception and production.

Speech Assessment and Interactive Learning System (SAILS)

Although researchers have used a variety of methods to assess speech perception, few procedures are available for clinical implementation that are sensitive to speech perception differences in children with SSD. Although instruments such as the *Test of Auditory Processing-3*[43] include general word discrimination tasks, clinical procedures are needed to address the *phoneme-specific* perceptual deficits that are most common in children with SSD. The most frequently studied instrument for clinical evaluation of speech perception skills in children is Speech Assessment and Interactive Learning System (SAILS),[2] which was developed primarily for preschool/kindergarten children. SAILS requires category goodness judgments. It includes assessment modules to evaluate children's ability to detect errors in specific phonemes by judging the accuracy of each token they hear. SAILS also includes treatment modules designed to train the ability to identify correct productions and to reject incorrect productions of words containing specific target sounds.[44] Children are typically presented with 10 recorded productions of a single word from multiple speakers. Some of the tokens are phonetically accurate (e.g., the target word "sheet" is produced as [ʃit]) and some of the tokens are authentic child productions reflecting various misarticulations (e.g., "sheet" is produced as [sit]). In a two-alternative forced choice response, children are instructed to point to a picture of the word if the token is "a good way" to say the target word or point to an X if it is not a good way to say the word. Incorrect tokens in SAILS include items representing both sound substitutions (e.g., "sheet" produced as [sit] or as [tit]) and sound distortions (e.g., "sheet" produced with a lateralized distortion [$ʃ^l$it]). Several of the phonemes have multiple levels of difficulty, where easier levels require judgment of target sounds versus sounds from other phoneme categories, and later levels require judgment of within-category distortions. Child-friendly visual reinforcers are embedded in the task to maintain attention. The task is clinically relevant because the errors reflect the acoustics of true child errors, rather than synthetic errors or errors that are "faked" by an adult.

Rvachew[28] provided normative data on SAILS for children with typical speech development and children with SSD from preschool through first grade. In preschool, children with typical speech identified, on average, 77.7% (SD 6.6%) of SAILS items correctly across the phonemes /l, k, r, s/. They identified one subgroup of preschoolers with SSD who performed within normal limits, as well as a subgroup of children with SSD who had difficulty on the task and who performed, on average, more than two standard deviations below children with typical speech (mean 59.6%, SD 8.6%). In first grade, these two groups continued to differ, but the magnitude was smaller (less than one standard deviation): children with typical speech correctly identified 84.1% of trials (SD 6.7%), while the group of children with SSD correctly identified 80.6% (SD 7.1%). Thus, perception deficits as identified by SAILS may be more apparent at younger ages.

Although many studies reporting on perceptual differences in children with SSD have used experimentally developed stimuli, SAILS is increasingly widely used in research and in clinical practice. In children between about 3–7 years of age, both single-subject experimental studies and randomized control studies indicate that a treatment program that includes SAILS as an adjunct to speech sound production training can facilitate improved speech sound production in children who also exhibit perceptual deficits.[1,2,42,45] For example, Rvachew and colleagues[1] reported that adding SAILS and stimulability training to cycles-based phonological therapy resulted in better outcomes than cycles-based therapy without SAILS and stimulability training. In a different study, results from a randomized control trial suggested that adding SAILS to a child's typical speech production training program resulted in better speech production outcomes than treatment that did not include SAILS.[45] Finally, Wolfe and colleagues[42] reported that speech perception training with SAILS facilitated improved speech production in children ages 3–4 years, but only among children whose speech perception was poor at the start of therapy. Thus, it is critical to be able to determine which children show poor perception.

Because of the demonstrated utility of SAILS in identifying perceptual differences in preschool and kindergarten children with SSD,[1,25,42,45] one important question is whether this same task would be sensitive to speech perception problems associated with speech production deficits in older children. School-age children with residual speech errors (RSE) are notoriously hard to treat, and identifying perceptual deficits would aid in treatment planning for these children. Therefore, we sought to determine if school-age children with RSE differ from children with typical speech development in their ability to detect errors on SAILS.

In addition, poor speech perception may account for unresolved speech production problems in children with SSD.[46] Among school-age children who have a history of preschool SSD, we explored whether children whose speech errors have resolved show better detection of misarticulations than children who exhibit persisting errors in production. It was hypothesized that children with RSE would exhibit poorer detection of errors. The following section summarizes data from studies testing for an association between speech sound production skills and SAILS performance in two school-age cohorts.

SAILS performance in children ages 9–14 with and without RSE affecting /r/

The first cohort included two groups of children ages 9;0 – 14;5 (years; months). The Typical Speech (TS) group included 20 children with typical /r/ production who had no history of speech or language disorders; all children in the TS group scored above the 19th percentile and above a standard score of 99 on the Goldman-Fristoe Test of Articulation-2 (*GFTA-2*).[47] The RSE group included 27 children who exhibited residual misarticulations of /r/; all of these participants scored at or below the 5th percentile on the *GFTA-2* and scored below 25% accuracy on /r/ in a 50-item single word production task. The group means were similar across several variables, including age (TS 11;0, SD 17 mos; RSE 10;10, SD 16 mos), receptive vocabulary as measured by the *Peabody Picture Vocabulary Test-4*[48] (TS 112, SD 12; RSE 111, SD 14), expressive vocabulary as measured by the *Expressive Vocabulary Test-2*[49](TS 113, SD 9; RSE 101, SD 11), and visual processing as measured by the Matrix Reasoning subtest of the *Wechsler Abbreviated Scales of Intelligence-II*[50] (TS 52, SD 5; RSE 49, SD 8).

To compare the groups on speech perception, 20 SAILS items were administered for each of five sounds: /f, θ, ʃ, s, r/. Because SAILS includes multiple levels for some phonemes, the highest level of difficulty was chosen for each phoneme, and 10 tokens of two different words were presented (i.e., 10 tokens each from “fat” and “feet” level 1, “thumb” and “thin” level 2, “shoe” and “sheet’ level 3, “Sue” and “soap” level 3, and “rope” and “rat” level 2). This resulted in a total of 100 SAILS tokens per child. It was hypothesized that the children with residual speech errors affecting /r/ would score lower on SAILS items for /r/ than children with typical speech.

Figure 2 displays the group means for each of the five phonemes. A 2 (group) by 5 (phoneme) repeated measures ANOVA was run comparing the groups on SAILS accuracy. There was no significant difference between the groups with respect to mean SAILS score (F [1, 45]=0.96, p=0.33, partial η^2=0.021), and no group-by-phoneme interaction (F [4, 45)=0.267, p= 0.90, partial η^2=0.006). Thus, speech perception as measured by SAILS did not reliably distinguish the TS and RSE groups, and the RSE group did not score significantly lower on perception of /r/ than on other sounds.

SAILS requires a two-alternative forced choice response, and therefore by randomly guessing children could achieve 50% correct. Correct responses to at least 15/20 trials (75%) indicate reliably better-than-chance performance on that phoneme (i.e., based on a binomial distribution with 20 trials, the 95% confidence interval around chance-level performance is 27–73%). One of 20 children in the TS group (5%) did not score above chance level on /r/, whereas 6 of 27 children in the RSE group (22%) did not score above chance level. This group difference was not statistically significant (χ^2 =2.69, p=0.101); however, it could be argued that these six children were unable to reliably identify correct and incorrect tokens of /r/ and might be in need of perceptual training.

Performance on SAILS for school-age children with histories of preschool SSD

The second cohort included 25 native English-speaking children from upstate New York who all had a history of a preschool SSD. They had completed the *GFTA-2* as preschoolers (ages 4;0–5;9), and at that point they had all scored below a standard score of 85. Additionally, all had exhibited receptive language within normal limits, and all were receiving speech therapy to address speech sound production skills.[27]

These 25 children were followed up approximately 3.5 years later to assess outcomes in speech, language, and literacy at an average age of 8;3 (range 7;4–9;3).[51] As part of the follow-up procedures, speech sound production skills were re-evaluated using the *GFTA-2*. At the school-age follow-up, *GFTA-2* standard scores ranged from 46 to 107 (mean 83.8, SD 14.7), with percentiles ranging from 1 to >48 (mean 14.2, SD 14.9). Thus, some children had achieved typical speech sound production, while others continued to exhibit speech production difficulties. To further assess production of /r/ and /s/, the most commonly misarticulated sounds in school-age children, additional single-word picture naming tasks were developed that elicited 40 tokens of /s/ and 50 tokens of /r/. Each word was scored as correct or incorrect for the target speech sound.

Although categorical goodness judgment tasks were not administered to these children as preschoolers, at the school-age follow-up, SAILS was used to evaluate perception of /s/ and /r/. Twenty tokens each of /s/ and /r/ were administered in SAILS, using the highest level for each phoneme (Level 2 for /r/, Level 3 for /s/), allowing for comparison of perception with their production accuracy of these later-developing sounds. It was hypothesized that persisting errors in speech production would be associated with poorer ability to detect errors on the SAILS assessment.

Correlation between /r/ production and /r/ perception did not reach statistical significance (Spearman's $\rho = -0.37$, p=0.068); moreover, the nonsignificant trend was not in the anticipated direction (i.e., children with more accurate /r/ productions tended to perform more poorly on the SAILS /r/ perception task than children who produced many /r/ errors).

Similarly, correlation between the 25 children's /s/ production and their /s/ perception on SAILS was not statistically significant (Spearman's ρ =0.30, p=0.148), although the trend was in the anticipated direction (i.e., children with more accurate productions on /s/ showed a trend toward better perception of /s/). Data for /r/ and /s/ perception and production accuracy are shown in Figure 3. The results from the perception and production data did not confirm the hypothesis that poorer production accuracy for a particular phoneme would be associated with poorer perception of that phoneme as assessed by SAILS in school-age children with histories of SSD.

Interpretations and recommendations

In both the group-level analyses from the first cohort and the correlational analysis of the second cohort, SAILS scores were not significantly associated with speech sound production skills in school-age children. Clinically, this is somewhat disappointing, given the results of prior studies with younger children and the fact that few other clinical procedures are available as alternatives. Several interpretations of these findings are possible. It is possible that perceptual deficits might be more common or more severe in preschool/kindergarten children with SSD but may resolve as children age and/or undergo treatment.[28] It is also possible that the school-age children reported here do not have speech perception difficulties; several studies report significant variability in perceptual performance among children with SSD, and there is evidence that some children with SSD have particularly good perceptual skills.[52] There may be only a small subset of school-age children with RSE who have perception difficulties. For example, 6 of 27 children with RSE affecting /r/ exhibited chance-level performance on the SAILS /r/ task (i.e., <15/20 correct), and these children may differ in their treatment needs compared to children who score above chance-level.[42] For children with SSD whose speech perception is within the average range, it is possible that speech motor impairments may hinder acquisition of speech sounds, and motor-based treatment approaches may be appropriate.[53]

Additionally, it is possible that perceptual deficits are present in many children with RSE but that SAILS may not be sufficiently sensitive to the perceptual differences in school-age children; that is, a deeper assessment with more tokens or a different task altogether might be needed to detect relevant auditory perception problems. Specifically, tasks that require children to judge *their own errors* may be more challenging for children with RSE than tasks requiring identification of errors in others' speech.[22,23,54] One clinical recommendation is to record a client speaking (e.g., reading a list of words or sentences loaded with the sounds in error) and to play back the recording to the client for self-judgment. This strategy would be particularly useful for children who occasionally produce correct tokens, as it would allow comparison of both correct productions and errors. (Children whose production of a target sound is in error 100% of the time may be less likely to benefit from this type of auditory self-judgment, as they would not be able to hear recordings of themselves producing accurate renditions of the sound to compare to inaccurate versions.) Requiring children to attend to and judge the quality of their own productions could enhance self-awareness and encourage self-monitoring by teaching the contrast between correct and incorrect tokens that exist within their own acoustic space.

Although SAILS might not be ideally suited for school-age children over the age of about 7 years, it is important to highlight that SAILS has been validated in preschool and kindergarten age children. Continued use of SAILS to assess and treat speech perception in children between 3–7 years is still recommended, and the present study does not dispute the use of this instrument for young children. However, there is need for further development of clinically viable perceptual assessments and interventions for school-age children with residual speech errors.

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Abbreviations used

ANOVA	analysis of variance
GFTA-2	*Goldman-Fristoe Test of Articulation-2*
RSE	Residual speech errors
SAILS	Speech Assessment and Interactive Learning System
SSD	Speech sound disorder
SD	Standard deviation
TS	Typical Speech

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Learning objectives for readers

1. Describe the nature of speech perception differences in children with speech sound disorders, including the role of "category goodness judgments"
2. Describe how Speech Assessment and Interactive Learning System (SAILS) is used to assess and treat speech perception difficulties in young children (i.e., preschoolers) and whether SAILS consistently identifies speech perception differences in school-age children with residual speech errors

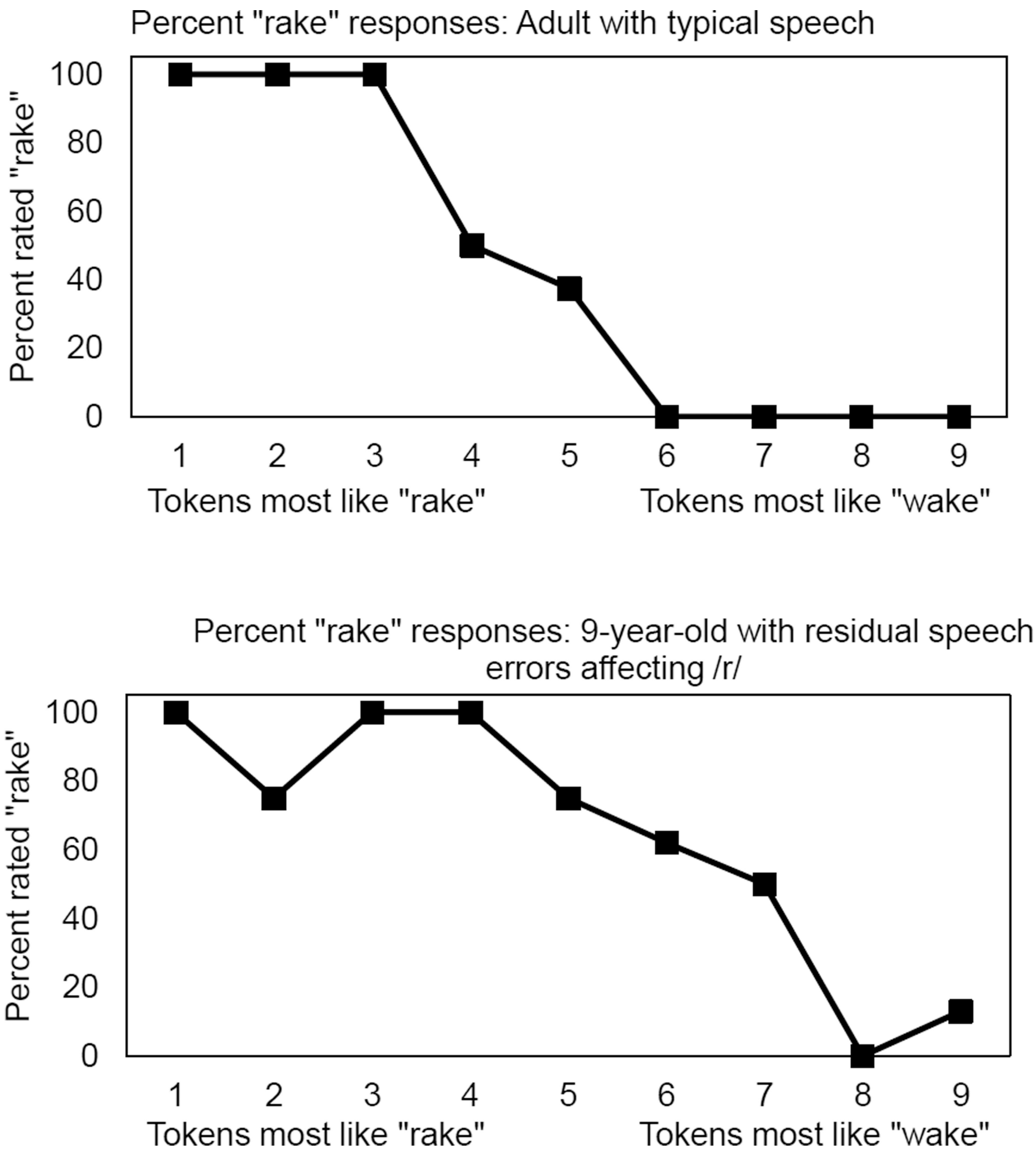

Figure 1.

Categorical perception data from synthetic rake-wake continuum for an adult with typical speech (top) and a 9 year old with residual speech errors affecting /r/ (bottom)

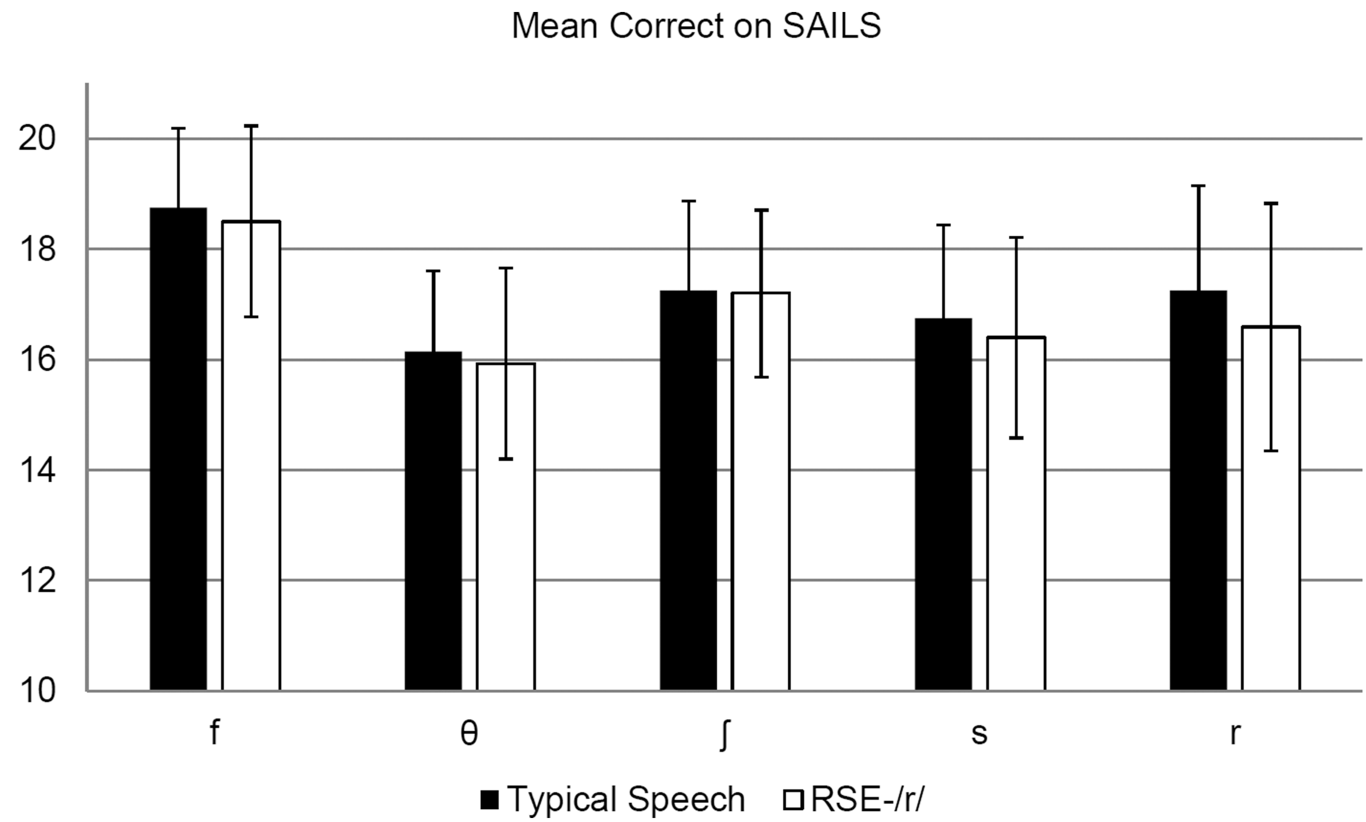

Figure 2.

Mean accuracy on 20 SAILS tokens each of /f, θ, ʃ, s, r/ for children ages 9–14 with typical speech and children with residual speech errors affecting /r/.

Note: Error bars represent 1 standard deviation. There were no significant differences between the groups on perception of any phoneme.

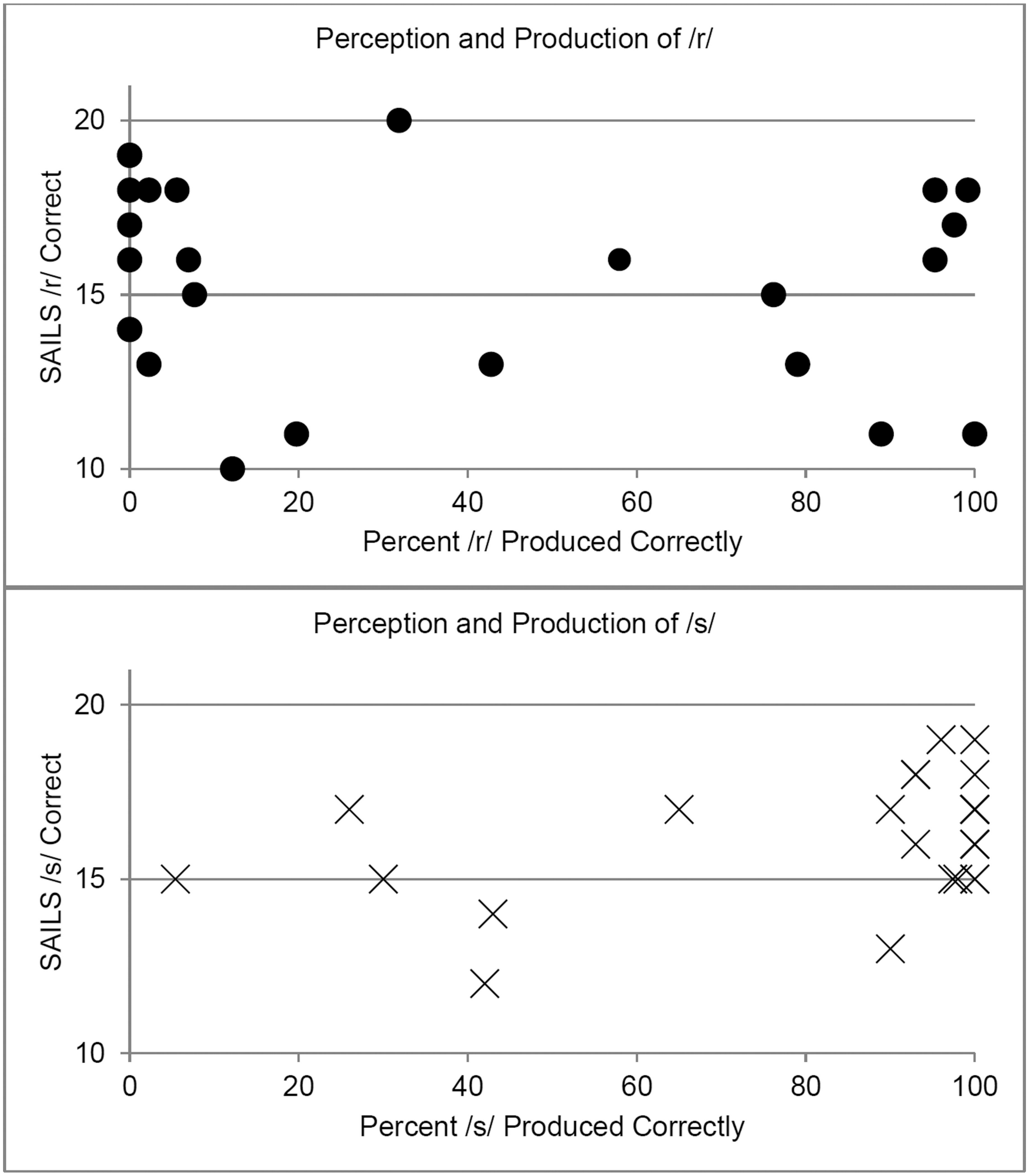

Figure 3.

Comparison of perceptual goodness judgments with SAILS and single word production accuracy of /r/ and /s/ for 25 children ages 7–9 with histories of preschool SSD

Note: Correlations between perception and production were not statistically significant for /r/ or /s/