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Research Article

Preschool Speech Error Patterns Predict Articulation and Phonological Awareness Outcomes in Children With Histories of Speech Sound Disorders

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Purpose: To determine if speech error patterns in preschoolers with speech sound disorders (SSDs) predict articulation and phonological awareness (PA) outcomes almost 4 years later.
Method: Twenty-five children with histories of preschool SSDs (and normal receptive language) were tested at an average age of 4;6 (years;months) and were followed up at age 8;3. The frequency of occurrence of preschool distortion errors, typical substitution and syllable structure errors, and atypical substitution and syllable structure errors was used to predict later speech sound production, PA, and literacy outcomes.
Results: Group averages revealed below-average school-age articulation scores and low-average PA but age-appropriate reading and spelling. Preschool speech error patterns were related to school-age outcomes. Children for whom >10% of their speech sound errors were atypical had lower PA and literacy scores at school age than children who produced <10% atypical errors. Preschoolers who produced more distortion errors were likely to have lower school-age articulation scores than preschoolers who produced fewer distortion errors.
Conclusion: Different preschool speech error patterns predict different school-age clinical outcomes. Many atypical speech sound errors in preschoolers may be indicative of weak phonological representations, leading to long-term PA weaknesses. Preschoolers' distortions may be resistant to change over time, leading to persisting speech sound production problems.

Key Words: speech sound disorders, speech production, phonological awareness, outcomes, literacy

Preschoolers with speech sound disorders (SSDs) have clinically significant impairments in the production of speech sounds of the ambient language. Although many of these speech sound errors resolve after several years (with or sometimes without intervention), age-appropriate speech sound production is not always achieved. For example, in a recent large-scale study, Roulstone, Miller, Wren, and Peters (2009) reported that 18% of 8-year-olds had unresolved speech sound errors, and in another study, Sax (1972) reported that /r, s, z/ were not yet mastered by at least 7% of the fifth graders they studied.

Some speech sound errors may persist into adulthood, with ~1.4% of college freshmen having persisting speech sound errors (Culton, 1986). Moreover, preschoolers with SSDs are at elevated risk of problems with phonological awareness (PA), which is an important skill for developing reading and spelling (e.g., Bird, Bishop, & Freeman, 1995; Nathan, Stackhouse, Goulandris, & Snowling, 2004). However, not all preschoolers with SSDs will go on to have persistent speech sound production or PA problems. The present study, therefore, sought to determine if speech characteristics in preschool are associated with school-age articulation and PA outcomes. Specifically, we aimed to determine if preschool speech error types (e.g., atypical sound errors and distortion errors), which may reflect different levels of psycholinguistic processing, are indicative of school-age PA and speech sound outcomes.

Psycholinguistic Bases of Speech Sound Errors

During speech development, children learn phonological categories (e.g., phonemes and syllable shapes) as well as fine-grained phonetic details associated with those sound categories. The (higher level) categorical features of the sound patterns of the language make up the phonological representations of the words. When speech is produced, the (lower level) motoric instantiation of those representations occurs as words are articulated (cf. Pascoe, Stackhouse, & Wells, 2006). Many children with SSDs at 4–5 years of age

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produce speech sound errors that include a mix of speech sound error types that may reflect problems in the higher level phonological representations as well as the lower level motoric aspects of these productions (Preston & Edwards, 2010).

Phonological representations are thought to be refined during normal phonological development as children acquire more knowledge of the phonemes and sound patterns of the language. As children learn the ambient language, certain predictable patterns of sound errors are observed in their output. These typical patterns of developmental speech sound errors have been well characterized in the literature. Typical substitutions and syllable structure errors, often described using phonological process labels (e.g., stopping fricatives, gliding liquids, fronting velars, deleting final consonants, etc.), are observed in most young children with or without SSDs, though these errors are generally observed to occur more frequently in the speech of children with SSDs (e.g., Edwards, 1992; Hodson & Paden, 1981; Ingram, 1976).

However, among children with SSDs, unusual or atypical speech sound errors may also occur. These atypical errors are substitutions and syllable structure errors that are not generally found in normal phonological development. Atypical speech sound errors may include, for example, deleting initial consonant singletons, backing of alveolars to velars, glottal replacement of oral consonants, and fricatives replacing stops (see Preston, 2008; Preston & Edwards, 2010). It has been postulated that such errors may reflect phonological representations that are particularly weak or poorly defined (Leonard, 1985; Preston & Edwards, 2010; Rvachew, Chiang, & Evans, 2007; Rvachew & Grawburg, 2006). Frequent production of atypical speech sound errors might indicate that a child's developmental path is unusual in how the phonological characteristics of the language are mastered (Leonard, 1985). Moreover, such atypical errors may reflect a phonological representational system that has gone awry, which may indicate the potential for long-term weakness in the foundations of a child's phonological system.

In contrast, some of children's speech sound errors may reflect lower level phonetic problems. Such distortion errors are often considered to have a motoric basis, in that the productions lack articulatory precision (e.g., problems with tongue placement or configuration, as in a dentalized /s, z/ or derhoticized /r/; Dodd, 1995; Dworkin, 1980; Shriberg et al., 2005). These distortion errors therefore likely reflect a motor template for a particular sound that is within the proper phoneme category (i.e., phonologically accurate) but is imprecise in the detailed specifications for the sound (i.e., phonetically inaccurate). Distortions may be observed in both typically developing (TD) children and children with SSDs.

Because problems in higher level representations and lower level phonetic realization of speech sounds may have different psycholinguistic bases, these different error types may be useful indicators of aspects of children's phonological and phonetic development. Errors that reflect weak phonological representations in preschool may be indicative of future difficulty with skills that require well-defined representations, whereas errors that reflect lower level articulatory precision may be indicative of difficulty refining articulatory targets.

Phonological Representations, PA, and Speech Sound Errors

There is now substantial theoretical and empirical support for the notion that PA skills are related to the quality of children's underlying phonological representations (e.g., Elbro, Borstrom, & Peterson, 1998; Fowler, 1991; Rvachew, 2006; Sénéchal, Ouellette, & Young, 2004). PA is a metalinguistic skill that involves awareness of the sound structure of words. It is a robust predictor of reading decoding and spelling both crosssectionally and longitudinally (Adams, 1990; Blachman, 2000; Bradley & Bryant, 1983; Catts, Fey, Zhang, & Tomblin, 2001). For example, in a large review of existing literature, the National Early Literacy Panel (2008) described the consistent finding of the important role of PA skills in predicting early literacy acquisition (even when controlling for other relevant variables such as IQ and socioeconomic status); many of the studies reviewed strongly support the notion of a causal link between PA and literacy such that weak PA can cause problems with early decoding and spelling.

In preschool children, PA often includes the awareness of syllables, rhymes, and initial consonants. In young school-age children, PA skills that develop include blending, deleting, and manipulating sounds in words. It is well established that preschoolers with SSDs are at increased risk for PA deficits (Anthony et al., 2011; Bird et al., 1995; Foy & Mann, 2012; Lewis et al., 2011; Lewis & Freebairn, 1992; Peterson, Pennington, Shriberg, & Boada, 2009; Raitano, Pennington, Tunick, Boada, & Shriberg, 2004; Rvachew, Ohberg, Grawburg, & Heyding, 2003). Moreover, for some of these children, long-term deficits in PA, reading, and spelling may be observed at school age (Clarke-Klein & Hodson, 1995; Lewis & Freebairn, 1992; Nathan et al., 2004; Preston & Edwards, 2007).

Although PA, reading, and spelling deficits are more common in children with co-occurring language impairments, several studies have reported that even children with SSDs who have typical language skills are at elevated risk for PA and reading problems (Bird et al., 1995; Overby, Trainin, Smit, Bernthal, & Nelson, 2012; Raitano et al., 2004; Rvachew et al., 2003). Moreover, recent functional magnetic resonance imaging results have demonstrated that school-age children with residual speech sound errors showed an array of cortical and subcortical differences in how they process phonological information in both spoken and written language (Preston et al., 2012). Thus, problems in producing speech sounds may be associated with weaknesses in processing phonological information in both auditory and written modalities.

Because the PA, reading, and spelling outcomes of children with SSDs vary widely, it is of clinical and theoretical interest to determine which children with SSDs are at the greatest risk for persisting PA problems. Recently, Preston and Edwards (2010) found that preschoolers with SSDs who produced frequent atypical speech sound errors are likely to have weaker PA (when controlling for age and receptive vocabulary) than preschoolers who produced few atypical errors. It was posited that frequent production of atypical phonological errors may reflect poorly specified or weak phonological representations (Preston & Edwards, 2010). Over the course of development, these weaknesses in the phonological foundations of children's linguistic systems may persist and may be evident in persisting PA problems. If this is the case, we hypothesize that there may be a long-term association between preschool atypical sound errors and later PA due to weak phonological representations.

Although the empirical link in crosssectional research between atypical speech sound errors and PA is moderate in terms of effect size, the association has now been replicated several times (Leitao, Hogben, & Fletcher, 1997; Preston & Edwards, 2010; Rvachew et al., 2007). However, the long-term association between preschool speech sound errors and school-age PA requires further exploration. Leitao and Fletcher (2004) reported a longitudinal investigation of 14 preschoolers with SSDs who were followed up at the ages of 12–13. Half of the children were classified as having developmental speech sound errors in preschool (i.e., <10% of their phonological errors were atypical), and half were classified as having atypical/nondevelopmental errors (i.e., >10% of their phonological errors were atypical). Follow-up testing showed that the group who previously exhibited more atypical error patterns performed lower than the group with few atypical error patterns on several tasks of PA, reading, and spelling. Due to the small sample size, replication is required.

Our study extends findings from Preston and Edwards (2010) by studying the long-term association between preschool atypical phonological errors and PA outcomes nearly 4 years later. Our study also provides a replication of Leitao and Fletcher's (2004) longitudinal investigation of PA and literacy outcomes using a larger cohort of children with SSDs.

Low-Level Phonetic Production and Distortion Errors

As children begin to establish phonological categories, they also learn the subtle features of the motor movements involved in the production of acceptable allophones. In preschoolers with SSDs, many of the errors observed are deletions and substitutions of phonemes. However, some errors may include speech sound distortions as well. In contrast, most of the errors exhibited by school-age children with SSDs involve distortions, primarily of rhotics and sibilants (Shriberg, 2009). These school-age errors may be indicative of problems with fine-grained motor specifications for a sound, and these problems may have been established in the preschool years. Although many preschoolers with TD speech also produce distortions, most will learn to refine their phonetic productions and achieve phonetically accurate speech. Shriberg et al. (2005) reported that most sound errors in preschoolers with SSDs resolve by about age 6, with the exception of errors involving rhotics and sibilants. Some children with SSDs, however, may lack the ability in their speech systems to "tune in" to subtle features of speech sounds and may therefore fail to refine their productions (Preston et al., 2012; Shriberg, 1994; Shriberg et al., 2005), resulting in distortions that persist into later years.

Shriberg and colleagues (Karlsson, Shriberg, Flipsen, & McSweeny, 2002; Shriberg, Flipsen, Karlsson, & McSweeny, 2001) postulated that children with early distortion errors may be likely to have residual speech sound errors later on due to early motor templates for sounds that do not resolve as the child's speech system matures. For example, some children may learn a motor plan for a specific sound or sound class that is not appropriate for the target language (e.g., dentalized or lateralized /s, z/, or derhoticized /r/); these distortions may go unresolved and may lead to persisting speech problems. In this case, we would expect that preschool distortion errors might persist into later school age.

Alternatively, some studies have suggested that young children who exhibit more severe SSDs (e.g., more errors) tend to have poorer speech sound production outcomes than children with less severe SSDs (Roulstone et al., 2009; Shriberg, Gruber, & Kwiatkowski, 1994; Steer & Drexler, 1960). In this case, measures of severity, such as the number of sound errors or scores on a standardized test, would be expected to predict later speech sound production outcomes (Bernhardt & Major, 2005). For example, Roulstone et al. (2009) reported that the greater the proportion of sounds that are in error at age 5, the greater the likelihood of errors at age 8. However, focusing on the specific nature of preschoolers' production errors might be more informative than considering global measures of speech sound accuracy. Therefore, a longitudinal investigation that includes emphasis on types of preschool speech sound errors and later speech outcomes is needed.

Purpose of the Study

The purpose of the present study was to determine if the types of preschool speech sound errors can predict school-age outcomes for children with SSDs. The first aim was to determine if preschool speech sound errors predict children's performance on standard clinical measures of PA. We hypothesized that increased production of atypical errors in preschool would be associated with lower school-age PA (and, consequently, lower early literacy skills that depend on PA). The second aim was to determine if preschool speech errors are indicative of school-age speech sound production skills. We hypothesized that children who produce many distortion errors in preschool may be at risk for persisting speech sound errors at school age.

Method

Participants

Forty-three preschoolers with SSDs, ages 4;0 (years; months) to 5;9, were recruited through clinical referrals in upstate New York from May 2007 to April 2008 (see Preston & Edwards, 2010). Children were primarily from middle socioeconomic homes, and all were speakers of General American English. All children had standard scores <89 on the Goldman-Fristoe Test of Articulation—Second Edition (GFTA–2; Goldman & Fristoe, 2000) and were enrolled in speech therapy. All had normal nonverbal cognition, as reported by the parents and confirmed by scores that were not lower than 1⅓ *SD*s below the mean on the Pattern Construction subtest of the Differential Ability Scales (Elliott, 1990). To rule out children who had significant language comprehension problems, all children had receptive language skills that were broadly within normal limits, as defined by scores no lower than 1⅓ *SD*s below the mean on at least two of the following three instruments: the Peabody Picture Vocabulary Test—4 (PPVT–4; Dunn & Dunn, 2007), the Sentence Structure subtest of the Clinical Evaluation of Language Fundamentals—Preshool, Second Edition (CELF–P2; Wiig, Secord, & Semel, 2004), and the Concepts and Following Directions subtest of the CELF–P2. Thus, this cohort included children whose receptive language skills were broadly in the average to above-average range.

Each preschooler participated in a 125-word picture-naming task that was designed to elicit all consonant sounds of English in all word positions (i.e., initial, medial, final) at least twice; numerous consonant clusters and multisyllabic words were also elicited (Preston, 2008). Productions were audio-recorded and were transcribed using narrow phonetic transcription (see Preston & Edwards, 2010, for further details and reliability data). All consonant errors were categorized as distortions, typical sound errors (described by common phonological processes), or atypical sound errors (i.e., substitutions, omissions, or distortions not commonly observed in TD children) based on previous reports in the literature on developmental speech error patterns. The relative occurrence of each of these error types was calculated for each child and was quantified as the number of distortions per consonant, the number of typical errors per consonant, and the number of atypical errors per consonant. For example, if the word *spoon* /spun/ was produced as [s̪puŋ], the dentalized /s/ would be characterized as a distortion, and the backing of the alveolar nasal /n/ to a velar nasal [ŋ] would be considered an atypical substitution because backing is quite uncommon in normal phonological development. Thus, for this word with three target consonants, there would be ⅓ = 0.33 distortions per consonant, ⅓ = 0.33 atypical errors per consonant, and 0/3 = 0 typical errors per consonant. However, if the same word were produced as [pun], there would be no distortions per consonant and no atypical errors per consonant, but ⅓ = 0.33 typical errors per consonant to account for the common pattern of /s/ cluster reduction. The child's total score in each of these three categories was based on the number of consonants attempted in the 125-word picture-naming task. Definitions of error types and additional examples can be found in Preston (2008) and Preston and Edwards (2010).

Approximately 3½ years after the initial assessments, letters were sent to the parents of all of the children who participated in the original study, inviting them to participate in a follow-up study (outlined below). Of the original 43 families, 25 replied to the letter and agreed to have their child participate in the summer of 2011 for a follow-up. Descriptive preschool data from these 25 children (18 males, 7 females) are presented in Table 1.

The 25 children who participated in the follow-up study were compared to the 18 children who did not participate to determine if the follow-up children differed in any systematic way. There were no significant differences in gender, age, maternal education, paternal education, CELF–P2 subtest scaled scores, nonverbal cognitive scores, GFTA–2 standard scores, number of atypical errors per consonant, number of distortions per consonant, or number of typical error per consonant (all $ps > 0.21$). The one variable on which the follow-up children differed was on the PPVT–4, with the follow-up children achieving higher average preschool vocabulary scores (median 117) than the children who

Table 1. Descriptive statistics for the 25 children with histories of preschool speech sound disorders (SSDs): Preschool measures.

Preschool measure	*M*	*SD*	Range
Age (years;months)	4;6	0;5	4;0–5;9
Years of maternal education[a]	15.8	2.1	12–18
Years of paternal education[a]	15.4	3.3	9–22
GFTA–2 Standard score	72.5	9.3	50–87
CELF–P2 Concepts & Following Directions scaled score	11.0	2.4	7–15
CELF–P2 Sentence Structure scaled score	11.2	2.3	6–15
PPVT–4 standard score	116.3	12.5	93–145
DAS Pattern Construction *T* score	58.1	7.3	43–70
Speech errors: Distortion errors per consonant	0.052	0.041	0.010–0.156
Speech errors: Typical errors per consonant	0.437	0.109	.237–0.649
Speech errors: Atypical errors per consonant	0.065	0.035	0.015–0.145

Note. GFTA–2 = Goldman-Fristoe Test of Articulation—Second Edition (Goldman & Fristoe, 2000); CELF–P2 = Clinical Evaluation of Language Fundamentals—Preschool, Second Edition (Wiig, Secord, & Semel, 2004); PPVT–4 = Peabody Picture Vocabulary Test—Fourth Edition (Dunn & Dunn, 2007); DAS = Differential Ability Scales (Elliott, 1990). Scaled scores are standardized with a mean of 10, *SD* of 3. Standard scores have a mean of 100 and *SD* of 15. *T* scores have a mean of 50 and *SD* of 10.

[a]Years of education reported by parents, with 12 = high school, 16 = four-year college, etc.

were not followed up (median 110.5, U =121.5, p = 0.011). Thus, the follow-up group included children with vocabulary scores that were above the population mean and also above the mean of the other members of the initial cohort.

Follow-up Procedure

Several tasks were selected for the school-age follow-up study to assess the children's speech production, PA, and early literacy skills. Norm-referenced tests were selected for comparison to children of the same age. A certified speech-language pathologist (SLP; the first author) administered all of the tests to each participant in a single session lasting 2–2½ hr that was conducted in the children's homes. Families were paid for their participation. Sessions were audio-recorded in Praat software (Boersma & Weeninck, 2011) using a Shure WH30 head-mounted microphone (½-in. mic-to-mouth distance) and a Hewlett-Packard Elitebook. Recordings were conducted at a sampling rate of 44 kHz and were saved as .wav files.

PA. PA was assessed using the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999). The PA composite score is derived from performance on two subtests: Elision (which requires deletions of sounds from words) and Blending (which requires synthesis of words spoken one sound at a time).

Literacy. Because of the link between PA and the phonological basis of literacy, we assessed the children's reading accuracy and spelling using three subtests from the Woodcock-Johnson Test of Achievement, Third Edition (WJ–III; Woodcock, McGrew, & Mather, 2001). The Letter-Word Identification subtest assesses accuracy of reading real words of increasing complexity, the Word Attack subtest assesses accuracy of reading nonwords of increasing complexity, and the Spelling subtest assesses spelling of real English words of increasing complexity.

In addition, we administered the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999) to assess speeded reading of real words (Sight Word Efficiency) and nonwords (Phonemic Decoding Efficiency). Children read lists of words or nonwords as quickly as possible; standard scores are based on the number of items read correctly in 45 s. This test has two alternate forms, both of which were administered (with Form A preceding Form B). An average of the standard scores from the two forms was used to obtain a more reliable estimate of performance.

Language. For descriptive purposes, we measured the children's language skills at the school-age follow-up using the Recalling Sentences and Formulated Sentences subtests of the Clinical Evaluation of Language Fundamentals—Fourth Edition (Semel, Wiig, & Secord, 2003) as well as the PPVT–4. These tests were selected for their strong psychometric properties and for their sampling of receptive and expressive vocabulary and morphosyntax. Descriptive statistics, shown in Table 2, indicated that the group means on oral language tasks were average to high average, with individual language performance ranging from mild-moderate delay to superior language skills.

Speech sound production. To measure speech sound production (articulation) accuracy, the GFTA–2 was re-administered. This measure was selected because of its strong psychometric characteristics at school age and to allow for comparison to standardized scores from preschool. Age-based standard scores were derived.

A review of distortion error patterns from preschool data from this cohort indicated that ⅔ (67%) were sibilant distortion errors. In order to determine the extent to which these errors persisted, a picture-naming task assessing /s, z/ in word-initial position was administered using images presented in PowerPoint. This task included four repetitions of the following words: *zoo, zip, Z, Zack, sip, sack, sank, saw,*

Table 2. Descriptive statistics for the 25 children with histories of preschool SSD: School-age measures.

School-age measure	*M*	*SD*	Range
Age (years;months)	8;3	7 mos	7;4–9;3
Months between preschool session and school-age follow-up	44	3	40–49
GFTA–2 standard score	83.8	14.7	46–107
PPVT–4 standard score	109.3	13.2	87–143
CELF–4 Recalling Sentences	10.6	3.4	5–19
CELF–4 Formulated Sentences scaled score	11.2	2.8	5–16
CTOPP Elision scaled score	9.16	2.5	6–16
CTOPP Blending scaled score	7.8	2.2	1–11
CTOPP phonological awareness composite	91.0	12.1	64–121
WJ–III Letter–Word Identification standard score	101.6	10.3	86–119
WJ–III Word Attack standard score	101.0	8.6	81–119
WJ–III Spelling standard score	98.3	14.4	72–129
TOWRE Sight Word Efficiency standard score	103.3	12.3	85–125
TOWRE Phonemic Decoding standard score	96.3	14.1	73–126

Note. CELF–4 = Clinical Evaluation of Language Fundamentals—Fourth Edition (Semel, Wiig, & Secord, 2003); CTOPP = Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999); WJ–III = Woodcock-Johnson Test of Achievement, Third Edition (Woodcock, McGrew, & Mather, 2001); TOWRE = Test of Word Reading Efficiency (Torgesen, Wagner, & Rashotte, 1999).

and *sick*. Additionally, 10 repetitions of the words *Sue* and *see* were elicited, for a total of 56 productions of initial /s, z/. Thus, the task was intended to balance depth (i.e., repeated attempts at words) with breadth (i.e., /s, z/ in different vowel contexts). From the audio recordings of these words, the percentage of alveolar sibilants correct was scored by a research assistant with a background in clinical phonetics who was trained to exceed a minimum of 80% agreement with the first author on identification of /s, z/ allophones. All distortions and substitutions[1] were counted as errors (no omissions occurred). A second listener performed reliability checks on data from 12 participants; interrater reliability on scoring accuracy of sibilants was 93% (Cohen's κ = 0.63).

Intervention histories. All of the children who participated in the follow-up study were enrolled in speech-language therapy as preschoolers, but their intervention histories varied thereafter: Based on parent report, 18 children continued to receive speech-language therapy services as kindergartners (range of 1–5 sessions per week, M = 2.6), 14 received therapy in first grade (range of 1–5 sessions per week, M = 2.5), and 10 received therapy in second grade (range of 1–3 sessions per week, M = 2.2). Additionally, seven of the children were diagnosed as having reading difficulty in school, and all seven were reported to have received intervention or tutoring to address reading/spelling.

Data Analysis

Group summary data are presented first using standard scores to show the group's overall performance relative to age-related normative data. Correlations between preschool speech errors and school-age outcomes are presented for PA and speech production outcomes. Additionally, subgroup analyses were conducted to support the correlational findings and to attempt to replicate the findings from Leitao and Fletcher (2004). Nonparametric statistics were used due to the sample size.

Results

Group Outcomes

Summary statistics from the speech, PA, and literacy measures at follow-up are provided in Table 2. The group average on the GFTA–2 was ~1 *SD* below the mean for the children's respective ages (M = 84). Not surprisingly, this indicates that children with histories of preschool SSDs may have continuing speech sound production problems. Errors observed on the GFTA–2 were on fricatives (/s, z, ʃ, θ, ð /), affricates /ʧ, ʤ/), liquids (/r, l/), and consonant clusters (e.g., /tr, sp/). As expected, errors included some common substitutions (e.g., [w] for /r/) and cluster reductions (e.g., [t] for /tr/), but most were distortions (e.g., lateralized or dentalized /s/, derhoticized /r/). Rarely, voicing errors on obstruents were also observed. From the 25 GFTA–2 samples, only one atypical error was observed (an instance of word-initial devoicing of a voiced stop), indicating that atypical errors were very uncommon at this age. Critically, not all children had persisting speech sound production difficulties (GFTA–2 range 46–107), motivating the need to identify preschool factors that were associated with persisting speech sound production problems.

PA composite scores on the CTOPP were ~2/3 of 1 *SD* below the mean for the children's ages (M = 91), although there was a wide range of performance. This cohort had generally strong language skills (average PPVT–4 standard scores were 109; scaled scores for Recalling Sentences and Formulated Sentences were 10.6 and 11.2, respectively); however, their PA skills were not commensurate with the average to high-average oral language performance. School-age CTOPP scores were not significantly correlated with school-age GFTA–2 scores (Spearman's ρ = 0.25, p = 0.23).

Reading and spelling of real words was age appropriate for the group as a whole based on the TOWRE Sight Word Efficiency subtest (M =103), WJ–III Letter-Word Identification subtest (M = 101), and WJ–III Spelling subtest (M = 98). Additionally, age-appropriate nonword reading was observed for the group on the WJ–III Word Attack subtest (M = 101). The group's lowest performance was on the TOWRE Phonemic Decoding Efficiency subtest (M = 96), which requires speeded reading of nonwords; however, the group average was within normal limits.

Predictors of Outcomes

Although the group's averages are informative, patterns of individual differences are of particular clinical relevance. Because PA and speech sound production accuracy were the outcomes of theoretical interest, analyses focused on predicting these outcomes from preschool speech patterns. Table 3 presents correlations between preschool speech production patterns and school-age outcomes.

Predicting PA and literacy outcomes. As shown in Table 3, the CTOPP PA composite score at school age was associated with the number of atypical errors per consonant in preschool. Greater production of atypical errors in preschool was associated with lower PA scores at school age (Spearman's ρ = –0.47, p = 0.008, 1-tailed). Thus, the same association between more atypical errors and lower PA that was observed crosssectionally in preschool (Preston & Edwards, 2010) was also found to be significant longitudinally. No other preschool speech production variable was significantly associated with school-age PA scores. Moreover, to explore if this association could be explained by socioeconomic status, a partial correlation analysis was run; the relationship between preschool atypical errors and school-age PA remained significant when controlling for maternal education (r = –.38, p = 0.035).

[1]For each child who produced substitution errors for /s, z/, these substitutions (which were rare) followed similar patterns to distortions but crossed a phoneme boundary for the listener. For example, children who primarily produced dentalized [s, z] occasionally substituted interdental fricatives [θ, ð]. Although dentalized [s] and [θ] productions were perceived as categorically different for the listener, we do not presume them to be categorically distinct for the speaker because they often happened on repeated attempts at the same word.

Table 3. Nonparametric correlation between the preschool speech measures and school-age outcomes.

	School-age outcome	
Preschool speech measure	**GFTA–2 standard score**	**CTOPP PA composite standard score**
Atypical errors per consonant	–.14	–.47*
Typical errors per consonant	.33	.09
Distortions per consonant	–.42*	.01
GFTA–2 standard score	–.08	.29

*Correlation significant at $p < 0.05$.

To replicate findings from Leitao and Fletcher (2004), a subgroup analysis was conducted. Participants were divided into two groups based on the proportion of preschool speech sound errors that were atypical according to the following formula:

$$\text{Percentage atypical speech sound errors} = (\text{atypical errors}/[\text{atypical errors} + \text{typical errors}]) \times 100$$

It should be noted that this formula does not count the raw occurrence of atypical errors per consonant, but instead expresses atypical errors as a ratio to all phonological errors (typical and atypical). Children with >10% atypical speech sound errors in preschool ($n = 16$) were compared to children with <10% atypical speech sound errors in preschool ($n = 9$). The results, shown in Table 4, essentially replicate the results reported by Leitao and Fletcher (2004), indicating that the group of children with >10% atypical speech sound errors performed significantly poorer on school-age PA.

As shown in Figure 1, six of the seven children who scored ≤85 on the CTOPP PA composite at the school-age testing (i.e., to the left of the solid line) had >10% atypical speech sound errors as preschoolers. Moreover, of the children who had >10% atypical speech sound errors in preschool (i.e., those above the dotted line), none scored >100 on the CTOPP PA composite at the school-age testing. In addition, as seen in Table 4, the group with >10% atypical speech sound errors as preschoolers scored lower on measures of word reading (TOWRE Sight Word Efficiency, WJ–III Letter-Word Identification), nonword reading (TOWRE Phonemic Decoding, WJ–III Word Attack), and spelling (WJ–III Spelling) at the follow-up testing than the group with fewer atypical speech sound errors. Effect sizes were medium-to-large. The subgroups did not differ in school-age GFTA–2 standard scores or vocabulary. Thus, preschool speech sound error patterns were significantly associated with later PA as well as later literacy skills.

Predicting speech sound production outcomes. As can be seen in Table 3, preschool GFTA–2 scores were not significantly correlated with school-age GFTA–2 scores. However, when specific preschool speech sound error types were examined, the number of distortion errors per consonant in the 125-word picture-naming task was found to be significantly related to the school-age GFTA–2 scores; specifically, children who produced more distortions in preschool had lower GFTA–2 scores almost 4 years later (Spearman's $\rho = -0.42$, $p = 0.019$, 1-tailed).

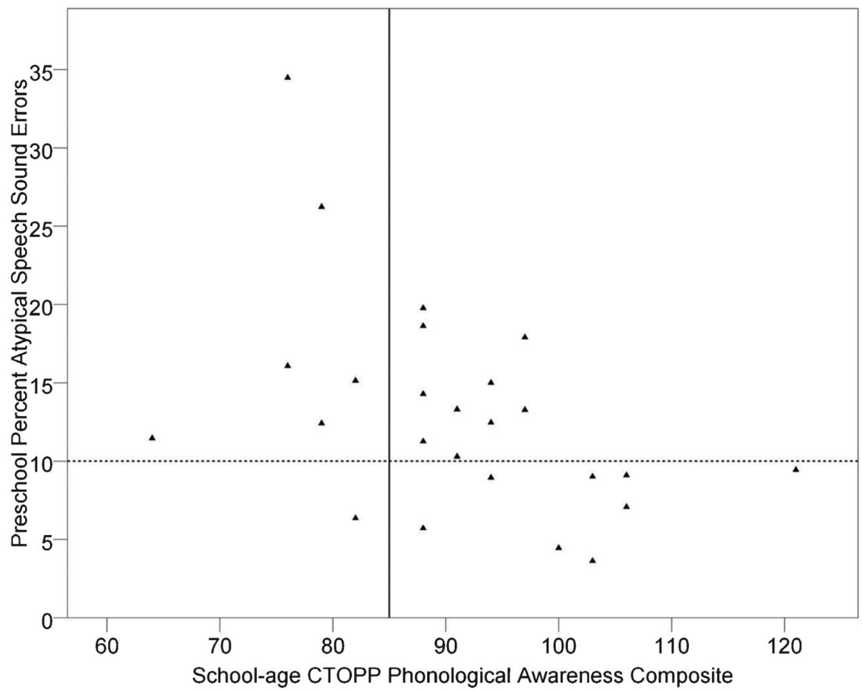
To further study the relationship between specific preschool distortions and school-age outcomes, the accuracy of the sounds that were most commonly distorted by preschoolers (/s, z/) was examined at follow-up. Fifty-six productions of /s, z/ were elicited from each child (nine words repeated four times, and two words repeated 10 times) on a picture-naming task. All errors observed at school age on this task were perceived as distortions (primarily dentalization, lateralization, and palatalization) or occasionally as substitutions ([θ] for /s/). On average, 80% of sibilants were correct (SD = 30%, range 11%–100%).

Table 4. Comparison of subgroups: Children with greater than and less than 10% of preschool speech sound errors classified as atypical.

	>10% atypical errors (n = 16)				<10% atypical errors (n = 9)						
Task	***M***	***SD***	**Median**	**Range**	***M***	***SD***	**Median**	**Range**	***U***	***p****	**Effect size *r***
GFTA–2	82.4	15.2	83.0	46–107	86.4	14.1	86.0	63–104	60.0	0.2600	0.14
PPVT–4	106.9	8.2	108.0	92–119	113.7	19.1	120.0	87–143	54.0	0.1600	0.20
CTOPP PA composite	85.8	9.1	88.0	64–97	100.3	11.3	103.0	82–121	21.5	0.0015	0.58
TOWRE Sight Words	97.9	10.9	96.5	85.5–120.5	113.0	8.1	113.5	95–124.5	23.0	0.0020	0.56
TOWRE Phonemic Decoding	91.5	14.7	89.0	73–126	104.8	7.8	104.5	92.5–117.5	23.0	0.0020	0.56
WJ–III Letter–Word ID	98.1	9.6	98.5	85–119	107.7	9.1	109.0	90–119	32.0	0.0120	0.45
WJ–III Word Attack	98.2	12.9	98.5	81–119	105.8	3.2	106.0	99–111	31.0	0.0100	0.47
WJ–III Spelling	92.8	12.9	90.0	72–125	108.0	12.0	106.0	90–129	20.5	0.0010	0.58

*p values based on Mann–Whitney U, 1-tailed.

Figure 1. Relationship between preschool percentage of atypical speech sound errors and school-age phonological awareness. The solid vertical line represents a standard score of 85 (1 *SD* below the mean), and the dashed horizontal line represents 10% of preschool errors classified as atypical speech sound errors, based on a 125-item picture-naming task. CTOPP = Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999).



The percentage of preschool productions of /s, z/ that were distorted (out of an average of 53 /s, z/ tokens) was calculated from the preschool picture-naming task; only tokens that were phonemically correct (i.e., perceived as within the correct /s/ or /z/ category) were considered. Thus, the percentage of /s, z/ phonemes distorted in preschool did not include /s, z/ targets that were omitted or replaced by other phonemes (n.b., very similar results were obtained if these tokens were included in the denominator). The correlation between preschool proportion of /s, z/ phonemes distorted and school-age (in)accuracy on these sounds was high and statistically significant (Spearman's $\rho = -0.77$, $p < 0.001$, 1-tailed, see Figure 2). The correlation suggests that the more distortions observed on /s, z/ in preschool (when considering phonemically correct productions), the more errors observed on these sounds at school-age follow-up.

Figure 2 displays the preschool and school-age data on /s, z/. If we consider children who produce <75% of /s, z/ tokens correctly as having persisting speech production problems on these sounds (i.e., left of the solid vertical line), seven of the 25 children had persisting /s, z/ errors (six male, one female). Five of these seven with persisting /s, z/ errors produced ≥40% of their /s, z/ phonemes as distortions in preschool (i.e., above the dotted horizontal line). All of the 18 children with positive outcomes (i.e., >75% correct /s, z/ at the school-age follow-up) had ≤40% distortions on these sounds in preschool.

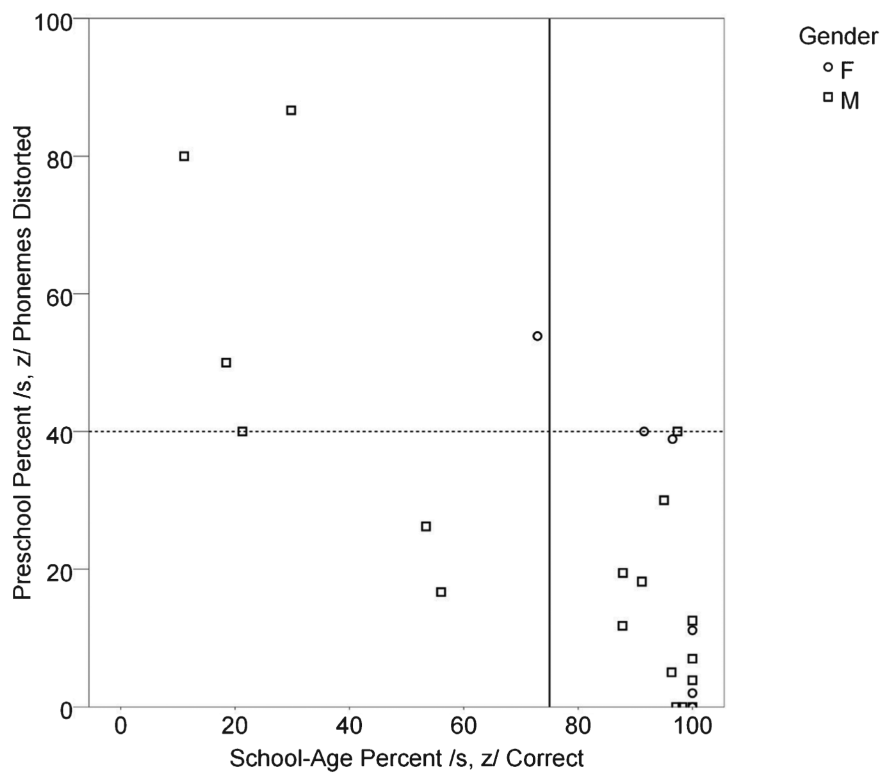
Discussion

Twenty-five children with preschool SSDs were followed up at an average age of 8;3. This is an age at which children rely on their phonological systems to acquire word reading and spelling skills, and it also represents the upper age of speech sound acquisition. It was found that preschool speech sound error patterns could predict school-age PA, literacy, and articulation scores almost 4 years later.

School-Age PA and Literacy Outcomes

An association between atypical speech sound errors and PA skills has been observed crosssectionally in preschoolers with SSDs (Preston & Edwards, 2010), and the present study suggests that the number of preschool atypical errors per consonant is correlated with school-age PA as well, indicating that individual differences in speech production patterns may have important implications. On average, the children's school-age PA scores were ~⅔ of 1 *SD* below age-expected norms in spite of the relative strengths these children had in oral language skills both at preschool and at the school-age follow-up. When 1 *SD* below the mean was used as a cutoff for "low" PA on the CTOPP PA composite, seven of the 25 children (28%) had weaknesses in this domain. Six of these seven children with low PA had >10% atypical speech sound errors as preschoolers. Moreover, the group of children with >10%

Figure 2. Relationship between preschool percentage of distortion errors on /s, z/ and school-age accuracy of /s, z/. The solid vertical line represents 75% accuracy on school-age /s, z/ productions, based on 56 attempts at word-initial /s, z/. Preschool percentage of /s, z/ phonemes distorted is based on tokens that were perceived within the proper /s, z/ phoneme categories and were perceived as either correct or distorted productions, based on an average of 53 targets on a picture-naming task. The dashed horizontal line represents 40% of preschool /s, z/ distorted.



atypical speech sound errors in preschool scored significantly lower on all of the school-age PA, reading, and spelling measures. These results are consistent with the longitudinal findings reported by Leitao and Fletcher (2004), and the associations identified here are in line with the notion that weak phonological representations may underlie both atypical speech errors and poor PA skills (Preston & Edwards, 2010).

These results are contrary to the longitudinal results reported by Rvachew et al. (2007), who found no association between preschool atypical errors and end-of-kindergarten PA. Thus, it is possible that the longitudinal effects may not be robust until beyond kindergarten. It is also possible that seemingly minor methodological differences could have weakened the effects in the study by Rvachew et al. Whereas the present study counted all atypical speech sound errors together, Rvachew et al. analyzed segmental or syllable structure errors separately. Rvachew et al. also used somewhat broader definitions of atypical speech errors and different PA tasks in the younger cohort, which might account for the difference.

Although the children's PA skills were relatively weak with respect to age, their reading and spelling scores were age appropriate for the cohort as a whole. This may be due, in part, to the relative strengths in oral language (particularly vocabulary) and nonverbal cognition (cf. Peterson et al., 2009). Hence, for some children with SSDs, oral language skills may serve as a protective factor against reading problems. It remains to be seen whether these children will (a) continue to compensate for lower PA while maintaining good reading/spelling, (b) develop more slowly in reading/spelling such that these skills begin to approximate their lower PA skills, or (c) show gains in PA skills over time. The longitudinal work that exists suggests that residual weaknesses in PA may continue to be present in some of these children, and that spelling, in particular, may be an area of concern (Bird et al., 1995; Clarke-Klein & Hodson, 1995; Lewis & Freebairn, 1992; Lewis, Freebairn, & Taylor, 2002).

The critical age hypothesis (Bird et al., 1995; Nathan et al., 2004) predicts a relationship between speech sound production and PA at school age, but there was only a weak and not statistically significant relationship between school-age PA and GFTA–2 scores in the present study. However, preschool speech patterns provided some indication of which children were likely to have later PA and literacy problems.

Thus, the specific factors that are associated with literacy risk in children with SSDs might be more observable in preschool (when atypical errors are more likely to be seen) than at school age (when distortions are the predominant errors). Larger cohorts and more frequent assessments are needed to fully explore individual trajectories of growth in speech sound production and PA.

Monitoring the development of PA skills in children with SSDs is critical, and understanding which children are at greatest risk might drive intervention decision making. For example, Gillon (2000, 2005) reported that including PA training in phonological treatment with preschoolers can yield positive outcomes in both speech and early literacy. The present data suggest that children who produce a high proportion of atypical phonological errors (such as ≥10% of their phonological errors) might be particularly good candidates for this type of intervention. From the current data set, for example, the child with the greatest percentage of atypical speech sound errors in preschool (35%) was diagnosed at the age of 8 years with a reading disability and scored below a standard score of 92 on all of the reading, spelling, and PA tasks. This type of child might benefit from direct focus on PA skills from an early age.

School-Age Speech Outcomes

School-age articulation scores were, on average, a full standard deviation below the mean for these children's respective ages based on the GFTA–2. Not surprisingly, this indicates that preschoolers with SSDs are at risk for persisting speech sound production problems at school age. The children's school-age GFTA–2 scores were not significantly correlated with their preschool GFTA–2 scores, suggesting that preschool performance on this instrument was not a robust indicator of later speech sound production outcomes for this cohort. In preschool, the children's GFTA–2 scores were associated with atypical speech sound errors (Preston, 2008); however, only one occurrence of an atypical error was observed at the school-age follow-up, indicating that atypical errors had resolved by this age. Critically, the children's school-age scores on the GFTA–2 were associated with the number of distortions these children produced in preschool.

Distortions occur primarily on later developing sound classes (Shriberg et al., 1994). An analysis of sibilants /s, z/ showed that the greater the occurrence of sibilant distortions in preschool (when /s, z/ targets were not substituted or omitted), the lower the accuracy on these sounds at school age. These data, therefore, provide support for the hypothesis that early distortion errors may become solidified motor templates that are resistant to change and may lead to persisting speech sound errors in some children (Karlsson et al., 2002; Shriberg et al., 2001). All 18 children who had good outcomes on /s, z/ (>75% accuracy at the school-age follow-up) produced no more than 40% of their /s, z/ as distortions in preschool; however, five of the seven children with poor school-age outcomes had distortions on ≥40% of their preschool /s, z/ tokens. The data provide a preliminary guideline for helping to determine which children are at greatest risk for persisting errors on these sounds. When making clinical decisions about treatment targets for preschoolers with SSDs, clinicians should consider monitoring children's progress with distortions or directly treating distortion errors (in addition to typical and atypical substitutions or omissions) to prevent the persistence of these errors.

Limitations and Future Directions

One uncontrolled factor in the current study was intervention history. Although all of the children were enrolled in speech-language therapy as preschoolers, subsequent intervention histories varied: Eighteen children received services in kindergarten, 14 in first grade, and 10 in second grade. However, when the parents were asked, "Do you feel your child continues to have speech (articulation) difficulties?" 10 parents of children who had been dismissed from services responded *yes*. Of these 10, five children scored <80 on the GFTA–2. Thus, some children who were dismissed from services had unresolved speech problems. Presumably, the children who were enrolled in services received intervention with varied emphasis on PA and/or specific sound errors, which may have contributed to the varied outcomes.

The present study did not address children's reading comprehension outcomes. Although the bulk of reading instruction emphasis in the first few years of school is on word-level reading and spelling, future work might examine whether reading comprehension outcomes differ among subgroups of children with SSDs. Other subgrouping approaches, such as etiological or neurobiological profiles, might also aid in specifying individual trajectories of growth. Finally, future studies of the differential effects of various treatment approaches on speech errors, PA, and literacy outcomes would be of clinical value.

Conclusion

Different preschool speech error types were associated with different outcome domains (i.e., atypical speech sound errors predicted PA, whereas distortions predicted speech sound production outcomes). From a psycholinguistic perspective, this indicates that speech production and PA may dissociate at some level of processing (cf. Pascoe et al., 2006). Atypical speech sound errors have been described as reflecting differences at a higher linguistic representational level, and these errors may reflect weaknesses in how phonological information is organized or represented (Dodd, Leahy, & Hambly, 1989; Preston & Edwards, 2010). Although these atypical speech sound errors do not necessarily persist for many years, their occurrence at the ages of 4–5 may be indicative of weaknesses in how children with SSDs process phonological information (Preston & Edwards, 2010), and the frequency of production of these errors appears to indicate risk for long-term PA difficulties. On the other hand, distortions are often described as having a lower level (motoric) basis (Dodd, 1995; Shriberg et al., 2005), and frequent distortion errors in preschool may suggest that the child is at risk for long-term speech sound production difficulties. Specifically, it was found that preschool distortions on /s, z/ are associated with long-term errors on these sounds. Thus, early phonetic templates for these later developing sounds may be resistant to change in children with SSDs (cf. Karlsson et al., 2002; Shriberg et al., 2001). Such knowledge may drive clinical decisions to give attention to distortions, even in preschool, in order to prevent persisting speech problems.

Preschoolers with SSDs may be at risk for persisting speech sound production and PA problems, but these school-age problems may arise via different (psycholinguistic/neurobiological) paths. Not all children with SSDs are alike in their speech error patterns, and the preschool age is an important age to understand the association between speech sound production and future skills. Preschool speech sound error patterns may be one of several factors that SLPs should evaluate when considering long-term prognosis for later outcomes.

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