Phonological Awareness and Types of Sound Errors in Preschoolers With Speech Sound Disorders

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Purpose: Some children with speech sound disorders (SSD) have difficulty with literacy-related skills, particularly phonological awareness (PA). This study investigates the PA skills of preschoolers with SSD by using a regression model to evaluate the degree to which PA can be concurrently predicted by types of speech sound errors.
Method: Preschoolers with SSD (n = 43) participated in PA and speech sound production assessment. Errors from a 125-item picture naming task were coded in 2 ways: (a) considering all consonant errors equally (percentage of consonants correct [PCC]) and (b) using a 3-category system that captures component features of sound errors (typical sound changes, atypical sound changes, and distortions). PA tasks included rhyme matching, onset matching, onset segmentation and matching, and blending.
Results: Variance in a PA composite score could be predicted partly by vocabulary and age (33%). Atypical sound changes accounted for an additional 6% of variance in PA, but distortions and typical errors did not account for significant variance. When the same consonant errors were analyzed using PCC, speech errors did not predict significant variance in PA.
Conclusions: Poorer PA is associated with lower receptive vocabularies and more atypical sound errors. Results are interpreted in the context of the accuracy of phonological representations.

KEY WORDS: speech sound errors, phonological awareness, preschool, atypical errors

L iteracy problems are a significant international concern, and early identification of such problems is essential so that early intervention can take place. Converging evidence suggests that literacy abilities such as spelling, reading decoding, reading comprehension, and reading fluency are related to phonological awareness (PA) skills both concurrently and longitudinally (e.g., Bradley & Bryant, 1983; Snow, Burns, & Griffin, 1998; Wagner & Torgesen, 1987). There is also evidence that children with speech sound disorders (SSD) of unknown origin (i.e., those with no known oral structural problems or developmental disorders) are at risk for preliteracy and literacy problems, particularly if they have an SSD and poor PA skills when they begin kindergarten (e.g., Nathan, Stackhouse, Goulandris, & Snowling, 2004). However, the specific relationship between speech sound production patterns and PA in children with SSD remains unclear. Therefore, to aid in the identification of (pre) literacy problems and associated risk factors, this study explores the relationship between PA and the specific types of speech sound errors exhibited by preschoolers with SSD.

PA refers to the metalinguistic awareness of spoken units of speech, such as syllables, rhyming words, and individual phonemes. In the current study, which is based on the phonological deficit hypothesis, PA is viewed as being causally related to literacy skills (National Reading Panel, 2000; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979; Snowling, 2000; Wagner & Torgesen, 1987). Moreover, the development of PA skills is thought to depend on accurate phonological representations (Elbro & Pallesen, 2002; Fowler, 1991; Snowling, 2000; Swan & Goswami, 1997).

Phonological representations are stored representations in the mental lexicon that contain the phonological characteristics of words (Edwards, 1995; Rvachew, 2006; Stackhouse, 1997). These representations include the constituent phonemes and phoneme combinations and possibly the associated phonetic specifications of the segments. Weaknesses in phonological representations have been discussed as a basis for both SSDs and poor PA, as well as poor literacy skills (Elbro, Borstrom, & Peterson, 1998; Larrivee & Catts, 1999; Perfetti & Hart, 2002; Rvachew, 2007; Rvachew & Grawburg, 2006; Sutherland & Gillon, 2005; Swan & Goswami, 1997).

Phonological representations are generally assumed to develop and become more adultlike as children get older (Nathan et al., 2004; Sutherland & Gillon, 2005). Therefore, age must be taken into account when considering a child's phonological representations. Phonological representations are also thought to become more precise as vocabulary skills develop (Metsala, 1999; Walley, Metsala, & Garlock, 2003). In fact, vocabulary has proven to be the most robust language measure when predicting PA, both for children with and without speech and language impairments. That is, vocabulary is reported to account for approximately 25%–30% of the variance in PA in preschool and young school-age children (Bishop & Adams, 1990; Elbro et al., 1998; Metsala, 1999; Rvachew, 2006; Rvachew & Grawburg, 2006; Rvachew, Nowak, & Cloutier, 2004). It is believed that children's performance on PA tasks improves as they become increasingly attuned to smaller phonological components of words as their vocabularies develop (Fowler, 1991; Metsala, 1999; Snowling, 2000). In the present study, the primary interest is in receptive vocabulary, in part because an SSD can influence the ability to reliably interpret a child's spoken vocabulary when speech sound errors are produced. Metsala reported that larger receptive vocabularies in children were correlated with better performance on PA tasks (e.g., blending, initial phoneme isolation, and rhyming), even when the influence of age was controlled. She attributed this finding to differences in phonological representations. Specifically, children who know more words are thought to have phonological representations that are more adultlike in their features and organization because they must store similar-sounding words separately from one another.

Although children with SSD, as a group, may have poor PA (Bird, Bishop, & Freeman 1995; Leitao & Fletcher, 2004; Leitao, Hogben, & Fletcher, 1997; Lewis & Freebairn, 1992; Raitano, Pennington, Tunick, Boada, & Shriberg, 2004) and may, therefore, be at risk for later literacy problems, this is not the case for every child with an SSD (Catts, 1993; Leitao et al., 1997). However, the variability in PA skills in this population is largely unexplained. Thus, this study seeks to determine if the variability in PA skills in children with SSD can be partly explained by the relative occurrence of the different types of speech sound errors the child exhibits, and whether speech errors provide a unique explanation for PA variance beyond the known contributions of vocabulary and age.

Measuring Speech Sound Production

The measurement of speech sound production is complex, with clinical and research methods varying widely. Research evaluating the relationship between PA and speech sound accuracy, quantified by the total number of consonant errors or scores on a standardized articulation test, has yielded mixed results (Catts, 1993; Larrivee & Catts, 1999; Rvachew & Grawburg, 2006). However, standardized tests typically include limited speech samples (often under 60 words and/or just one occurrence of each sound in each word position), and all types of errors are generally weighted equally (e.g., distortions may be counted the same as both common and uncommon substitutions and omissions).

McDowell, Lonigan, and Goldstein (2007) used the Goldman Fristoe Test of Articulation—Second Edition (GFTA–2; Goldman & Fristoe, 2000) along with a measure of nonsense word repetition to estimate speech sound accuracy in 700 children between the ages of 2 and 5 years. The combined GFTA–2 and nonword repetition measure was found to account for significant variance (5%) in PA (rhyme, blending, and elision) beyond receptive vocabulary. However, limitations of this study include the use of a small speech sample and the use of a task that involves phonological memory/perception (nonword repetition) to assess speech sound accuracy. It is also unclear how many of these children actually had an SSD. In addition, McDowell et al. did not consider the types of speech sound errors made by the children.

Percentage of consonants correct (PCC) is a widely used measure for assessing severity of a speech sound disorder (Shriberg, Austin, Lewis, McSweeny, & Wilson, 1997; Shriberg & Kwiatkowski, 1982). In this measure, however, all consonant errors are weighted equally. Although PCC has been found to relate to severity of

speech production problems (Shriberg & Kwiatkowski, 1982), it may not be the best measure for evaluating the relationship between speech sound accuracy and PA because it does not distinguish between types of errors. In some studies, PCC has been found to predict PA and early literacy (Bird et al., 1995; Bishop & Adams, 1990; Larrivee & Catts, 1999; McDowell et al., 2007), but in other studies, PCC has not been found to be related to PA (Gillon, 2005; Nathan et al., 2004; Rvachew & Grawburg, 2006). Therefore, the current study utilizes a procedure for measuring speech sound errors that may be more sensitive to PA problems than PCC is, in part, because it takes into consideration the presumed relationship between the types of errors and phonological representations.

Difficulty learning to produce and/or use speech sounds correctly can be manifested in a variety of types of speech sound errors, and these errors can be characterized in various ways. In the current study, speech sound errors are categorized according to typical and atypical sound changes, often referred to as *phonological processes* (Edwards, 1992; Edwards & Shriberg, 1983; Ingram, 1976; Khan, 1982). In this type of analysis, errors are characterized in terms of assimilation, as well as changes in place of articulation, manner of articulation, voicing, and syllable structure. Such sound changes have been used in the literature for many years to describe speech sound errors produced in typically developing children, as well as those with SSD. Although previous investigations have often used such error patterns to describe the types of sound errors made by individual children or small groups, there have been relatively few attempts to use such error patterns to quantitatively describe children's speech sound accuracy. In the present study, each speech sound error is classified according to the types of individual (component) sound changes involved: distortions, typical sound changes, and atypical sound changes. It is hypothesized that atypical errors reflect relatively weaker phonological representations (cf. Dodd, 2005; Leitao & Fletcher, 2004) and thus will make a significant contribution to the variance in PA. Typical errors are assumed to reflect less impaired phonological representations than atypical errors and, therefore, to have a weaker relationship with PA. Finally, errors that represent minor deviations from a target (e.g., distortions) and that presumably reflect more accurate phonological representations will not significantly contribute to the variance in PA.

Distortion Errors

Distortion errors typically reflect a slight alteration in the production of a sound (e.g., a slight problem with tongue shape or placement). The resulting productions are in the correct phoneme category but lack phonetic precision or accuracy. Distortions are prevalent in the speech of young children with typically developing speech as well as those with SSD (Shriberg & Kwiatkowski, 1994; Smit, Hand, Freilinger, Bernthal, & Bird, 1990). It has been suggested that distortions or "subphonemic errors" (e.g., dentalized or lateralized /s/, labialized /r/) may represent a breakdown in motoric processes (Dodd, 2005; Dworkin, 1980; Shriberg et al., 2005). As such, distortions might not be closely related to PA (Shriberg, 1997). For example, Rvachew, Chiang, and Evans (2007) reported that groups of 4- to 5-year-old children with SSD who had normally developing PA and those with delayed PA were not significantly different in the number of distortions produced on the GFTA–2. Thus, it is hypothesized that distortions are not indicative of weak phonological representations and therefore will not be related to PA.

"Typical" Sound Changes

"Typical" sound changes represent substitutions, additions, or deletions that affect a class of sounds or a sound sequence (Edwards, 1992; Edwards & Shriberg, 1983). For example, children with typically developing speech, as well as children with SSD, often produce stops in place of fricatives, as in [tu] for *Sue* /su/. Some errors involve more than one feature change at a time, as in [du] for *Sue* /su/, which would be accounted for by a combination of stopping the fricative and adding voicing. These are sometimes referred to as *constituent processes* (Stampe, 1972) or *interacting processes* (Edwards, 1992). The difference between these two error productions for /s/ would not be captured using PCC because in both [tu] and [du], the one consonant that is assessed (/s/) is produced incorrectly; thus, both productions would be counted the same.

"Atypical" Sound Changes

Some speech sound errors exhibited by children with SSD reflect sound changes that are found rarely, if at all, in typical phonological development. For example, children with SSD may delete the initial consonant in a word, as in [u] for *Sue* (Dodd & Iacano, 1989), or they may replace a sound produced in the front of the mouth with one produced further back in the mouth, as in [hu] or [gu] for *Sue*. Such errors have been characterized as unusual, deviant, atypical, nondevelopmental, or different from those exhibited by normally developing children (Dodd, 2005; Dodd & Iacano, 1989; Dodd, Leahy, & Hambly, 1989; Edwards & Shriberg, 1983; Ingram, 1976; Klein & Spector, 1985; Leonard, 1985; Lowe, 1994).

One of the goals of this study is to investigate the hypothesis that atypical sound changes may be associated with poorer PA outcomes. There is some limited support for this hypothesis. For example, Dodd et al.

(1989) reported that preschoolers who consistently used atypical sound changes had more difficulty detecting whether a word obeyed the phonotactic rules of the language (e.g., /zmebi/ violates an English phonotactic rule concerning initial clusters) than a group of children who consistently used typical sound changes. Although this earlier study generally lends support to the notion that atypical errors may be indicative of a poorer understanding of phonological rules, the data indicate that children with atypical speech sound errors also produced more total errors than did the children in the typical error group. Additionally, vocabulary and age were not considered when the groups were compared. Hence, it is unclear whether atypical sound changes, more total sound errors, or other factors (e.g., vocabulary differences) may have contributed to the low performance on this task.

Leitao et al. (1997) compared typically developing, speech impaired, language impaired, and speech and language impaired 6-year-olds on several measures of PA. They noticed a range in the performance of the speech-impaired group on the PA tasks (blending, segmenting, and elision) and speculated that children who frequently used atypical sound changes might perform more poorly on PA tasks than those who frequently used typical sound changes. In a follow-up study, Leitao and Fletcher (2004) examined two cohorts of children with SSD at age 6 and followed them prospectively until ages 12–13. They discovered that children in the group who used more atypical sound changes at age 6 performed significantly more poorly on PA and literacy measures at follow-up than children who produced few atypical changes. However, there were only 7 children in each group, making it difficult to generalize the findings.

Rvachew et al. (2007) explored the relationship between PA and speech sound errors by analyzing children's consonant errors on the GFTA–2. The 58 children with SSD, ages 4–5, were divided into two groups: those with and without PA problems. The groups were compared on the types of speech sound errors they produced. Errors were classified as distortions, typical syllable structure errors (e.g., final consonant deletion), typical segmental errors (e.g., /s/ → [t]), atypical syllable structure errors (e.g., initial consonant deletion), and atypical segmental errors (e.g., /t/ → [k]). Among preschool children, the only significant group difference was that the children with PA problems produced more typical syllable structure changes. When the same children were in kindergarten, the only significant difference was that children with PA problems produced more atypical segmental errors. Although this study relied on a small speech sample (one production of each phoneme per word position) and did not consider phonetic context, it does highlight the need to consider that atypical speech errors may be related to PA.

In the present study, a summary of each child's speech sound errors includes a score in each of three categories: (a) distortions, (b) typical sound changes, and (c) atypical sound changes. Thus, both the types of sound changes and their frequency are taken into account. Additionally, the current classification system also captures two or more sound changes that co-occur on the same phoneme. For instance, if the word *cap* /kæp/ is produced as [dæp], two sound changes are counted for the initial phoneme (fronting of the velar and initial voicing). Both of the constituent sound changes involved in this error (in this case, two typical sound changes) are counted in the present analysis, whereas only one error would be counted in the PCC analysis. In addition, some sound errors may be accounted for by the interaction of sound changes from different categories. For example, in [gi] for *tea* /ti/, one typical error (initial voicing) and one atypical error (backing to velars) co-occur.

Primary Goals and Hypotheses

There are several limitations in prior research that are addressed in the present study. Many existing studies have failed to control for vocabulary differences when evaluating the variability in PA. In addition, only Rvachew and colleagues have evaluated the relationship between speech sound error types and PA in preschoolers with SSD (a population that is frequently served clinically), and they did not consider phonetic context. Speech samples used in prior research have often been small, and analyses have been based on correct/incorrect judgments, making it difficult to adequately quantify a child's speech sound accuracy. Although previous studies have examined how the frequency of speech sound errors (e.g., on standardized tests or PCC) relates to PA, this study is unique in that it evaluates both the frequency and types of sound changes involved in children's errors. Thus, the following hypotheses are investigated here: (a) PA will be related to speech sound error types in preschoolers with SSD according to the proposed accuracy of phonological representations; (b) types of speech sound errors thought to reflect weak phonological representations will predict variance in PA beyond receptive vocabulary and age; and (c) an analysis that characterizes sound changes according to the relative accuracy of phonological representations will provide a better explanation of the variance in PA than an analysis that does not differentiate among types of speech sound errors.

Method
Participants

Preschoolers ages 4–5 with a diagnosed SSD of unknown origin participated in the study. No attempt

was made to include or exclude children based on the type of SSD (articulation or phonological disorder, suspected childhood apraxia of speech, deviant or delayed speech sound production, etc.) because of the lack of agreed-upon criteria for such diagnoses. Children were sought who did not have a moderate or severe receptive language delay, but they were not excluded from the study for expressive language concerns. Children were recruited through public notices as well as referrals from speech-language clinicians who were contacted about the study via e-mails, letters, presentations, and so forth. Parents who were interested contacted the first author and completed a telephone interview to confirm that the child had difficulty with speech sound production and no known permanent hearing loss or developmental disability that might cause an SSD (cleft palate, autism, etc.) and that the adults in the home were native speakers of Standard American English (this was also informally confirmed in the screening).

Part I: Screening

A screening was conducted by the first author, a certified speech-language pathologist, to determine eligibility for the experimental portion of the study. Screenings took place either at the child's home ($n = 49$) or at a quiet room used for child research at Syracuse University ($n = 2$). The following tasks were administered in random order. Participants were offered a short break after two or three tasks.

Speech

The Sounds-in-Words subtest of the GFTA–2 (Goldman & Fristoe, 2000), which is commonly used with preschoolers, was administered to screen speech sound production. To qualify for the experimental portion of the study, children had to achieve a standard score below 90 on the GFTA–2. Although 90 is a somewhat liberal estimate of speech disorder (only 3 participants were above 85), this score was used for several reasons: The scores on this test are not normally distributed; we wanted to include children with so-called "mild" impairments; the GFTA–2 score does not take in to account the nature of speech errors when scoring, a characteristic in which we were interested; and presence of an SSD had been confirmed by parents/referring clinicians.

An informal oral mechanism screening devised for this study was used to confirm that there were no gross structural or functional problems contributing to the SSD. No child was excluded because of concerns on this task.

Receptive Language

Children were required to demonstrate receptive language skills that were adequate for participating in PA tasks. This was operationally defined as achieving scores not lower than 1.33 *SD*s below the mean on at least two of three receptive language tasks (described below). This was believed to be a reasonable way of including children who might have subtle receptive language difficulties but who would still be able to follow directions and understand vocabulary well enough to participate in the research tasks. Expressive language was not formally evaluated because none of the experimental tasks required more than single-word responses and because expressive language skills were not relevant to the theoretical justification for the study.

The Concepts and Following Directions subtest of the Clinical Evaluation of Language Fundamentals: Preschool—2 (CELF:P–2; Wiig, Secord, & Semel, 2004) requires children to follow verbal directions by pointing to pictures of animals, usually in a specified order. For example, "Point to the big dog, then point to the little monkey." Items increase in length and complexity.

The Sentence Structure subtest of the CELF:P–2 requires children to point to a colored picture (from a field of four) that depicts a scene corresponding to the examiner's description, such as "Point to: The girl who is standing in the front of the line is wearing a backpack."

The Peabody Picture Vocabulary Test—Fourth Edition (PPVT–4; Dunn & Dunn, 2007) assesses children's comprehension of single words by requiring them to point to a colored picture (from a field of four) that corresponds to the word spoken by the examiner. Items increase in complexity, and testing continues until a ceiling is reached.

Nonverbal Cognition

The Pattern Construction subtest of the Differential Ability Scales (DAS; Elliott, 1990) was used as a brief screening of nonverbal intelligence. Children are shown pictures depicting patterns of yellow and black squares. They then try to manipulate blocks to replicate the patterns shown in the pictures. Both speed and accuracy of responses are considered in scoring. Children were included if they achieved a *t* score above 37 (i.e., 1.33 *SD*s below the mean).

Participants Included in Part II

Fifty-one children participated in Part I (screening), and the 44 who met the criteria described earlier were invited to participate in Part II. Because one parent canceled the second session, a total of 43 children participated in the experimental tasks. Time between Parts I and II was always less than 4 weeks ($M = 10$ days). Table 1 summarizes the performance of these 43 participants on the Part I tasks. There were 34 males and 9 females, a 3.78:1 male:female ratio, which is not statistically

Table 1. Descriptive statistics for the 43 preschoolers with SSD who participated in Part II and were included in the final analysis.

Test	Statistic	M	SD	Range
GFTA–2 Sounds-in-Words subtest	Standard score (M = 100, SD = 15)	71.1	11.7	49–89
	Percentile	8.3	5.6	0.5–23
DAS Pattern Construction subtest	t score (M = 50, SD = 10)	57.2	7.8	43–70
	Percentile	71.4	23.1	24–98
CELF:P–2	Sentence structure scaled score (M = 10, SD = 3)	10.9	2.4	6–15
	Concepts and following directions scaled score	10.5	2.5	4–15
PPVT–4	Standard score (M = 100, SD = 15)	112.4	12.3	84–145
	Percentile	73.8	21.6	14–99

Note. Mean age of children (in months) = 54.7 (SD = 5.4, range = 48–69). SSD = speech sound disorders; GFTA–2 = Goldman Fristoe Test of Articulation—Second Edition; DAS = Differential Ability Scales; CELF:P–2 = Clinical Evaluation of Language Fundamentals: Preschool—2; PPVT–4 = Peabody Picture Vocabulary Test—Fourth Edition.

different than the 2.75:1 ratio reported for children with SSD by Shriberg (1994), $\chi^2(1, N = 43) = 0.724, p = .395$. All participants were Caucasian except 1 female who was adopted from Asia as an infant. All had been recommended for speech therapy, and all but 1 were enrolled in speech therapy at the time of the study. The average reported maternal education level was 16 years of formal schooling (SD = 2.3 years) or the equivalent of 4 years of college. The mean paternal education level was 15 years of formal schooling (SD = 2.9) or about 3 years of college. It is evident from Table 1 that some participants had relatively high scores on the PPVT–4 and DAS Pattern Construction subtest compared with the standardization samples (p values < .01 based on one-sample t tests), possibly because of referral bias or self-selection bias.

Part II: Experimental Session

Part II was conducted at a quiet research laboratory for 9 of 43 children; the remainder were seen at their homes. Part II, which took between 70 and 110 min, was split into two sessions if the child showed significant signs of fatigue or was distracted. Children were offered frequent breaks throughout the sessions. Task order was pseudorandomized, with tasks being administered as follows: (a) hearing screening, (b) familiarization with 96 target pictures used in the PA tasks, (c) and (d) randomly chosen PA tasks, (e) picture naming task (for speech sample), (f) and (g) randomly chosen PA tasks, and (h) and (i) rapid naming and syllable repetition tasks (not reported here).

Hearing was screened using a portable MAICO MA 27 audiometer. Pure tones were presented at 20 dB SPL (or up to 25 dB SPL if screened at home) at 1, 2, and 4 kHz (American Speech-Language-Hearing Association, 1997). Forty-one participants passed the screening. One participant was not screened because the audiometer was not available, and 1 participant passed the screening

in the left ear but did not pass in the right ear (all thresholds < 35 dB), possibly because of a cold. He was kept in the study because there was no history of permanent hearing loss, and he did not appear as an outlier in the data; conclusions were unchanged when the participant was excluded from analyses. Audio stimuli were presented to this participant at a loudness level that he indicated was adequate.

Speech Assessment

Speech sample. Speech samples were obtained by means of a spontaneous (i.e., nonimitated) picture naming task so that the same speech sounds and word structures were elicited from all of the children. Because sound changes may affect both syllable/word structure and individual phoneme production, extensive samples were needed that contained a variety of syllable structures and phonemes in different word positions, along with many consonant clusters and multisyllabic words (cf. Larrivee & Catts, 1999). Thus, a 125-word picture naming task (PNT) adapted from prior research (Wolk, Edwards, & Conture, 1993) was used to assess all consonants at least twice in nearly every position in which they occurred. The sample consisted of 480 consonants (including rhotic vowels), although this total was adjusted when necessary (e.g., if the child did not produce a particular word). If the child mislabeled a picture, scripted prompts were used to elicit the desired target word, with delayed imitation used if necessary. For approximately half of the children, the PNT was administered in order from Item 1 to Item 125. For the rest, the PNT was administered in the reverse order, starting with Item 125.

Recording. The PNT was audio recorded with a Zoom H4 Handy Recorder with two studio quality X/Y pattern condenser microphones and was recorded as a WAV file at 24-bit quantization and 48-kHz sampling rate. The PNT was also recorded on an Olympus WS-331M digital voice recorder, recorded on extra-high-quality stereo mode with

no low-cut filter. The clearer of the two recordings was used for transcription. For 1 participant, a cassette recording was made and later digitized because the digital recorders were not brought to the session.

Transcription and error coding. Children's responses on the PNT were narrowly phonetically transcribed by the first author. To ensure accuracy of the transcriptions, audio files were reviewed a minimum of three times for each participant. If the child spoke a word more than once, the clearer recording of the two renditions was used; if both were clear, the first was chosen. When there was overlay with another speaker or if background noise covered a portion of the word, the child was given credit for producing those overlaid sounds correctly. If a child added morphological endings, those were not analyzed (e.g., if a child said "toys" for *toy,* the plural was not scored).

Using these transcriptions of responses from the PNT, two consonant analysis schemes were carried out and were compared to determine if either could predict variance in PA: (a) PCC and (b) a three-category system (see Appendices A and B) that included the following measures:

1. *Distortions per consonant:* The number of consonants distorted divided by the total number of consonants attempted. Subphonemic sound changes that are dialectally acceptable (e.g., partial devoicing of voiced final consonants) were not counted as errors.

2. *Typical sound changes per consonant:* The number of typical sound changes divided by the number of consonants attempted (cf. the process density index described by Edwards, 1992, and the relative influence on unintelligibility described by Dodd & Iacano, 1989).

3. *Atypical sound changes per consonant:* The number of atypical sound changes divided by the number of consonants attempted (cf. Dodd & Iacano, 1989).

Speech errors for both analyses were computed by hand (rather than by using a computer algorithm) to allow for dialectal variations (e.g., affrication of /tr, dr/ clusters, [ʔ] for final /t/) and for interacting or "constituent" sound changes. Because it was necessary to refine some of the sound change definitions as the study progressed, transcriptions of each participant's speech sample were reviewed a minimum of three times to ensure accuracy and consistency of coding.

Typical changes in syllable structure, place of articulation, manner of articulation, and voicing, as well as assimilatory changes commonly found in children's speech sound development, have been generally well described (Edwards & Shriberg, 1983; Ingram, 1976; Khan, 1982). In addition, there has been a moderate amount of discussion about what constitutes atypical or unusual sound changes. However, definitions differ somewhat, and some sound changes have not been discussed extensively. For the present study, atypical sound changes were defined based on prior research, to the extent possible, but some definitions had to be refined to be sufficiently explicit. Appendix A lists the sound changes used in this study; complete definitions are available from the first author (see also Preston, 2008). To avoid overestimation of atypical changes, a relatively conservative approach was used. When there was lack of agreement in the literature, a general rule of phonetic plausibility was adopted. Thus, if a consonant sound change occurred that was potentially due to phonetic context, word position, or influence of other consonants in the word, it was not considered atypical. For example, velarization of alveolars (e.g., /d/ → [g]) has often been described as atypical (e.g., Dodd & Iacano, 1989) because typically developing English-speaking children generally do not replace front sounds with back sounds. Given the definitions developed for this study, this sound change would be considered atypical only if it could not be accounted for by a typical sound change, such as velar assimilation. Thus, /d/ → [g] in *dinosaur* would be considered atypical because there are no other velars in the word to trigger this change, but /d/ → [g] in *pudding* would be attributed to the typical error of velar assimilation (i.e., /d/ takes on the velar feature of /ŋ/).

PA

Although some PA tasks require spoken responses, this may confound results when assessing PA in children whose speech is often difficult to understand (Sutherland & Gillon, 2005). Therefore, PA tasks selected for this study met the following criteria: (a) No spoken response was required, (b) the task had been shown to be related to later literacy development, and (c) the task was age appropriate. PA tasks were therefore based on prior research (see next section).

Ninety-six words (different from those on the PNT) were selected for use in the PA tasks. All 96 words were monosyllabic, and most were CVC syllables, with a few CV (e.g., *shoe*) or CCVC (e.g., *spoon*). Words were chosen based on (a) their use in prior research, (b) their phonological features, and (c) their picturability/interpretability by 4-year-olds in pilot testing. To limit the number of items with which the children had to be familiar, each word was used either two or three times, but no word was used more than twice in a given task, and no word was used twice as the target response. For example, *coat* appeared once as a distracter word in onset matching, once as a distracter in rhyme matching, and once as a correct target in the blending task.

Audio stimuli were recorded by the first author and paired with visual stimuli, which were clip art pictures taken from a variety of sources (e.g., Microsoft Word,

Google Images). Stimuli were presented to participants on a Dell Inspiron 8600 laptop in Microsoft PowerPoint. An external speaker was used to amplify the audio signal in environments where the internal speakers of the laptop were judged to be insufficient.

Before the PA tasks were administered, children were shown the 96 pictures on the laptop and asked to name them. If a child was unfamiliar with the picture or provided the wrong label, a spoken model was provided, he or she was asked to imitate the word, and then another model was provided.

General procedure for PA tasks. Children sat on the floor or at a table and pointed to pictures on the laptop screen in response to the stimuli. Some children provided verbal responses as well, but they were also encouraged to point because verbal responses could be unintelligible. The recorded audio stimuli were played only once unless the child failed to respond (e.g., if distracted) or requested repetition. The examiner pointed to the pictures on the screen as the audio stimuli were presented. If a child changed his or her response, the final response was scored. The examiner controlled the rate of presentation.

The first three PA tasks (rhyme matching, onset segmentation and matching, and onset matching) were adapted from Bird et al. (1995). All have been used with preschoolers with SSD to predict early literacy skills (Rvachew, 2006; Rvachew & Grawburg, 2006). The tasks were adapted to be presented with recorded audio stimuli and pictures on a laptop in PowerPoint (instead of using puppets and live voice, as in the original research). Items were modified to control phonological similarity of distracter items to the targets.

Rhyme matching. The rhyme matching task included 16 experimental items, with four blocks of four rhymes (4 items that rhyme with *Dan, Doug, Pete,* or *Ned*). For each trial, four pictures appeared on the computer screen: the correct picture and three distracters. Each block was introduced by the presentation of a photo of a person paired with an audio recording. For example, "This is *Dan. Dan* likes things that rhyme with his name. Help *Dan* find things that rhyme with his name." The name was repeated during each item: "Which one rhymes with *Dan? spoon, cap, mouse, pan.* Which one rhymes with *Dan?*" (child points). For each rhyme matching item, one of the distracters had the same vowel as the target (here, /æ/ in *cap*), one had the same final consonant (here, /n/ in *spoon*), and one had no phonemes in common with the target (here, *mouse*). A picture of the character whose name was to be rhymed always appeared in the upper-left hand portion of the screen (here, a picture of *Dan*). One instructional item and five training items were provided with corrective feedback as necessary.

Onset segmentation and matching. A similar paradigm was used for the onset segmentation and matching

task. When presented with four pictures, children were instructed to find a word that "begins like" a particular name. For example, "Which one begins like *Tom? Pin, juice, tie, door.* Which one begins like *Tom?*" (child points). One of the distracter items always began with a phoneme that children frequently produce as a substitute for the target phoneme. For example, all of the distracter items for *Tom* included a foil beginning with /d/ (e.g., *door*). There were five experimental items that began with /t/ (to match *Tom*) and five that began with /s/ (to match *Sam*). The distracter items for /s/ always included a word starting with /t/ or /θ/. One instructional item and five training items were provided with corrective feedback.

Onset matching. From a field of four pictures, children had to select the one whose name began with a given sound. In this task, children were given the phoneme they had to listen for. Five items requested the child to choose a word beginning with /p/ and five with /tʃ/ (ch). For example, "Which one begins with /p/? *Deer, kite, bug, pin.* Which one begins with /p/?" Five training items (three with /r/, two with /m/) were provided with feedback to familiarize the child with the task. As with the onset segmentation and matching, one foil or distracter item in the onset matching task began with a phoneme that children often produce as a substitute for the target. Thus, all /p/ matching items had a foil beginning with /b/, and all /tʃ/ items had foils beginning with /ʃ/ (sh). The remaining two distracters began with phonemes less similar to the target (e.g., /d/ in *deer* differs from /p/ in both place and manner of articulation).

Blending. To assess onset-rhyme blending and CVC phoneme blending (or synthesis), a task was adapted from previous research (Larrivee & Catts, 1999). Children were presented with a set of three pictures on the computer screen (e.g., fan, fish, and dish) and listened to a recorded presentation of the target word spoken in segments with approximately 1 s between sounds. To introduce the task, children were shown a picture of a monster and were told, "This monster says things in a funny way. He says words in pieces. See if you can guess what he is saying." For each item, a carrier phrase spoken by a woman ("Point to the one that you hear") preceded the segments, which were spoken by the monster (a man). Twelve experimental items were presented in a gamelike format. The first 6 items required onset-rhyme blending; the last 6 required blending of individual phonemes (CVC). All targets were CVC words. Three training items with corrective feedback were presented before the 6 onset-rhyme blending items (e.g., /f--ɪʃ/). Two more training items with corrective feedback were presented before the 6 CVC blending items (e.g., /f--ɪ--ʃ/). Both distracter words had phonological similarity to the target: One foil began with the same phoneme as the target (e.g., *fan* begins like *fish*), and one foil had the same vowel and/or final consonant as the target (e.g., *dish* has the same rhyme as *fish*).

Reliability of PA Tasks

For children seen at the university laboratory, sessions were video recorded. A graduate research assistant reviewed the videos to verify the accuracy of the responses recorded at the time of the testing. Agreement between the PA responses recorded "live" and those obtained from the video was 99.7% for a total of 288 PA items from 9 participants. Additionally, for this sample, the split-half reliability (odd–even correlation) for all of the PA items was .77, and Cronbach's alpha (a measure of internal consistency) was .87.

Reliability of Speech Production Measures

Each speech sample from the PNT was narrowly phonetically transcribed by the first author; then the transcriptions were reviewed and coded for errors according to the scheme developed for this study. Therefore, reliability was obtained for both steps. The second author, who has 30 years of experience with transcription of children's speech, completed the reliability.

The first reliability measure evaluated the replicability of the error coding scheme. The second author reviewed the first author's narrow transcription of a randomly selected sample of at least 20 words from each participant. She used the error coding system developed for this study to classify each speech sound error. Word-by-word agreement was computed, scoring "agree" if the initial rater and the reliability judge completely agreed on the number of distortions, typical sound changes, and atypical sound changes in the word. Disagreements were reviewed and were used to further refine definitions of error patterns. Given the phonetic transcription of a child's speech, the two judges completely agreed on speech error coding of all of the sound changes in 834 of 903 words (92.4% of words). Following adjustments to the coding system, 41 of those words that the two judges disagreed on were independently coded a second time. Agreement was reached on 83% (34/41) of these words on which the judges originally disagreed.

Both authors worked together to transcribe and code data from 5 participants to ensure consistency in scoring. Interrater reliability was also collected for 41 participants. The second author independently transcribed 25 consecutive words of the 125-word speech sample, with the starting point randomly chosen for each participant. She then coded errors based on her transcriptions. This was a "worst case scenario" measure because differences in phonetic transcription could inherently result in different coding of sound changes. These 25-word samples ranged from 90 to 104 consonants, depending on the words transcribed. For these 41 participants, the mean difference between the two estimates for the 25-word sample was 0.020 atypical sound changes per consonant (SD = 0.027), 0.022 typical sound changes per consonant (SD = 0.046), and 0.025 distortions per consonant (SD = 0.026).

Data Analysis

A correlational design was used to examine the concurrent relationship between measures of speech sound accuracy and PA in preschoolers with SSD. Hierarchical multiple regression was used to evaluate the proportion of variance in PA that could be explained by age, vocabulary, and speech sound errors. An alpha of .05 was used as a guide for statistical significance testing. As a conservative estimate of the proportion of variance explained, adjusted R^2 values are presented.

Results
Summary of Speech Sound Production

A primary goal of the present study was to evaluate appropriate methods of quantifying speech sound errors in children with SSD and to determine how those errors relate to PA skills. PCC was calculated from the 125-item PNT for each child, with any phonemic change (substitution or omission) or clinical distortion being considered an error. The mean PCC (see Table 2) is similar to findings in other studies of children with SSD that have used PNTs (Bird et al., 1995; Wolk, 1990), is lower than means from connected speech samples in normally developing children, and is near values reported for conversational samples from children with SSD (Campbell, Dollaghan, Janosky, & Adelson 2007; Shriberg et al., 1997; Shriberg & Kwiatkowski, 1982).

From those same speech samples, all sound changes were also analyzed based on the three-category system: distortions, typical sound changes, and atypical sound changes. As expected, children produce significantly more typical than atypical sound changes. However, all children were found to produce at least some atypical sound changes. Distortions were also produced relatively infrequently, as reported in other studies (Gruber, 1999).

Table 2. Summary of speech sound production for 43 preschoolers with SSD.

Sound error measure	M	SD	Range
Percentage of consonants correct	48.45	11.44	16.29–69.17
Distortions per consonant	0.047	0.036	0.00–0.156
Typical sound changes per consonants	0.453	0.128	0.236–0.819
Atypical sound changes per consonants	0.073	0.044	0.015–0.249

As described earlier, PCC is not simply a linear combination of the three error types, as PCC does not take into account the components/features of sound changes. Higher values on the typical sound changes per consonant, atypical sound changes per consonant, and distortions per consonant indicate more errors and, therefore, less accurate speech production, whereas higher PCC values are indicative of greater speech sound accuracy. Table 3 reports correlations among the three types of speech sound errors. Similar correlation matrices are not available from other studies because this is the first to quantify all consonant errors according to this three-category system; however, these values are not unexpected. Typical and atypical sound changes were positively correlated ($r = .344$, $p < .05$), suggesting that children who produce more atypical sound changes also produce more typical sound changes. Distortions were negatively correlated with typical sound changes ($r = -.440$, $p < .01$), which is in accord with literature on speech development suggesting that children may progress from making phonemic errors (substitutions and omissions) to distortions as their speech sound accuracy improves (Gruber, 1999).

Summary of PA

Table 4 summarizes the group performance of the preschoolers with SSD on the PA tasks: rhyme matching, onset matching, onset segmentation and matching, and blending. Means represent the number of correct responses on each task. The means and standard deviations are generally in agreement with those reported in other studies that used similar tasks with 4- to 6-year-olds with SSD (Bird et al., 1995; Rvachew & Grawburg, 2006). As expected, there was a broad range in performance on the PA tasks among these 43 children with SSD. Therefore, there is interest in explaining this variability of PA skills.

Table 3. Pearson's correlation coefficients (*r*) of speech sound error types.

Sound error type	PCC	Typical sound changes per consonant	Distortions per consonant
Typical changes per consonant	−0.924**		
Distortions per consonant	0.302*	−0.440**	
Atypical changes per consonant	−0.600**	0.344*	−0.183

Note. PCC = percentage of consonants correct.

*Correlation was significant at the .05 level (two-tailed). **Correlation was significant at the .01 level (two-tailed).

Table 4. Number of items correct by 43 preschoolers with SSD on the four PA tasks.

Task	M	SD	Range
Rhyme matching (out of 16 items)	6.8	3.4	2–14
Onset matching (out of 10 items)	4.5	2.6	0–10
Onset segmentation and matching (out of 10 items)	3.5	2.2	0–10
Blending (out of 12 items)	7.0	2.6	2–12

Note. PA = phonological awareness.

As shown in Table 5, and as anticipated from other studies, significant positive correlations were found among the PA variables. A PA composite score was therefore calculated using a principal component analysis to summarize the four PA tasks (note that other factor analytic methods yielded similar results). This is a multivariate technique that derives a linear combination of several variables while retaining the maximum possible variance. For these data, the principal component derived from the four PA tasks retained 63% of the original variance. It can be seen that blending had the lowest correlations with the other three PA tasks (it also had the lowest correlation with the overall PA composite), possibly because the blending task requires different skills (e.g., memory and synthesis) than the other tasks.

Hypothesis 1

Hypothesis 1 was that a relationship would be found between PA and speech sound error types, with PA being most strongly predicted by errors that represented the weakest phonological representations (atypical sound changes). Correlation analyses and inspection of scatterplots between the PA composite and speech production variables showed that there was no significant relationship between PA and distortions ($r = .129$, $p = .429$), nor between PA and typical sound changes ($r = -.171$, $p = .273$). However, a significant relationship was found between PA and atypical sound changes ($r = -.362$, $p = .009$). That is, atypical sound changes predicted about 13% of the variance in PA. As anticipated, the negative correlation indicates that children who produced more atypical sound changes performed more poorly on the PA tasks, possibly because both reflect weak phonological representations.

Hypothesis 2

Because PA skills are often related to vocabulary and age, this study examined the extent to which PA variance can be predicted by speech sound errors when vocabulary and age are taken into account. To address this question, hierarchical multiple regression was used (see Table 6). As in other studies, receptive vocabulary

Table 5. Pearson correlation coefficients (*r*) for the PA tasks for 43 preschoolers with SSD.

Task	Onset matching	Onset segmentation and matching	Blending	PA principal component
Rhyme	.621	.508	.356	.789
Onset matching		.637	.401	.854
Onset segmentation and matching			.490	.706
Blending				.463

Note. All correlations were significant at *p* < .05.

was correlated with PA; in this study, vocabulary accounted for about 27% of the variance in the PA composite (*r* = .517, *p* < .001). The bivariate correlation between age and the PA composite was not statistically significant (*r* = .264, *p* > .05), possibly because of the restricted age range of the participants (21 months). However, when included in a model with other variables, age is a significant predictor of PA (see next section).

In the first step of the regression, age and receptive vocabulary (PPVT–4 standard score) were used to predict PA. These two variables accounted for about 33.3% of the variance in PA, and both were significant predictors (*p* < .05). In the second step, the three speech production variables were tested in the model using stepwise entry.[1] Atypical sound changes were the only significant speech production variable selected into the equation, and vocabulary and age remained significant predictors of PA. The new model accounted for additional unique variance in PA (ΔR^2 = .070, ΔAdj R^2 = .059, *p* = .033), confirming the second hypothesis: Atypical sound changes predicted approximately 6% of the variance in PA beyond what was already accounted for by vocabulary and age.

Hypothesis 3

Because atypical sound changes predict significant variance in PA beyond vocabulary and age, it was of interest to determine whether a similar result would be found using PCC as the speech sound accuracy variable. The correlation between PCC and the PA composite was not significant (*r* = .222, *p* = .153). However, a similar hierarchical multiple regression was performed to predict PA, with PCC forced to enter in the second step after vocabulary and age. The results (see Table 7) indicated that PCC did not explain any variance in PA

beyond receptive vocabulary and age in these 43 children. Therefore, the speech analysis based on presumed reflection of phonological representations provided a better explanation for the relationship between PA and speech sound production than did the analysis weighting all errors equally.

Discussion

In this study, the relationship between speech sound errors and PA was assessed in preschoolers with SSD. The fact that there is often a wide range of performance on PA tasks by children with SSD was confirmed in the present study. The variability in PA could be accounted for, in part, by vocabulary and age (about 33%). Yet, as with prior studies, there remained much unexplained variance in the performance of the children on PA tasks. One additional consideration, therefore, was that speech sound production, which is also thought to rely, in part, on phonological representations, could predict variance in PA. The results confirmed that prediction: A measure thought to reflect poorly specified phonological representations in speech sound production, atypical sound changes per consonant, was found to account for significant variance in PA beyond the variance explained by vocabulary and age. However, no additional variance was explained in PA when PCC was used to measure speech sound accuracy, suggesting that PCC may not be sensitive to variation in PA skills.

One of the unique features of the current study is that it was designed to provide a more complete explanation of the component feature changes involved in children's speech sound errors than has been done in the past. Whereas PCC considers all speech sound errors as equal, the current study calls on phonetically motivated explanations of how those errors could be derived. That is, the three-category system was designed to more fully account for the features of a child's surface errors. As expected, distortion errors were unrelated to performance on any of the PA tasks. This is in line with previous findings and supports the notion that these phonetic variations are not indicative of poorly specified phonological

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[1]Stepwise entry was chosen for the second step of the regression (as opposed to forcing the three speech variables into the equation together) because it was presumed that some of the variables would not be related to PA. Therefore, only those speech production variables that contribute to the prediction of PA variance would be chosen. That is, the goal is to determine if certain variables are more robust predictors of PA, not to determine if all three speech variables together are robust predictors.

Table 6. Hierarchical regression used to predict PA principal component.

| Variable | Method | b (SE) | β | Sig. | Model | | | | | | | | | |
					F	df	p	R^2	Adj R^2	ΔF	df	p	ΔR^2	Δ Adj R^2
PPVT–4	Enter	.044 (.010)	.545	.000	11.5	2, 40	.000	.365	.333					
Age	Enter	.058 (.023)	.314	.017										
PPVT–4		.040 (.010)	.487	.000						4.8	1, 39	.033	.070	.059
Age		.060 (.022)	.322	.011										
ATYP	Stepwise	–6.149 (2.799)	–.217	.033										

Not in the equation				Sig.
Distortions per consonant				.557	Total R^2 = .435
TYP				.247	Total adj R^2 = .392

Note. ATYP = atypical sound changes per consonant; TYP = typical sound changes per consonant; Sig. = significance.

representations (Preston & Edwards, 2007; Rvachew et al., 2007; Shriberg et al., 2005). Also, typical sound changes were found not to be correlated with PA skills in this study. Thus, it appears that the occurrence of distortions and typical sound changes provides little information regarding a child's PA skills.

In contrast, atypical sound changes were found to account for significant variance in PA (r^2 = 13%), including about 6% of the unique variance in PA when controlling for age and receptive vocabulary. Although this is not necessarily a robust explanation of the variance in PA skills, it may be indicative of a shared phonological deficit, speculated here to be weak underlying phonological representations. That is, children with SSD who use unusual sound changes to produce words may also have trouble attending to the sound features of words in tasks such as rhyming, initial consonant matching, and blending. This helps to support claims made by other researchers regarding the importance of evaluating atypical speech sound errors (Dodd, 2005; Leitao & Fletcher, 2004; Rvachew et al., 2007).

To avoid overestimation of what was considered atypical, the classification scheme developed for this study was relatively conservative. The decision was made a priori to score errors in a manner that would give

children the most possible "credit" (i.e., counting the smallest number of errors possible and considering typical errors rather than atypical errors when alternate accounts were possible). Although others might reach slightly different conclusions about which sound changes should be considered atypical, the error coding system was intended to be comprehensive and replicable, and it was based on extant literature and the notion of phonetic plausibility. Even with this conservative estimate, all participants were found to produce at least a few atypical errors in their 125-word samples. It is acknowledged that defining atypical errors differently could result in different findings. Additionally, it is important to acknowledge that atypical errors, as defined here, represent errors that are not common in the speech of typically developing 4- and 5-year-olds who are native speakers of Standard American English; the extent to which atypical errors occur in other populations is open to investigation.

Although the present results suggest a relationship between PA and atypical sound changes in preschoolers, Rvachew et al. (2007) reported no significant relationship in preschoolers but did find a significant relationship in kindergarteners. Thus, the present findings are more in agreement with their kindergarten findings. As compared with their preschool findings, we may have

Table 7. Regression using PCC as the speech production variable to predict PA.

| Variable | Method | b (SE) | β | Sig. | Model | | | | | | | | | |
					F	df	p	R^2	Adj R^2	ΔF	df	p	ΔR^2	Δ Adj R^2
PPVT–4	Enter	.044 (.010)	.545	.000	11.5	2, 40	.000	.365	.333					
Age	Enter	.058 (.023)	.314	.017										
PPVT–4		.044 (.011)	.540	.000						.009	1, 39	.932	.000	–.017
Age		.058 (.024)	.314	.011										
PCC	Enter	.001 (.012)	.013	.923										

observed a significant relationship among atypical errors and PA for several reasons: differences in statistical power reflected in the statistical techniques, size of the speech sample (480 consonants in a range of word structures, as opposed to one sample of each consonant per word position), or differences in speech error coding schemes (the current study took phonetic plausibility and the effects of nearby sounds into consideration when trying to logically account for errors).

Clinical Implications

The ability to develop accurate or refined phonological representations for PA tasks (to the point that they may be used for comparing and contrasting initial consonants and rimes of words) had a modest, but significant, negative relationship with the production of atypical sound changes. The primary impact of low PA is likely to be on early decoding and spelling. That is, if children do not have clearly defined representations for the essential sound features of words, they may have difficulty using phonological information for sounding out words and spelling. There is mounting evidence that children who enter kindergarten with an SSD and weak PA skills are at particular risk for early literacy problems. Thus, the results of this study could have diagnostic significance. Clinically, PA assessments are still not routine for all children with SSD. Thus, it would seem appropriate for speech-language pathologists to assess the PA skills of all children with SSD, perhaps paying special attention to those who exhibit numerous atypical speech sound errors, as they may be at a slightly elevated risk for PA problems.

As expected, there were several children with SSD who performed quite well on the PA tasks, and these children had relatively few atypical errors. It could be argued, then, that intervention focusing on speech sound production and PA should be implemented for children who exhibit atypical sound changes (cf. Gillon, 2005), perhaps targeting atypical errors. There are few studies investigating treatment of children with atypical sound changes, but those that exist suggest that these errors can be improved with standard phonological treatment techniques, such as minimal pair intervention and facilitating contexts (Dodd & Iacano, 1989; Leonard & Brown, 1984; Stringfellow & McLeod, 1994).

Caveats and Limitations

Several caveats related to the findings of the current study should be noted. For example, as with many cross-sectional clinical samples, intervention histories were not assessed and could account for additional variance in PA. Also, replication of these results in other samples (including longitudinal samples) will help to clarify the strength of the relationship between PA and types of speech sound errors. Additionally, interpreting the size of ΔR^2 is not straightforward (Keith, 2006), and the amount of variance in PA explained by adding atypical sound changes per consonant to the equation is relatively modest (ΔR^2Adj = .059). Thus, in comparison to the other variables, particularly receptive vocabulary, this does not appear to be a large effect. However, because a significant amount of additional variance can be accounted for by adding atypical sound changes and because there is theoretical reason to include this variable (i.e., it is thought to reflect weak phonological representations), this suggests that the model is useful in explaining variance in PA for children with SSD. It may be that vocabulary is causally related to the development of accurate phonological representations, such that increased vocabulary results in refinement of phonological representations (Metsala, 1999), whereas speech errors might be considered a result of inaccurate representations. However, this remains a matter of theoretical speculation.

The method of quantifying speech sound accuracy in this study, while theoretically motivated, is not the only method for analyzing speech sound production. Other transcription-based methods exist, although they have not consistently revealed a relationship between speech production and PA. For example, PA skills have been found to be unrelated to phonological features (e.g., sonorant, labial, and nasal; Rvachew et al., 2007) and to some standardized tests of speech sound accuracy (e.g., Larrivee & Catts, 1999). It is possible that transcription-based methods are not highly sensitive to subtleties in speech sound production that relate to PA and/or phonological representations. Future studies could implement instrumental analysis of phonetic output, including segmental and suprasegmental analysis (e.g., Shriberg et al., 2003; Smith, Roberts, Lambrecht Smith, Locke, & Bennett, 2006). Additionally, the current study did not analyze vowel production errors, in part, because it was designed to remedy some of the limitations associated with consonant analysis schemes; the relationship between vowel accuracy and PA requires further study (cf. Elbro et al., 1998).

Several classification systems exist for SSD based on suspected etiology, speech error patterns, concomitant language disorders, and so forth, but there is poor consensus on how to differentially diagnose particular subtypes of SSD. Because none of these classification systems have robust empirical support, they were not utilized here. Many of the children in this study probably fell into one or more subgroups described in the literature, but there is no consistent description of the use of different types of sound errors by subgroups of children with SSD. Additionally, the results should be interpreted within the scope of the participant characteristics (e.g., primarily middle-class, monolingual English-speaking preschoolers with idiopathic SSD). Thus, the

results may not be applicable to all children with PA difficulties, particularly those who do not have an SSD.

Speculations on Phonological Representations

Phonological representations are thought to develop with vocabulary and age and to rely on a child's ability to extract and/or infer linguistically meaningful sound patterns in the speech signal. As vocabulary skills increase, children develop a broader variety of words from which to draw inferences about the essential phonological features of words (Metsala, 1999). These inferences are thought to help children recognize contrasts, sound patterns, and appropriate sound combinations in the adult language. When children's ability to extract salient phonological features of words (and use them to form phonological representations) is weak, their ability to recognize some of the salient phonological components of words (such as rhymes or initial consonants) might be weak as well. For these children, salient features in speech sound production might also be poorly represented, resulting in unusual productions of words (e.g., deletions of initial singleton consonants or strong syllables). Broadly, one possible explanation is that genetic factors, or a combination of genetic and environmental factors, play a role in speech and literacy difficulties (Lewis et al., 2006; Raitano et al., 2004; Shriberg et al., 2005). The current study follows a research line that presumes that phonological representations may be impaired, but we did not attempt to explain how or why they become weak. Some possible explanations include poor speech perception (e.g., Rvachew & Grawburg, 2006), problems making the appropriate inferences about the phonetic or phonological components of words to store them correctly, and/or impaired subvocal articulatory rehearsal (Locke & Scott, 1979). Further study of causal mechanisms is needed so that research can extend beyond descriptive relationships and more adequately address causation.

Conclusions

The study explored PA and speech sound production in preschoolers with SSD, a population that is frequently served clinically. We addressed within-group variability in PA through a measurement system that analyzes all consonant errors based on both types and frequency. A three-category scheme for coding speech sound errors was developed that accounted for the component features in the children's sound errors, and it was found that atypical sound changes were better predictors of PA than distortions and typical sound changes. Atypical sound changes were found to predict unique variance in PA, whereas distortions and typical sound changes did not. Poorly specified phonological representations have

been posited as the link between PA difficulties and some speech sound errors.

This research provides important evidence in light of the critical age hypothesis for literacy development, which suggests that children who enter kindergarten with speech sound production problems and poor PA are at significant risk for literacy problems (Bird et al., 1995; Nathan et al., 2004). Moreover, the results help to further clinicians' understanding of which children may be at particular risk for (pre)literacy problems so that early intervention can be implemented. Thus, it would seem prudent for clinicians to consider the specific types of speech sound errors when evaluating and treating preschoolers with SSDs.

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Appendix A. Coding sound changes.

"Surface errors" were broken down into component sound changes, each of which was coded as typical, atypical, and/or a distortion. That is, an error could involve interacting changes (more than one typical change, atypical change, and/or distortion). Surface errors were coded based on the smallest number of sound changes needed to arrive at the child's production. If multiple "paths" of interacting changes were possible to account for a child's production, we chose the one with the fewest atypical changes.

Distortion Errors
    Clinically significant distortions (not appropriate for the context) were considered as distortion errors. They could be marked for any consonant (not just sibilants and liquids). Partial voicing and partial devoicing were not considered to be distortion errors. Only one distortion was coded on a particular phoneme.

Typical Changes
    Typical syllable structure changes: final consonant deletion; typical /s/ cluster reduction; typical liquid cluster reduction; glide cluster reduction; nasal cluster reduction; segment coalescence; consonant sequence reduction (across syllable boundary); weak syllable deletion; syllable coalescence; epenthesis; reduplication
    Typical place of articulation changes: palatal fronting; velar fronting; labialization of front sounds; alveolarization of front sounds
    Typical manner of articulation changes: vocalization of liquids; gliding of liquids; gliding of intervocalic fricatives; stopping of fricatives and affricates; deaffrication; affrication of fricatives
    Typical voicing changes: initial voicing; final devoicing
    Other typical changes: metathesis; assimilation (velar, palatal, nasal, liquid, fricative; either partial [some features] or complete)

Atypical Changes
    Atypical syllable structure changes: atypical /s/ cluster reduction; atypical liquid cluster reduction; atypical glide cluster reduction; initial (singleton) consonant deletion; intervocalic consonant deletion; addition of consonants, vowels, or syllables; migration of a segment to a different position; strong syllable deletion
    Atypical place of articulation changes: backing to velars; palatalization; labialization of back sounds; glide interchange; liquid interchange; glottal replacement
    Atypical manner of articulation changes: denasalization; nasalization; fricative replacing stop; liquid replacing glide; tetism; gliding of intervocalic consonants (other than fricative or liquid); stopping of liquids or glides
    Atypical voicing changes: initial/prevocalic devoicing; final voicing

Appendix B. Examples of interacting sound changes.

Interacting sound change	Example
Nasalization (ATYP) + labialization of velar (ATYP)	guitar /gɪtar/ → [mɪtar]
Liquid interchange (ATYP) + /r/ distortion	yellow /jɛlo/ → [jɛrʷo]
Palatalization (ATYP) + initial voicing (TYP)	scissors /sɪzɚz/ → [ʒɪzɚz]
Palatal fronting (TYP) + sibilant distortion	shovel /ʃʌvəl/ → [s̺ʌvəl]
Backing to velar (ATYP) + initial devoicing (ATYP) + stopping (TYP)	zebra /zibrə/ → [kibrə]

Note. One error could include combinations of typical changes, atypical changes, and/or a distortion. ATYP = atypical sound changes; TYP = typical sound changes.