Phonological Processing Skills of Adolescents With Residual Speech Sound Errors

Jonathan L. Preston
Mary Louise Edwards
Syracuse University, Syracuse, NY

Phonological processing skills involve metalinguistic awareness of the sound system (phonological awareness), the ability to retain and immediately recall speech sound stimuli (phonological memory), and the ability to rapidly and accurately retrieve phonological representations during speech-related tasks. Such skills undoubtedly play some role in both speech development and literacy acquisition (Stackhouse,

ABSTRACT: **Purpose:** Research has shown that young children with speech sound disorders may have weaknesses in phonological processing. However, such skills have not been thoroughly examined in adolescents with residual speech sound errors. Therefore, this study compared the phonological processing abilities of adolescents with residual speech sound errors to those of normally speaking peers.
Method: Two nonword repetition tasks, multisyllabic word repetition, spoonerisms, phoneme reversals, and an elision task were used to compare the phonological processing skills of 10–14-year-olds with residual speech sound errors that include rhotic phonemes (RE, $n = 13$) to those of normally speaking (NS, $n = 14$) adolescents of similar age and receptive vocabulary abilities.
Results: The 2 groups were found to differ on 5 of the 6 phonological processing tasks. Discriminant analysis showed that 85% of the participants could be correctly classified into the RE and NS groups based solely on phonological processing skills.
Conclusion: The possible nature of the phonological processing impairment is discussed in the context of current theoretical understanding. It is recommended that when planning assessment and intervention for adolescents with residual speech sound errors, clinicians be cognizant of the fact that the adolescents may also have weaknesses in phonological processing.

KEY WORDS: persistent speech errors, adolescent speech, residual /r/ errors, phonological processing

1997; Stackhouse & Wells, 1997). It has been well documented that preschool and young school-age children with speech sound production problems may demonstrate deficits in phonological processing skills (e.g., Bird, Bishop, & Freeman, 1995; Hesketh, 2001; Leitao & Fletcher, 2004; Leitao, Hogben, & Fletcher, 1997; Lewis & Freebairn, 1992). However, little research has focused on the phonological processing abilities of adolescents with residual speech sound errors. Residual speech sound errors have frequently been discussed in the context of motoric deficits, with little emphasis on a possible linguistic component (see Gibbon, 1999, for a review of linguistic and motoric deficits). However, it has been suggested that the ability to perform phonological processing tasks is related to the ability to construct and retrieve accurate representations of phonemes or phoneme combinations (Sutherland & Gillon, 2005; Swan & Goswami, 1997). The quality of these phonological representations may also impact speech sound production (Shuster, 1998).

In case studies of 1 boy and 1 girl (ages 10 and 11, followed over 5 years), Stackhouse (1997) described these children as having deficits in phonological processing, as evidenced by difficulties in repeating nonwords, reading, and spelling. She suggested that "children with persisting phonological impairments have sound segmentation difficulties when processing sound sequences within novel words and thus are more likely to form inaccurate phonological representations" (Stackhouse, 1997, p. 176). More evidence is needed beyond case studies to support this claim that phonological processing deficits may be present among children with residual speech sound errors. If the children are found to have such difficulties, this would have important clinical implications.

Phonological Processing

Research quite consistently suggests a relationship between a history of speech sound production difficulty and later deficits in

phonological processing and/or literacy skills (Leitao & Fletcher, 2004; Lewis & Freebairn, 1992), but this association has not been thoroughly explored in adolescents with residual speech production errors. Studies that have examined phonological processing in individuals with histories of speech production problems generally have included individuals with normalized speech in addition to individuals with residual speech sound errors (e.g., Leitao & Fletcher, 2004; Lewis & Freebairn, 1992; Lewis, Freebairn, & Taylor, 2000; Stothard, Snowling, Bishop, Chipchase, & Kaplan, 1998). For example, Lewis and Freebairn compared preschoolers, elementary school-age children, adolescents, and adults with and without histories of phonological impairments on a variety of tasks. They found significant differences between those with and without a history on several tasks that tap phonological awareness (e.g., pig latin), phonological memory or repetition (e.g., nonword repetition, multisyllabic word repetition), rapid articulatory productions (e.g., tongue twisters), spelling, and reading. Thus, it appears that children who exhibit speech production difficulties at a young age may be at risk for deficits in phonological processing throughout their lives. However, the authors did not differentiate between the performance of participants with residual speech sound errors and those whose errors had been resolved.

Speech production difficulties that co-occur with other language problems have been discussed as a potential risk factor for phonological processing weaknesses. Lewis et al. (2000) suggested that children 4 to 6 years of age with phonological production difficulties are at risk for deficits in phonological processing and reading during third and fourth grade. In their study, the children with concomitant phonological and language disorders were at greater risk of literacy problems at follow-up than were the children with phonological disorders alone. The authors did not find an association between comorbid language or reading problems and residual speech production difficulties at follow-up, although this may have been due to limited assessment of speech production using a short picture naming task (i.e., the Goldman-Fristoe Test of Articulation; Goldman & Fristoe, 1986). In contrast, some reports have suggested that speech sound errors that persist and are present at the time of beginning reading instruction may be a risk factor for later reading and spelling problems (Bird et al., 1995; Nathan, Stackhouse, Goulandris, & Snowling, 2004; Raitano, Pennington, Tunick, Boada, & Shriberg, 2004). Additionally, concomitant language problems do not seem to be able to fully explain phonological processing difficulties among children with speech production problems (Bird et al., 1995; Rvachew, Ohberg, Grawburg, & Heyding 2003).

The literature suggests that a history of speech and language problems may put adolescents at risk for phonological processing difficulties (e.g., Lewis & Freebairn, 1992). However, no attempts have been made beyond case studies to specifically investigate the phonological processing abilities of adolescents with residual speech sound errors. More exploration is necessary to determine the nature of the deficits.

Speech Features of Children With Residual Speech Sound Errors

Although the anticipated age of speech sound acquisition may not be universally agreed on, it is generally accepted that correct production of American English speech sounds should be mastered no later than 9 years of age (Shriberg, 1994; Shriberg, Lewis, McSweeny, & Wilson, 1997; Smit, 1986; Smit, Hand, Freilinger, Bernthal, & Bird, 1990). Children who fail to normalize their speech by 9 years of age exhibit what are generally referred to as residual sound errors (e.g., Shriberg, 1994; Shriberg, Lewis, et al., 1997). Despite the social consequences of such errors (Silverman & Paulus, 1989), not all children with residual sound errors qualify for speech intervention services through school districts because it is sometimes assumed that the deficit simply involves misarticulation of a few sounds without broader implications, such as the development of literacy.

The phonemes /s, z, r, l/ are among those that are the most frequently misarticulated by individuals with residual speech sound errors (e.g., Gross, St. Louis, Ruscello, & Hull, 1985; McNutt, 1977; Shriberg, 1994; Shriberg, Gruber, & Kwiatkowski, 1994). These errors typically involve phoneme distortions (i.e., within-phoneme errors) but may also consist of substitutions and/or omissions. Shriberg (1994) suggested that individuals with residual /r/ difficulties may have been delayed in "tuning in" to speech and language, and thus may have failed to attend to the necessary phonological features of this sound class until the window for speech acquisition began to close. Hence, the population of interest for the present study was adolescents with residual errors involving rhotic sounds.

Shriberg, Flipsen, Karlsson, and McSweeny (2001) indicated that adolescents with residual distortions of the rhotic vowel /ɝ/ (as in bird) may be a heterogeneous group, as evidenced by the acoustic features of their error productions. It was suggested that such differences might be attributable to the speech histories and suspected etiologies of the individuals' speech errors. Shuster (1998) reported that children who had persistent /r/ errors (i.e., had been receiving therapy for /r/ for at least 2 years) had difficulty identifying errors in their own recorded speech, suggesting that differences in internal phoneme representation and self-monitoring capacity may be related to the persistent speech errors.

It has been suggested that adolescents with residual speech production difficulties demonstrate deficits that are based in motor production (Flipsen, 2003; Hall, 1989; McNutt, 1977; Shriberg, 1997; Shuster, Ruscello, & Haines, 1992; Stackhouse, 1997). To date, little attention has been given to the linguistic processes that may be disrupted in this population. Because of the lack of well-defined contributing factors (i.e., motoric or linguistic) and the possible interaction between linguistic and motoric processes (Kent, 2000), the term residual speech sound errors will be used here to describe the speech of young adolescents whose speech sound production differs from the ambient language, regardless of the underlying factors.

Assessment of Phonological Processing Skills

Many tasks have been used to assess phonological processing skills in young children, including rhyme identification and production, phoneme segmentation, syllabification, and nonword repetition. However, many of these tasks may be too simple to be sensitive to differences in young adolescents. Therefore, more challenging tasks are needed to assess phonological processing in this age group. Such tasks may include those described in the following paragraphs.

Nonword repetition. Nonword repetition tasks have been used frequently as one measure of phonological processing skills. Although these tasks do not require direct access to the lexical representation of a word, accuracy in nonword repetition has been shown to be related to vocabulary (Edwards, Beckman, & Munson, 2004; Gathercole, Hitch, Service, & Martin, 1997). Weaknesses in nonword repetition have been found to exist in young school-age children with language disorders (Dollaghan & Campbell, 1998), as well as in school-age children, adolescents, and adults with a history of speech production problems (Lewis & Freebairn, 1992). Young children with phonological disorders (ages 3–6) have been found to perform more poorly than typically developing children on nonword repetition tasks (Munson, Edwards, & Beckman, 2005), but nonword repetition has not been directly assessed in adolescents with residual speech sound errors.

Multisyllabic word repetition. Multisyllabic word production requires the planning and execution of complex articulatory sequences. A repetition task, however, frees the speaker from having to draw on his or her own representation of the word, which may be inaccurate (Stackhouse & Wells, 1997). Lewis and Freebairn (1992) found that multisyllabic word repetition was a sensitive measure for differentiating among both elementary school-age children and adolescents with histories of phonological disorders and controls with no such histories. Multisyllabic word repetition has also been found to be a sensitive measure for separating normally speaking 6-year-olds from those with isolated speech impairments as well as combined speech and language impairments (Leitao et al., 1997).

Spoonerisms. Spoonerisms involve saying a pair of words so that the initial phonemes (or entire onsets) of the two words are exchanged. For example, the phrase *hair cut* would be produced as [kɛr hʌt]. The ability to purposefully perform a phoneme exchange of this type requires knowledge of the phonological structure of the words involved and the ability to isolate segments and manipulate them. Spoonerisms are appropriate for assessing phonological processing in adolescents because they involve high-level metalinguistic skills (Stackhouse & Wells, 1997) and are not frequently taught to children (Walton & Brooks, 1995; although Catts [1991] suggested teaching spoonerisms to children to help them understand phoneme manipulation). Spoonerisms have been found to be useful in detecting subtle differences in the phonological processing skills of older adolescents (15–16-year-olds) with histories of speech-language therapy, as compared to age-matched peers without such histories (Stothard et al., 1998). McMahon, Stassi, and Dodd (1998) used spoonerisms to detect phonological processing differences in multiple-birth children who were considered at risk for literacy/phonological processing problems.

Phoneme reversals. Another complex task that requires segmentation and manipulation of phonemes is a phoneme reversal task. During this task, participants are required to listen to a spoken word (without seeing it written out) and then sound it out backwards. For example, the word *pit* backwards would be *tip*. This task requires recall of the phonological structure of a word as well as the ability to retain and mentally manipulate the segments. Lewis and Freebairn (1992) included a similar task in their assessment of phonological processing skills of adolescents and adults with histories of phonological disorders. Phoneme reversals have also been used as a phonological processing measure with adults with dyslexia (Kitz & Tarver, 1989).

Elision. Elision (deletion) tasks are also frequently used to assess phonological processing (e.g., Ball, 1993; Lewis et al., 2000). With younger children, such tasks may involve deletion of a syllable from a compound or multisyllabic word. A more challenging task would require deletion of a phoneme from within a word. Lewis et al. found that an elision task was particularly challenging for third- and fourth-grade children with phonological and language problems, and that this task separated these children from three other groups of children: those with phonological disorders only, those with reading problems, and those with spelling problems. Leitao et al. (1997) discovered that a deletion task separated 6-year-olds with speech, language, and concomitant speech-language problems from normal controls.

The purpose of the present study was to determine whether adolescents with residual speech sound errors involving rhotic phonemes differ from peers of similar age and receptive vocabulary in phonological processing abilities. It was hypothesized that, given the results of previous studies with different groups, adolescents with residual speech sound errors would perform more poorly than their peers. The tasks described above were selected to sample a variety of skills that involve both repetition and manipulation of phonological information. Such tasks have not been previously used with this particular population.

METHOD

Participants

Because American English phonemes are typically mastered by age 9 (Shriberg, 1994; Shriberg et al., 1994; Smit et al., 1990), preadolescents and adolescents (hereafter, adolescents) who were beyond the age at which normal speech sound development should have been achieved were selected for this study. Following Shriberg, Lewis, et al. (1997), these adolescents, ages 10–14, with speech sound production problems were considered to have residual speech sound errors.

Two groups were selected for study. The residual error (RE) group was recruited via referrals from local speech-language pathologists (SLPs) in the Central New York region, in addition to public notices in clinics. However, not all of the children were enrolled in intervention at the time of the study. Although participants were selected on the basis of their rhotic errors, most also exhibited at least a few other sound errors, as summarized in Table 1. The RE group consisted of 13 adolescents with speech sound difficulties, ages 10–14 years (*M* = 11;11 [years;months], *SD* = 1;5; 6 male and 7 female). To be included in the RE group, all participants had to produce 15 or more errors (i.e., substitutions, omissions, or distortions) on a 50-item rhotic picture naming task that assessed pre- and postvocalic /r/ and /ɜ/ in various contexts (see below).

The normal speech production (NS) group, which was matched based on group means for age and score on the Peabody Picture Vocabulary Test—III (PPVT–III; Dunn & Dunn, 1997), consisted of 14 adolescents ages 10–14 (*M* = 12;1, *SD* = 1;5; 6 male and 8 female) who had no history of speech or language problems, as reported by the parents. All were judged by the two authors (a doctoral student with CCC-SLP and a professor of clinical phonetics and phonology) to have speech productions skills within

Table 1. Descriptive data for the residual error (RE) group participants.

Participant	Age	PPVT–III	Lit. int.	Sp. int.	PCC	PCC–R	Speech sound error patterns
RE1 (F)	10;4	97	Y	PS-Pres	77	83	GL/DER /r, l/, VOC /r, l/, FD fricatives & affricates, GR syllable final /t/ & word final /p/
RE2 (F)	10;6	114	Y	EI-Pres	81	87	GL/DER /r/, VOC /r, l/, DEP, FD fricatives & affricates
RE3 (M)	10;9	93	Y	K-Pres	71	76	GL/DER /r/, VOC /r, l/, CR /r/, FD fricatives & affricates, DEP, GR final /t, nt/
RE4 (M)	11;0	122	N	gr. 3-5	86	93	GL/DER /r/, VOC /r, l/, FD fricatives & affricates
RE5 (F)	11;4	105	N	EI-gr.4	85	89	GL/DER /r/, GL /l/ clusters, VOC /r, l/, FD fricatives & affricates, GR final /t, p/
RE6 (F)	11;4	118	Y	gr.2-Pres	84	90	GL/DER, VOC /r/, VOC/deletion postvocalic /l/, CR /fr/, FD /dʒ/
RE7 (M)	11;9	93	N	EI-Pres	75	77	GL/DER /r/, VOC /r, l/, DEP, LAB /θ, ð/
RE8 (F)	11;9	97	Y	EI-Pres	58	77	GL/DER /r/, GL /l/, VOC /r, l/, DENT/LAT /s, z/, FD fricatives & affricates, LAB /θ, ð/
RE9 (M)	12;0	126	N	gr.2-Pres	73	88	GL/DER /r/, VOC /r, l/, LAT /s, z, ʃ, t ʃ, ʒ, dʒ/, FD fricatives & affricates
RE10 (M)	12;2	111	Y	None	89	92	GL/DER /r/, VOC /r/
RE11 (F)	14;1	87	Y	EI-Pres	74	83	GL/DER /r/, VOC /r, l/, Epenthesis (liquid clusters), FD fricatives & affricates, Vowel changes /aɪ/→ [ɑ] or [ʌ], /ɑ/ → [ʌ]
RE12 (M)	14;3	83	Y	PS-Pres	73	81	GL/DER /r/, VOC /r, l/, DEP, FD fricatives & affricates, CR /r/, CR /nt/, LAT & Palatal distortions /s, z/
RE13 (F)	14;6	113	N	PS-gr.3, 6	85	96	GL/DER /r/, VOC /r, l/, FD fricatives & affricates
Mean	11;11	104.5			78	86	
SD	1;5	13.8			8.6	6.6	

Note. PPVT–III = Peabody Picture Vocabulary Test—III (Dunn & Dunn, 1997); Lit. int. = literacy intervention (i.e., had the child ever been diagnosed with a disability in, or received special tutoring for, reading or spelling, as per parent report); Sp. int. = speech intervention, based on parent report; Numerals represent grade levels at which the child received speech intervention; EI = early intervention (before 4 years); PS = preschool (4–5 years); K = kindergarten; Pres = present; PCC = percentage of consonants correct; PCC–R = percentage of consonants correct—revised (distortions considered correct); F = female, M = male; GL = gliding; DER = derhoticization; VOC = vocalization; FD = final devoicing; DEP = depalatalization of palatal obstruents; CR = cluster reduction; GR = glottal replacement; LAB = labialization of interdentals; DENT = dentalization of sibilants; LAT = lateralization of sibilants. Age is reported in years; months. Error patterns occurred in at least 20% of contexts on the 64-item picture naming task.

normal limits. There was no significant difference in the ages of the RE and NS groups ($t = 0.259$, $p = 0.798$). Information regarding the NS participants is included in Table 2.

All participants were required to meet the following criteria: native speakers of Standard American English; no known neurological or cognitive problems, as reported by the parent; no history of oral structural problems (e.g., cleft palate); no fluency disorder; and no current hearing loss (although a history of otitis

Table 2. Descriptive data for the normal speech production (NS) group participants.

Participant	Age	PPVT–III	Lit. int.
NS1 (F)	10;0	115	N
NS2 (M)	10;2	104	N
NS3 (M)	10;8	123	N
NS4 (F)	11;0	122	N
NS5 (F)	11;2	105	N
NS6 (F)	11;3	103	N
NS7 (F)	12;0	94	Y
NS8 (F)	12;1	85	Y
NS9 (M)	12;4	114	N
NS10 (M)	12;6	111	N
NS11 (F)	13;1	120	N
NS12 (F)	13;9	92	N
NS13 (M)	13;11	117	N
NS14 (M)	14;7	115	N
Mean	12;1	108.6	
SD	1;5	11.9	

media was acceptable). All participants were required to pass a pure-tone hearing screening at 20 dB HL at 500, 1000, 2000, and 4000 Hz. The participants with speech errors who were referred by school SLPs ($n = 10$) had confirmed full-scale IQs of 85 or greater at the most recent assessment. The remaining participants ($n = 3$) were referred via speech-language clinics and no IQ data were available; however, none was receiving other special educational services, and none of the parents of these 3 participants indicated concerns about cognitive functioning. In addition, all participants achieved a standard score of 83 or better on the PPVT–III, which was administered as part of this study (see Tables 1 and 2). Vocabulary was chosen as a group matching criterion because previous research has suggested that phonological processing skills are related to vocabulary ability (Rvachew & Gillon, 2005; Rvachew & Grawburg, 2006; Stothard et al., 1998; Uhry, 1999). No significant differences were observed between the two groups on the PPVT–III ($t = 0.811$, $p = 0.425$, Cohen's $d = 0.318$). There was also no significant difference between the RE and NS groups in the number of years of parent education (taking the higher level when both parents' education was reported), as determined from a case history form ($t = 0.908$, $p = 0.374$, Cohen's $d = 0.364$).

Procedure

Before the testing session, parents completed a questionnaire related to their child's medical, developmental, educational, social, and speech-language history. Each adolescent participated in one testing session lasting approximately 2.5 hr. During the testing session, which took place in a quiet room, digital recordings were acquired via a Shure WH20 head-mounted microphone

worn by the participant and a SONY ECM-16 electret condenser lapel microphone worn by the examiner. The signals were mixed using a Rolls MX 54s Pro Mixer Plus and were recorded as .wav files using Praat V 4.2.19 on a Dell Inspiron 8600 laptop. All tasks were also audio recorded using a Bell and Howell 3191A tape recorder.

Task order was randomized for each participant. A brief oral peripheral examination was performed to rule out gross oral structural or functional deficits. In addition to the PPVT–III, the tasks described below were administered.

Picture naming tasks. To assess speech sound production at the single-word level, a 64-item picture naming task was administered (see Appendix A). This instrument was devised by the authors to include examples of phonologically complex words that sampled a variety of consonant clusters and syllable structures, as these are often not well represented in standardized tests. All words were narrowly transcribed by the two authors working independently. The diacritics used were primarily those in Appendix F of Edwards (1986). The independent transcriptions were compared, and any discrepancies were later resolved through review of the digital recording until consensus was achieved (cf. Shriberg, Kwiatkowski, & Hoffman, 1984). As a very rough measure of severity, percentage of consonants correct (PCC), in which all substitutions, omissions, and distortions are considered incorrect (Shriberg, Austin, Lewis, McSweeny, & Wilson, 1997), was computed. In addition, percentage of consonants correct—revised (PCC–R), in which all distortions are considered correct (Shriberg, Austin, et al., 1997), was computed from this picture naming task and is reported in Table 1 (these were not computed for the NS participants because they produced virtually no sound errors). For example, a /w/ for /r/ substitution or a /θ/ for /s/ substitution would be considered incorrect using both PCC and PCC–R, but a derhoticized /r/ or a lateralized /s/ would be considered correct using PCC–R. Because these PCCs were obtained from a picture naming task, not conversational speech, direct comparison to normative data (e.g., Shriberg & Kwiatkowski, 1982; Shriberg, Austin, et al., 1997) cannot be made. However, all RE participants achieved greater than 75% on the PCC–R.

Based on the transcriptions from the picture naming task, each RE participant's error patterns were determined by the authors working together. Error patterns were defined as specifically as necessary to capture any sound changes that occurred in 20% or more of the possible contexts (e.g., reduction of /fr/ clusters; glottal replacement of final /p/). This was done to aid in scoring the experimental tasks so as not to penalize the participant for "errors" that were observed elsewhere in his or her sample. For example, a participant who glided prevocalic /l/ in 20% or more of the exemplars on the picture naming task would not be penalized for gliding prevocalic /l/ on the experimental tasks. Table 1 lists these error patterns. It should be noted that these errors had very little impact on intelligibility, and all of these children were considered to have mild speech sound production problems.

A separate 50-item rhotic picture naming task was devised by the authors and was administered to all participants to validate groupings. Drawings, digital photos, clip art, and items from the Contextual Test of Articulation (Aese et al., 2000) were used to elicit target words. The task contained items that sampled stressed /ɝ/ as well as prevocalic singleton /r/, two- and three-element /r/ clusters, and postvocalic /r/ in a variety of vowel contexts (high,

low, front, back, lax, tense). Appendix B includes the list of target words for this task. Adolescents were included in the RE group only if they produced 15 or more errors on the 50-item test, as judged by the two authors (the RE group actually ranged from 27 to 50 errors). Adolescents in the NS group would have been excluded if they had produced two or more errors on this task; however, no members of the NS group needed to be excluded for this reason.

Experimental tasks. Each participant's responses on all tasks were digitally recorded, and the individual's error patterns were used to aid in scoring. This provided the opportunity to discount speech production errors that were consistent with the participant's phonological system. However, all misarticulations that were not attributable to the participant's error patterns were counted as errors.

Nonword repetition. Two lists were used for the nonword repetition task. The first list, taken directly from Dollaghan and Campbell (NWR–1; 1998), consisted of 16 nonwords, with four exemplars of CVC, CVCVC, CVCVCVC, and CVCVCVCVC (e.g., /tʃinɔɪtaʊb/). As described by these authors, all of these nonwords contained full vowels and were limited in the repertoire of consonants sampled (i.e., none of the late-eight sounds were included). Additionally, none of the syllables was a real English word (see Dollaghan & Campbell, 1998, for a complete description of the stimuli). Stimuli were audio files that were provided by the first author of the original work. Three practice items were included to introduce the task.

The second nonword repetition task (NWR–2) included items that were taken directly from or adapted from the list provided by Lewis and Freebairn (1992, taken from Kamhi & Catts, 1986). It included 10 recorded multisyllabic nonwords that were three or four syllables in length. This list contained items that were more similar to real English words than those included in the NWR–1 list, as they included consonant clusters, reduced vowels, and typical American English stress patterns (e.g., /ˈspɛθəˌstoʊp/). Neither NWR task contained a rhotic phoneme. Scoring procedures for both lists followed those outlined by Dollaghan and Campbell (1998) and involved phonetically transcribing the participant's responses and computing a percentage of phonemes correct. However, in the current investigation, errors that were attributable to the participant's error patterns were not counted as incorrect.

Multisyllabic word repetition. As described by Lewis and Freebairn (1992), multisyllabic word repetition evaluates an individual's ability to sequence sounds in longer, phonetically complex words. The multisyllabic word repetition (MWR) task consisted of 20 multisyllabic words that were chosen for their varied phonological complexity (i.e., syllable structures, stress patterns). Items were presented as digital sound files, and the respondent was required to repeat the word. The participant's final response for each word (after any self-corrections) was scored correct or incorrect, taking into consideration the error patterns of participants in the RE group.

Spoonerisms. The spoonerism (SP) task was modeled after Stothard et al. (1998) and required the reversal of word-initial onsets (or phonemes) of two words in a common phrase (e.g., *bus station → stus bation*). One model and three trial items with corrective feedback were presented to teach the concept of the sound exchange. Twenty-four items were presented via live voice. Participants were given as much time as necessary to respond. Scores reported are the total correct out of 24 items. For each item, two judgments were made regarding the accuracy of the sound

exchange, with each being scored as 0.5. For example, a correct response to *bus station* would be *stus bation,* which would be scored as 1, whereas a response such as *stus station* would be scored as 0.5 because only one of the onsets was moved correctly.

Phoneme reversals. In the phoneme reversal (PR) task, real words were presented via live voice with no written cues. The participant was instructed to first say the word and then say the word backwards. Participants were reminded to focus on the sounds, not to think of the spelling. The sounds in each real word could be reversed to form another real word, but items were selected that required more than just reversing the letters (e.g., *fits → stiff*). All items were one-syllable words, but they varied in syllable structure (CV, VC, CVC, CCVC, CVCC, CCVCC). No items contained a rhotic phoneme. Scores reported represent the total correct out of 18 items. One model and three trial items were presented to teach the concept of the reversal. Items chosen for this task were taken from or modeled after Edwards and Rider (2003) or Lewis and Freebairn (1992).

Elision. The elision (EL) task consisted of 16 items, eight of which included a rhotic phoneme and eight of which did not. Items were modeled after the Elision subtest of the Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999). These items were presented via live voice with no written cues. Participants were required to repeat each word and then say it without a specified phoneme (e.g., "Say size. Now say size without the /z/"). For each participant, a maximum score of 16 correct items was possible. Three trial items with corrective feedback were presented to introduce the task.

Reliability

The first author scored all tasks, and interjudge reliability was obtained by having the second author rescore the data for 5 randomly selected participants per task, 2 from the NS group and 3 from the RE group (an additional participant from the RE group was used because scoring also required an additional step: the application of the error patterns). Reliability means (and ranges) for the tasks were as follows: NWR–1, 95% (91%–98%); NWR–2, 98% (96%–99%); MSW, 93% (90%–95%); SP, 97% (96%–100%); PR, 98% (95%–100%); EL, 100% (all 100%). Discrepancies were reviewed together and were re-examined until concensus was achieved.

RESULTS

The phonological processing tasks used in this study were found to be significantly correlated (see Table 3). As would be expected, a high correlation was found among tasks that involved similar types of responses, such as real word and nonword repetition (MWR and NWR–1, $r = 0.87$). In addition, although somewhat different internal processes may be used for each task, those that required manipulation of phonemes (e.g., spoonerisms) showed a moderately strong relationship with tasks that required simple repetition (e.g., MWR, $r = 0.73$). An interesting finding is that, among the RE participants, PCC–R (in which only phonemic errors are considered incorrect) was more strongly related to five of the six phonological processing tasks than was PCC (in which both phonemic and phonetic errors are considered incorrect).

Due to the moderate to high correlations among the dependent variables, a multivariate analysis of variance (MANOVA) was used to evaluate whether differences existed between the RE and NS groups on the phonological processing tasks. The original data (raw scores for MWR, SP, PR, and EL; percentage of phonemes correct (PPC) for NWR–1 and NWR–2) did not conform to multivariate normality. Therefore, a square transformation of the variables was used for the analysis to more closely approximate a normal distribution. Following squaring of the original data, multivariate normality was achieved (Mardia skewness = 12.4, $p = 0.215$; Mardia kurtosis = 45.3, $p = 0.473$). The MANOVA result was significant, Wilks' lambda = 0.556, $F(6, 20) = 2.67$, $p = 0.046$, suggesting that the RE and NS groups differed significantly in their phonological processing abilities. Next, one-sided t tests were used to determine which tasks contributed to the group differences (Stevens, 2002). Each t test tested the assumption that the RE group's scores would be lower than those of the NS group. Five of the six phonological processing tasks (NWR–1, NWR–2, MWR, SP, EL) were significant in separating the groups at the $\alpha = 0.05$ level, with another approaching significance (PR, $p = 0.053$). Table 4 provides summary statistics, the results of these t tests, and effect sizes. Mean scores reported for both NWR tasks are PPC. Means reported for the other tasks are out of the maximum number of correct items possible on the task.

To verify the utility of the phonological processing tasks in separating the two groups, a canonical discriminant analysis was

Table 3. Pearson's correlation coefficients (*p* values) for phonological processing tasks. Task correlations combine both the RE and NS groups; PCC and PCC–R correlations use only the RE group.

	EL	MWR	NWR–1	NWR–2	PR	SP
RE and NS groups						
MWR	.54 (.004)					
NWR–1	.57 (.002)	.87 (<.001)				
NWR–2	.48 (.011)	.77 (<.001)	.82 (<.001)			
PR	.59 (.001)	.63 (<.001)	.57 (.002)	.53 (.005)		
SP	.53 (.005)	.73 (<.001)	.64 (<.001)	.48 (.012)	.69 (<.001)	
RE group only						
PCC	.59 (.034)	.31 (.312)	.36 (.224)	.23 (.449)	.64 (.018)	.58 (.038)
PCC–R	.69 (.009)	.65 (.016)	.64 (.019)	.65 (.016)	.71 (.007)	.54 (.057)

Note. EL = elision, MWR = multisyllabic word repetition, NWR–1 = nonword repetition 1, NWR–2 = nonword repetition 2, PR = phoneme reversals, SP = spoonerisms.

Table 4. One-sided *t* tests for comparison of the RE and NS groups included in the MANOVA's design.

Task	Max score	Group	Mean	SD	Squared Mean	Squared SD	*Welch*'s df	T	p *value*	*Cohen's* d
PR	18	NS	10.8	4.6	138	102	26.5	1.68	0.053	0.64
		RE	7.5	4.7	77	82				
EL	16	NS	13.2	1.8	177	46	23.2	1.79	0.041*	0.69
		RE	11.5	2.9	139	64				
SP	24	NS	20.75	2.7	437	100	21.2	2.45	0.012*	0.96
		RE	16.81	5.4	311	159				
NWR–2	100	NS	93.4	3.3	8732	606	21.2	2.62	0.009**	1.02
		RE	87.0	8.1	7633	1397				
MWR	20	NS	16.9	2.0	288	66	18.2	3.66	0.001**	1.43
		RE	10.4	5.7	139	132				
NWR–1	100	NS	93.4	3.1	8728	579	16.6	4.11	<.001**	1.60
		RE	83.6	8.2	7049	1362				

Note. Summary of the original data is provided beside the square transformed data. The MANOVA, *t* tests, and Cohen's *d* used the square transformed data, as these more closely approximated a normal distribution.

*Significant at the 0.05 level. **Significant at the 0.01 level.

used, again using the square transformed data. The pooled co-variance matrix was used to compute the discriminant function. Because only two groups were evaluated, the data could be summarized in just one linear combination of the variables. The discriminant function was then used to separate all of the participants into two groups. A plot of the separation of groups using the discriminant function is shown in Figure 1; a second discriminant function is plotted on the *y* axis to provide a second dimension to the graph, although this second function does not contain information that is necessary for group separation. Hence, group separation is depicted on the *x* axis.

Classification of the participants by the canonical discriminant function is displayed in Table 5. One of the participants in the NS group was misclassified as RE (7.1% error), whereas 3 of the RE participants were misclassified as NS (23.1% error). This suggests that at least some members of the RE group had phonological processing skills that were similar to those of the NS group. These misclassifications are graphically visible in Figure 1 as

Figure 1. Plot of canonical discriminant function for separating participants in the RE and NS groups using the phonological processing tasks.

Canonical Discriminant Function Score for Each Participant
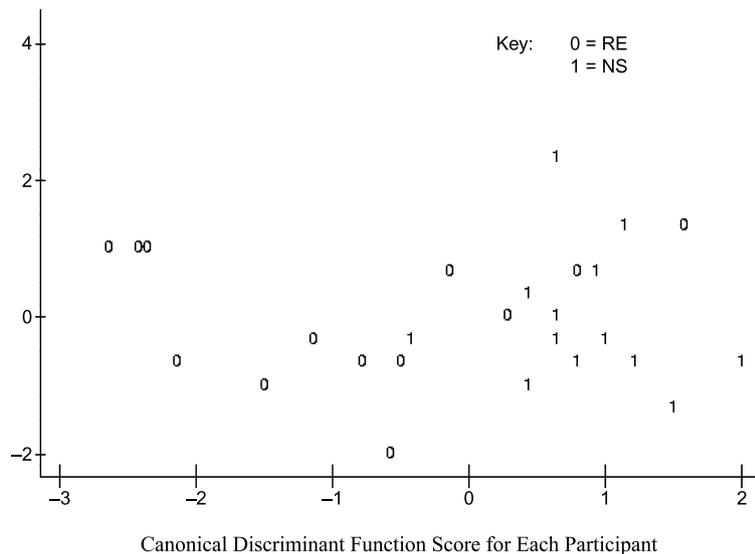
Note. Values to the left of 0 indicate classification in the RE group; values to the right of 0 indicate classification in the NS group using the discriminant function.

Table 5. Number of participants and percentage classified into each group.

From Group	To Group		
	RE	NS	Total
NS	1	13	14
	7.1%	92.9%	100%
RE	10	3	13
	76.9%	23.1%	100%
Total	11	16	27
	40.7%	59.3%	100%

RE participants who do not fall to the left of 0 (*n* = 3) and as NS participants who do not fall to the right of 0 (*n* = 1). Combining the groups, the overall misclassification rate was 15% (4 out of 27 participants), suggesting that the majority of participants (85%) could be correctly classified as RE or NS based solely on their performance on phonological processing measures. Thus, phonological processing skills, as assessed by the tasks used in this study, were useful in distinguishing most adolescents with residual errors from their normally speaking peers.

DISCUSSION

It was hypothesized that adolescents with residual speech sound errors that include rhotics would demonstrate weaknesses in phonological processing compared to adolescents of the same age and with comparable receptive vocabulary abilities. This was supported by the data, suggesting that, as has been shown for younger children with speech production difficulties, adolescents with residual speech sound errors may have weaknesses in phonological processing. As implied by studies with somewhat younger children (Nathan et al., 2004; Raitano et al., 2004), it appears as though the presence of a persisting speech sound disorder may be a risk factor for phonological processing difficulties. Although causal relationships cannot be shown here, it is possible that an underlying mechanism for phonological processing may be related to speech production outcomes (Stackhouse & Wells, 1997). Such abilities may also be related to literacy skills, as there is an abundance of research indicating a relationship between phonological processing and literacy outcomes. Future research should investigate possible relationships among speech production, phonological processing, and literacy skills in adolescents with residual speech sound errors.

Theoretical Considerations

The notion that a simple motoric deficit is associated with residual speech sound errors does not seem justified. Even when each participant's error pattern was taken into account, group differences in phonological processing were still realized (with large effect sizes between the groups). If the difficulty lay solely in the ability to execute the motor movements associated with the phonemes in error for each child, we should have seen no observable differences between groups on phonological processing. Hence, it appears that the ability to process speech, not just execute

movements for particular phonemes, is disrupted in at least some adolescents with residual speech sound errors. The nature of the underlying linguistic deficit involved in this processing weakness could be related to the ability to establish solid phonological representations of words, syllables, or phonemes (cf. Shuster, 1998); the ability to recall sequences of phonemes; the ability to segment words into constituent phonemes; or other processes invoked in phonological working memory (see below).

It was found that PCC on the picture naming task was more highly correlated with five of the six phonological processing tasks than was PCC–R, in which distorted phonemes are counted as correct. The implication is that phonemic changes, rather than phonetic changes (i.e., distortions), may be more strongly related to phonological processing skills, possibly supporting linguistic rather than (or in addition to) motoric involvement. More exploration into this matter is warranted.

The specific factors associated with phonological processing weaknesses among the RE population remain in question. Difficulty with nonword repetition tasks has been implicated as a marker for language impairments (Dollaghan & Campbell, 1998). Given the significant differences in performance between the RE and NS groups on the nonword repetition tasks, one might hypothesize that the RE group may have more global language deficits in addition to residual speech production errors. It is also possible that other cognitive or linguistic factors that were not assessed here may be contributing to their trouble with phonological processing tasks (e.g., working memory, expressive vocabulary). Additionally, although the RE group was not significantly different than the control group on the PPVT–III standard score (means differed by ~4 points), a moderate effect size was found (Cohen's *d* = 0.318), and this may have played a role in the observed group differences. The strength or precision of phonological representations has been linked to vocabulary ability (e.g., Rvachew & Grawburg, 2006), and it has been suggested that individuals with residual errors may have weak phonological representations (Shuster, 1998). Weaknesses in these representations may be related to the ability to segment a word into its constituent phonemes (Sutherland & Gillon, 2005; Swan & Goswami, 1997). Such weaknesses could therefore affect phonological processing. Thus, a more thorough evaluation of vocabulary skills and phonological representations in the RE population is warranted and may help to further describe subpopulations.

It may also be possible that a more complete assessment of each adolescent's phonological processing skills could provide a greater understanding of the processes that may be disrupted. The model presented by Stackhouse and Wells (1997) outlines features of a speech processing system that involves both speech input (i.e., receptive) and output (i.e., expressive) skills. The current analysis was limited to speech output processing, so it is possible that additional breakdowns may be occurring at other levels of speech processing, such as speech sound discrimination, phoneme representations, or self-monitoring of errors. These factors could be explored in future research. Nonetheless, given the moderate to strong correlations among the tasks used in this study, it is apparent that some relationship exists among a variety of phonological processing tasks for adolescents with residual speech sound errors involving rhotics.

The tasks used in the current investigation conceivably could all be completed using a "bottom-up" processing strategy (e.g., Stackhouse & Wells, 1997). Bottom-up processing strategies are used to complete tasks based on a more peripheral analysis of the

stimuli, while using previously stored information to a lesser degree. This is in contrast to top-down processing, in which a task is completed by accessing previously stored information. For example, the repetition of nonwords is necessarily completed without direct access to the lexicon because the nonwords have not been previously stored, and repetition of real words may also be completed without lexical access (e.g., if the words are unfamiliar, or if the individual attempts to simply repeat the sounds without accessing any prior knowledge of the meaning or phonological structure). These repetition tasks may reflect the integrity of the individual's phonological loop (as described by Baddeley, Gathercole, & Papagno, 1998) as a component of working memory that processes incoming phonological information. Even the tasks that require phoneme manipulation (PR, SP, EL) could conceivably be dealt with in working memory and performed without access to the individual's internal representation of the words if the words were processed simply as phoneme sequences rather than actual words (Stackhouse & Wells, 1997). However, this seems unlikely, as the repetition tasks generally were produced with a very immediate response, whereas the manipulation tasks often required a great deal of time for a response on each item. It seems plausible that, during this time, the participants might be accessing the lexicon, thereby making use of top-down processing. Indeed, the tasks requiring manipulation were somewhat less effective at separating the RE and NS groups (see effect sizes in Table 4), suggesting that accessing the lexicon may be a more effective strategy (or a skill that is better developed) for adolescents with residual errors than relying on bottom-up processing.

As can be seen in Table 4, there was significantly more variability in the performance of the RE group than the NS group on the phonological processing measures. This may be indicative of more heterogeneity among the adolescents with residual speech sound errors. It has been suggested that different etiologies and/or different speech development paths may ultimately result in the manifestation of residual speech sound errors (Shriberg et al., 2001; Shriberg, Lewis, et al., 1997). The current RE group was recruited because of their residual errors on rhotic phonemes, but only 1 adolescent's error pattern was limited to rhotic phonemes. Hence, further examination of adolescents whose errors involve exclusively rhotic phonemes could reveal findings that differ from the current study. It is possible that the etiology of the speech sound production difficulties, as well as their severity, developmental history, history of intervention (e.g., duration, intensity, or type), or other personal or environmental factors could all be related to the nature of phonological processing abilities of these adolescents (see below). Ideally, prospective longitudinal studies could address these issues.

Misclassifications

Three of the participants in the RE group were misclassified as normally speaking based on their phonological processing skills using the discriminant function (as shown in Figure 1). It was of interest to determine whether any identifiable factor(s) could account for these misclassifications. The 3 participants who were misclassified were RE9, RE10, and RE13. These were 3 of 5 of the oldest participants in the RE group. This may suggest that these particular phonological processing tasks may be less sensitive to RE and NS group differences at older ages (>12 years), or perhaps that the development of phonological processing skills may simply

be delayed among this population. A larger cohort would be required to explore these possibilities.

Examination of PCC and PCC–R scores (Table 1) indicates that these 3 RE participants were above the group mean on the 64-item picture naming task. Hence, more accurate production of speech sounds, as evidenced by fewer errors on this picture naming task, might be an indicator of better phonological processing.

Additionally, these 3 misclassified RE participants achieved three of the top six PPVT–III scores in the group, which lends support to the notion that better vocabulary skills are related to better phonological processing abilities. It should also be noted that the 1 NS participant who was misclassified as RE was NS8, who had the lowest PPVT–III score in the NS group (see Table 2). This lends further support to a possible relationship between receptive vocabulary and phonological processing.

One final consideration was the speech intervention history of the child. It is possible that the age at which a speech problem becomes apparent may distinguish individuals with residual errors in terms of etiology, genetics, and possibly speech patterns (Shriberg, Lewis, et al., 1997). In the present study, data were not available to determine the age at which the speech problem was first identified, so a classification identical to that of Shriberg, Lewis, et al. could not be used. Hence, parent reports were used to help determine the age/grade at which each participant began intervention. Of the 3 RE participants who were misclassified, RE13 began intervention at 4 years of age, RE9 in second grade (approximately 7 years), and RE10 had no history of intervention (he had recently been evaluated by a clinic and had not yet begun therapy). Therefore, the history of intervention, insofar as it could be determined in this study, did not help to explain these misclassifications. More detailed information regarding speech development and intervention histories could be useful.

CLINICAL IMPLICATIONS

Often, children with residual speech sound errors fail to qualify for speech-language intervention through public schools in the United States under the assumption that the speech production problems are not of academic significance. If, in fact, such children are shown to have deficits in phonological processing, this may help to strengthen the case for providing clinical intervention for adolescents with residual speech sound errors. It has been documented that children with residual errors may be at risk for social consequences (Silverman & Paulus, 1989), and the current data may offer support to the notion that literacy development may be at risk as well. For example, performance on a spoonerism task may be related to spelling (Stackhouse & Wells, 1997) and to reading performance (Wolff & Lundberg, 2003). Weak performance on several of these tasks could signify a problem with phonological working memory, which, in turn, could impact the ability to decode unfamiliar words when reading. Moreover, inaccurate repetition could certainly impact the ability to spell to dictation, which is frequently done for spelling tests. Difficulties segmenting and manipulating phonemes could also have implications for learning spelling rules.

It is evident that SLPs need to be mindful of possible phonological processing difficulties in adolescents with residual speech sound errors. It is possible that overt speech problems, even if

not severe, are only one manifestation of a breakdown in the ability to process phonological information. There may also be broader implications related to literacy development. Thus, it is suggested that a comprehensive clinical evaluation for children/adolescents with residual speech sound errors should include an assessment of phonological processing skills. Collaboration with other professionals who are familiar with a student's reading and spelling skills may help to provide a thorough understanding of the impact of weak phonological skills. In addition, intervention that integrates both phonological processing and speech production training may be considered, as this approach has been found to be effective in remediating speech and improving phonological processing in younger children (Gillon, 2000, 2005). Future research should examine to what extent explicit training in various phonological processing skills might be useful in improving both speech production and phonological processing in adolescents with residual speech sound errors.

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Contact author: Jonathan Preston, Syracuse University, Communication Sciences and Disorders, 805 South Crouse Avenue, Syracuse, NY 13244. E-mail: jopresto@syr.edu.

APPENDIX A. 64-ITEM PICTURE NAMING TASK

Cheeseburger
Present
Thank You
Valentine
Brother
Splash
Ketchup
Breathe
Chocolate cake
School bus
Baby carriage
Toothbrush
Volleyball
Sixty eighth
Jacks
College
Seventy three
Goldfish
Magazine
Olive
Aces
Furniture

Magician
Thanksgiving
Library
Asparagus
Xylophone
Umbrella
Garage
Stethoscope
Measuring cup
Helicopter
Refrigerator
Pajamas
Giraffe
Shampoo
Television
Sandwiches
Elephant
Glasses
Squirt gun
Cheese
Flower

Shovel
Scissors
Clock
Feather
Zebra
Dish washer
Screwdriver
Squirrel
Thirsty
Splinter
Bicycle
Twelve
Glove
Ladder
Cheerios
Stage
Flashlight
French fries
Vacuum cleaner
Thermometer
Washing machine

APPENDIX B. 50-ITEM RHOTIC PICTURE NAMING TASK

Syllable onset singleton

Wreath
Read
Ring
Rich
Rag
Rat
Root
Rule

Syllable coda

Car
Jar
Hear
Deer
Core
Four
Pear
Hair

Two-element syllable-onset clusters

Dream
Three
Prick
Crib
Shrimp
Track
Grass
Broom
Fruit
Green

Syllable coda clusters

Farm
Sharp
Cheered
Tears
Short
Doors
Chairs
Bears

Three-element syllable-onset clusters

Spree
Scream
Spring
String
Scratch
Strap
Screw
Strudel

Preconsonantal stressed /ɝ/

Worm
Burn
Nurse
Church
Purse
Work
Shirt
Bird