

Speed and accuracy of rapid speech output by adolescents with residual speech sound errors including rhotics

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Abstract

Children with residual speech sound errors are often underserved clinically, yet there has been a lack of recent research elucidating the specific deficits in this population. Adolescents aged 10–14 with residual speech sound errors (RE) that included rhotics were compared to normally speaking peers on tasks assessing speed and accuracy of speech production. The two groups were evaluated on an oral diadochokinetic task, which required rapid production of the trisyllable /pAtAkA/, and two rapid naming tasks: monosyllabic letter names and multisyllabic picture names. No significant group differences were observed in the speed of trisyllables on the DDK task, whether examining all attempts or only correct productions. However, the RE group was less accurate and more variable in their production of the trisyllables. In addition, the RE group was slower and phonologically less accurate in rapidly naming multisyllabic pictures, but not in naming letters. A combination of speed and accuracy measures from these tasks revealed relatively little overlap between groups. Results suggest that both speed and accuracy may be impaired in adolescents with RE, although the underlying causal mechanisms require further exploration.

Keywords: *Residual speech errors, diadochokinesis, rapid naming, adolescent, speed, accuracy*

Introduction

Children whose speech sound errors persist beyond the typical age of normalization (i.e. 8 or 9 years of age) are often said to have ‘residual speech sound errors’ (hereafter, RE). Of particular clinical interest are children whose errors involve rhotics, a sound class frequently in error in children with RE (Shriberg, Gruber, and Kwiatkowski, 1994). These errors have been reported to be resistant to change (Ruscello, 1995), and may be present in as much as 5% of the population (Shriberg, 1994). However, the underlying factors associated with residual errors are not well understood. To date, rhotic errors have been discussed as involving deficits in phonemic perception (Shuster, 1998), oral sensory features (McNutt, 1977), ‘phonological attunement’ (see Shriberg, 1994; Shriberg, Lewis, Tomblin, McSweeney, Karlsson, and Scheer, 2005), and, most commonly, motor abilities (McNutt, 1977; Hall, 1989; Shuster, Ruscello, and Haines, 1992; Flipsen, 2003). Recent evidence also indicates that adolescents with RE have difficulty with phonological

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manipulation and repetition tasks (Preston and Edwards, 2007), which may suggest that the linguistic system is compromised as well.

If children with residual rhotic errors are delayed in ‘tuning in’ to speech and language, as noted by Shriberg (1994), the speed and accuracy with which they retrieve phonological information might be weak. It is likely that the speed and accuracy with which phonological information can be retrieved/processed for speech-related tasks reflects a combination of motoric and linguistic processes, either of which may be impaired in children with RE (Pascoe, Stackhouse, and Wells, 2006). Research has shown that the ability to rapidly process and retrieve phonological information is important in speech production (Stackhouse and Wells, 1997), and it is known that this ability may be impaired in some younger children with speech sound disorders (Bird, Bishop, and Freeman, 1995; Leita, Hogben, and Fletcher, 1997; Raitano, Pennington, Tunick, Boada, and Shriberg, 2004). However, little information is presently available for adolescents with RE. Therefore, the present study will examine the speed and accuracy of phonological retrieval in adolescents with and without RE.

One way to investigate rapid access to linguistic information and rapid execution of speech motor movements is to consider speaking rate during conversation, as noted by Flipsen (2002). He reported on the conversational speaking rate of two groups of children (ages 9 and 12–16) with histories of speech sound disorders as preschool children. At follow-up, they were found to speak more slowly than typically-developing peers in phones per second, but not in syllables per second. With respect to those children who retained speech sound errors, Flipsen (2003) reported that the conversational speaking rate of the RE participants with /r/ or /s/ distortion errors was not significantly different than the conversational speaking rates of similar age children whose speech errors had normalized. Flipsen’s older RE group spoke more slowly on words embedded in phrases than their peers whose speech had normalized (as measured by both syllables per second and phones per second). Verbal short-term memory deficits were also observed in the children with RE, as evidenced by lower scores on the Recalling Sentences sub-test of the Clinical Evaluation of Language Fundamentals-Revised. Overall, Flipsen posited speech motor and/or language formulation deficits to account for this slower rate.

General problems in speech processing have been hypothesized to contribute to various communication disorders. For example, speed and accuracy of processing in a variety of functional domains (e.g. motor, cognitive, verbal) have been discussed as contributing to the children’s learning of speech, language, and literacy (e.g. Denckla and Rudel, 1976; Hetrick and Sommers, 1988; Leonard, Ellis Weismer, Miller, Francis, Tomblin, and Kail, 2007; Peter and Stoel-Gammon, 2008). More specifically, the speed and efficiency with which children can rehearse verbal information (e.g. the phonological loop) is thought to contribute to speech, language, and literacy impairments (Locke and Scott, 1979; Baddeley, Gathercole, and Papagno, 1998; Nicolson, Fawcett, and Dean, 2001; Baddeley, 2003). In the present study, the speed and accuracy with which children with RE can overtly produce phoneme sequences is evaluated.

It is important to examine speed and accuracy of the speech production of children with RE in tasks that require retrieval of stored phonological information and tasks that do not require such retrieval. That is, experimental tasks designed to tax the speech production system might reveal rate differences in adolescents with RE that are not apparent in conversational speech or short phrases. Moreover, while retrieval of phonological information of sounds or words is necessarily rapid during conversational speech, this might not be the most demanding task for the speech production system, and therefore it

might not reveal a child's maximum capability to quickly and accurately process and produce speech. Tasks that elicit maximum performance may be useful in determining the extent to which the speed and accuracy of the speech production system is impaired and may help to identify reduced capabilities in the speech system (Kent, Kent, and Rosenbek, 1987). That is, they may tap skills that are not generally required for conversational speech. The current study will examine phonological production of adolescents with RE on two tasks. The rapid naming task requires rapid access to stored phonological representations of words, while the oral diadochokinetic task (DDK) requires rapid articulatory movement without the retrieval of phonological forms from long-term memory. According to a model of phonological processing proposed by Stackhouse and Wells (1997), DDK skills and picture naming tasks are at opposite ends of a speech output continuum. Because it is thought that DDK tasks do not require access to a stored (long-term) phonological representation, they are often used to assess speech motor function. Rapid picture naming tasks, on the other hand, necessitate access to stored representations. Hence, examining performance on these two tasks should provide evidence of the ability of the speech production system to quickly and accurately perform both with and without accessing stored representations.

Speed and accuracy of rapid speech output

Oral diadochokinetic tasks (DDK). Oral diadochokinetic tasks that require participants to rapidly produce syllables or syllable sequences have frequently been used to assess speech motor skills in both adults and children with speech sound disorders (Shriberg, Kwiatkowski, Best, Hengst, and Terselic-Weber, 1986; Crary and Anderson, 1990; Henry, 1990; Shriberg and Kwiatkowski, 1994). Because these tasks require temporary retention and processing of speech sound information that is not tied to the lexicon, they may reveal important information about the ability to co-ordinate and execute rapid articulatory movements (Shuster et al., 1992; Williams and Stackhouse, 1998).

Children with speech sound disorders have been reported to articulate more slowly than children with typical speech on DDK tasks. For example, 7–12 year olds with frontal lisps have been found to perform more slowly than their normally-speaking peers on lingual DDK tasks (Dworkin, 1980), as have children with /r/ problems (Smith Jordan, Hardy, and Morris, 1978). McNutt (1977) examined DDK skills of adolescents with RE, and found that 12–15 year-olds with residual /r/ errors or residual /s/ errors were slower than their age-matched normally-speaking peers in their production on a DDK task, but he did not evaluate the accuracy of their productions. Although more recent research on DDK skills of adolescents with RE has not been reported, recent studies with younger children (Williams and Stackhouse 1998; 2000) have suggested that speed, accuracy, and consistency of DDK productions should be considered. In fact, inconsistent errors on DDK tasks may be more sensitive to speech development than accuracy or rate in young children, and inconsistent errors have been suggested to reflect more pervasive speech processing problems (Williams and Stackhouse, 2000). Thus, in the present study, speed, accuracy, and consistency of DDK productions are considered. Additionally, the relationship between speed and accuracy is examined to determine if there may be a trade-off such that faster productions are less accurate than slower productions.

Rapid naming (RN). Rapid serial naming tasks also require rapid articulatory movements, but with the additional demand of accessing the lexicon in order to quickly and accurately

retrieve the phonological form of a word. Six-year-old children with isolated speech impairment, as well as those with speech and language impairment, have been found to perform more slowly than their normally-speaking peers on rapid naming of colours, letters, numbers, and pictures (Leitao et al., 1997). This may be due to difficulty retrieving phonological forms of lexical items, increased time for speech-motor planning, generally slow processing speed, or other factors. No rapid naming data are currently available for adolescents with RE. To provide a more challenging rapid naming task for this older group than is often used with younger children, multisyllabic words are utilized in this study. Previous research has shown that word length may influence both speed of naming (Klapp, 1971; Okada, Smith, Humphries, and Hickok, 2003) and accuracy of naming (Swan and Goswami, 1997), presumably because of the complexity required in accessing or planning the motor movements associated with the phonological structure of longer words.

The purpose of the present study is to determine whether adolescents with residual speech sound errors will show speed and/or accuracy differences from their normally speaking peers when their speech production systems are taxed during rapid speech output tasks. Two tasks were chosen: a rapid naming task (RN) that requires access to stored phonological forms, and an oral diadochokinetic (DDK) task that does not. Given the results of studies with younger children with speech sound disorders, it is hypothesized that adolescents with residual speech sound errors will perform more poorly than their normally-speaking peers in both speed and accuracy.

Method

Participants

As part of a larger project, 27 participants were recruited. All were 10–14 years of age, were speakers of Standard American English, and had no known hearing loss, neurological or cognitive problems, or developmental delays, as reported by their parents. All participants passed a bilateral hearing screening at 20 dB at 500, 1000, 2000, and 4000 Hz, and all achieved a standard score of 83 or above on the Peabody Picture Vocabulary Test-III (Dunn and Dunn, 1997).

The Residual Error (RE) group consisted of 13 adolescents (six male, seven female, mean age 11;11) recruited by referrals from local speech-language pathologists ($n=12$), or in response to public notices in local speech-language clinics ($n=1$). Participants were sought who did not have moderate or severe language problems, and all RE participants were reported by referring clinicians or parents to have full scale IQs above 85. All had errors on more than 25% of the items on a 50-item rhotic picture-naming task developed for the study. None of the participants had difficulty producing syllable-initial /p, t, k/ in single words. Table I provides further descriptive information for these participants.

The normal speech production group (NS) consisted of 14 adolescents (six male, eight female, mean age 12;1) who made no more than three errors on the 50-item rhotic picture-naming task. The groups did not differ significantly in age ($p=.798$), PPVT-III score ($p=.425$, Cohen's $d=.318$), or maximum number of years of parental education ($p=.374$, Cohen's $d=.364$) based on independent-sample t -tests.

Because the genetic bases of speech sound disorders have been widely discussed, parents were asked to complete a questionnaire adapted from Lewis and Freebairn (1993) about any speech, language, or learning problems in the family. All 12 RE participants for whom information was available had at least one nuclear family member with a positive history of

Table I. Descriptive data for RE participants.

Participant	Gender	Age	PPVT-III standard score	Recalling sentences scaled score	PCC-R from PNT	Rhotics correct/50	Approximate years of therapy
RE1	F	10;4	97	7	83	0	7
RE2	F	10;6	114	8	87	1	8
RE3	M	10;9	93	7	76	6	5
RE4	M	11;0	122	11	93	23	3
RE5	F	11;4	105	10	89	7	7
RE6	F	11;4	118	14	90	11	3
RE7	M	11;9	93	8	77	0	8
RE8	F	11;9	97	10	77	6	8
RE9	M	12;0	126	12	88	0	4
RE10	M	12;2	111	11	92	0	0
RE11	F	14;1	87	9	83	0	11
RE12	M	14;3	83	4	81	4	10
RE13	F	14;6	113	9	96	36	6

PNT=64-item picture naming task. Years in therapy based on parental report.

speech, language, or learning problems (no information was available for one who was adopted). However, only six of the 13 NS participants for whom information was available reported nuclear family members with such histories. As expected, there was a significant group difference in the percentage of nuclear family members with positive histories (Mann-Whitney $U=12$, $p<.001$).

Procedure

Participants were individually assessed in a quiet room at a university laboratory, at the child's school, or at home. All wore a Shure WH20 head-mounted microphone fed into a Rolls MX 54s Pro Mixer Plus. The signal was recorded as a .wav file using Praat v. 4.2.19 (Boersma and Weeninck, 2004) on a Dell Inspiron 8600 laptop. Task order was randomized for each participant, and the current tasks were interspersed with other phonological processing tasks (see Preston and Edwards, 2007).

Speech sound accuracy

Speech sound accuracy was assessed via two picture naming tasks. One involved 64 phonologically complex words (e.g. *stethoscope*, *xylophone*). Percentage Consonants Correct-Revised (PCC-R, Shriberg, Austin, Lewis, McSweeny, and Wilson, 1997a) was computed from productions on this task. The other picture naming task included 50 monosyllabic words with rhotic phonemes, including /r/ in word-initial and word-final position and in consonant clusters, as well as vocalic /ɜ/. Responses were considered correct or incorrect based only on the accuracy of the rhotic phoneme. Stimuli are listed in Preston and Edwards (2007).

Oral diadochokinetic (DDK) task

Each participant was instructed to produce the trisyllable /pʌtʌkʌ/ 10 times in a row as rapidly as possible (the first author counted during the sessions to be certain that at least 10 trisyllables were produced). This was repeated five times for each participant. Four sets of 10 trisyllables were scored for each participant. The first trial was generally considered a 'warm-up,' and the

other four were scored. However, in three cases, one of the later trials was interrupted (e.g. the participant stopped part-way through, took a long breath, or began to talk/laugh). Therefore, the first trial was scored to provide a more accurate sample for the child.

Speed. For each participant, two duration measures were computed (cf. Fawcett and Nicolson, 2002) using digital waveform measurements in Praat:

- (1) The average time required to produce 10 trisyllables, regardless of accuracy (averaged over the four trials).
- (2) The average speed (rate) of consecutive correct trisyllables. This average was computed by measuring the duration of each string of at least three consecutive correct trisyllables, and dividing by the number of correct trisyllables. For example, if a child produced six correct trisyllables in a row, followed by four incorrect trisyllables, the duration of the first six trisyllables was computed and was divided by six to determine the average speed of consecutively produced correct trisyllables. Hence, only error-free productions were analysed in the second duration measure.

Accuracy. Consonant production errors were classified using a system similar to that of Yaruss and Logan (2002). Incorrect productions were classified as involving changes in voicing, manner of articulation, metathesis, regressive assimilation, progressive assimilation, other non-assimilatory place of articulation changes, additions of segments/syllables, and deletions of segments/syllables. Table II provides examples of these types of sound errors. Note that if a given error included more than one change, such as both manner and voicing as in [vʌtʌkʌ], both changes were counted.

An additional feature of DDK accuracy may involve the variability of production within one child. In this study, variability was assessed by summing the number of different ways that /pʌtʌkʌ/ was realized in the 40 productions (four trials of 10 trisyllables) (cf. Williams and Stackhouse, 1998; 2000). For example, if a participant repeatedly produced a consistent error form [bʌtʌkʌ], this would be scored 1; however, if a participant produced five different error forms of the trisyllable, such as [pʌpʌkʌ, pʌgʌkʌ, pʌkʌtʌ, kʌtʌkʌ, bʌtʌkʌ], this would be scored 5.

Table II. Classification of speech sound errors on the DDK task.

Error Type	Description	Example
Voicing change*	Target consonants /p/ or /k/ are voiced	[bʌtʌkʌ]
Manner change	Target consonant is produced as something other than a stop	[fʌtʌkʌ]
Exchange (Metathesis)	Place of articulation of two consonants in the trisyllable is switched	[pʌkʌtʌ]
Regressive assimilation	Place of articulation matches the place of a following consonant in the trisyllable	[pʌkʌkʌ]
Progressive assimilation	Place of articulation matches the place of a preceding consonant in the trisyllable	[pʌtʌtʌ]
Place change (other)	Place of articulation is different from the target consonant and is <i>not</i> explained by any of the above three place change categories	[pʌtʌqʌ]
Addition of segment/syllable	Consonants and/or vowels are added to the trisyllable	[pʌtʌkʌtʌ]
Deletion of segment/syllable	Consonants and/or vowels are deleted from the trisyllable	[pʌtʌ]

* Note: /d/ was allowed for target /t/ because intervocalic /t/ is often flapped in American English, and it may be difficult to distinguish between alveolar (tongue tip) flap /ɾ/ and /d/.

Rapid naming (RN) tasks

Two rapid naming tasks were used in this study. The first task (RN-1) required rapid production of monosyllabic words, and the second task (RN-2) required production of multisyllabic words. RN-1 was the Rapid Letter Naming sub-test of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, and Rashotte, 1999). It involved rapidly naming two plates with the letters *a, c, k, n, s, t* arranged in random order, with four rows of nine letters each. Hence, all productions were monosyllables (V, CV, or VC). A break occurred between the naming of the two plates. The total duration measure reported is the sum of the naming times for these two plates.

RN-2 involved rapid naming of pictures of *elephant, umbrella, strawberries, thermometer, helicopter, and spaghetti*. These items were chosen for this study because of their varied syllable structures and stress patterns, and because of the relative ease of representing these words through simple coloured pictures. These pictures were randomly ordered, and appeared in four rows of seven pictures each on a single sheet of 8.5 × 14" paper.

Speed. The duration of each rapid naming task (from energy onset to energy offset in the waveform) was measured using Praat software (Boersma and Weenink, 2004).

Accuracy. Responses on the RN-1 task were not scored for accuracy because few errors were made. For the RN-2 task, however, it was necessary to consider phonetic accuracy. Each participant was first asked to name each of the six target pictures. These productions were phonetically transcribed by the two authors. When scoring production accuracy on this task, sound errors were counted only if they (a) differed from the child's preliminary naming of the item, or (b) differed from the child's typical error patterns (defined as errors occurring at least 20% of the time on the 64-item picture naming task made up of phonologically complex words). For example, a participant who produced *umbrella* on the RN-2 task as [əm'bwəwə] would not be penalized if his/her error pattern included gliding of prevocalic /r/ and /l/, or if this production matched his/her preliminary naming of the picture. Otherwise, a production of [əm'bwəwə] would be counted as one error. Each word was therefore judged to be correct or incorrect, regardless of the number of individual sound errors.

Control of language variables. It has been suggested that vocabulary might mediate recall of phonological representations in naming tasks (Swan and Goswami, 1997; Metsala and Walley, 1998; Snowling, 2000; Rvachew and Grawburg, 2006). The PPVT-III (Dunn and Dunn, 1997) was therefore administered as a measure of receptive vocabulary to control for the potential influence of vocabulary skills on the RN-2 task.

Additionally, there has been discussion that RN may be related to verbal working memory (Troia, Roth, and Yeni-Komshian, 1996). Therefore, the Recalling Sentences sub-test of the Clinical Evaluation of Language Fundamentals-4 (Semel, Wiig, and Secord, 2003) was administered to estimate verbal working memory. In this sub-test, children repeat sentences of increasing length spoken by the examiner. While this measure is at times used to assess expressive language, there are undoubtedly demands on verbal memory. This task was used in the present study so that performance could also be compared to Flipsen's (2003) finding that adolescents with RE had difficulty on a sentence repetition task. Raw scores were used in the analysis.

Transcription and reliability

The first author scored all tasks, and reliability was calculated as reported below.

50-item rhotic naming task. An undergraduate student in speech-language pathology who was trained in phonetics listened to productions of all NS participants on the rhotic naming task to confirm that no more than three errors were made on rhotics. In addition, a certified speech-language pathologist listened to all RE participants' productions on the rhotic naming task. She agreed with the first author's judgements of the accuracy of the rhotic phoneme in 570/650 words (88%), and the two judges never disagreed on more than 10 words (20%) for any given child. For those words on which a disagreement occurred, the second author made an independent judgement, which was used as the deciding factor. Thus, two judges were required to agree on the accuracy of each production. Table I lists the number of rhotics produced correctly by each participant.

DDK. Phonetic transcriptions were derived from the digital recordings of the DDK productions by listening to one trisyllable at a time. The DDK task was transcribed by the first author; then all participants' responses were reviewed again with the second author, with disagreements being resolved through discussion until consensus was achieved (cf. Shriberg, Kwiatkowski, and Hoffmann, 1984). This was done to maximize scoring accuracy (particularly because the DDK duration measurements depended on reliable transcriptions of the trisyllables).

Duration measurements for the DDK task were completed by the first author. Five participants were independently rescored by the second author, and 90% of the measurements were within 100 ms of the original timing. Specifically, reliability measurements of 10 trisyllable attempts differed from the original timings by an average of .04 seconds (range .01–.19 seconds), and reliability measurements of consecutive correct trisyllables differed from the original timings by an average of .04 seconds (range .00–.18 seconds).

RN. Duration measures for the RN tasks were rescored for five participants by a trained research assistant. For the RN-1 (monosyllabic) task, the absolute difference between the two measurements ranged from .05–.9 seconds (mean .19 seconds). For the RN-2 (multisyllabic) task, the absolute difference between measurements ranged from .01–.5 seconds (mean .16 seconds).

Recalling sentences. The corrected test–re-test stability coefficient of the Recalling Sentences sub-test of the CELF-4 is .90, with split-half reliability ranging from .86–.93, and internal consistency reliability coefficients of .86–.91 for the age groups tested in this study (Semel et al., 2003). Additionally, a trained research assistant who is a certified speech-language pathologist rescored all sentences for six randomly selected participants (three RE and three NS). Percentage of item-by-item scoring agreement ranged from 88–100% for these six participants, with an average of 95% agreement.

Results

Table III provides descriptive statistics for both groups, along with results of group comparisons. Table IV reports correlations among the speed and accuracy measures on the DDK and RN tasks. Because it was expected that some of the variables would be correlated, a MANOVA was used first as an omnibus test to compare the two groups on the following variables: speed of 10 trisyllable attempts, speed of correct trisyllables, number of speech sound errors in 40 trisyllable attempts, number of different incorrect realizations of

Table III. Summary statistics and group comparisons (t-tests) for speed and accuracy measures on DDK and RN tasks.

Measure	Group	Mean (SD)	p*	Cohen's d
<i>DDK speed</i>				
Speed in seconds for 10 trisyllable attempts	NS	5.2 (.7)	.203	.32
	RE	5.5 (.8)		
Speed in seconds for correct trisyllables	NS	.48 (.05)	.396	.10
	RE	.49 (.08)		
<i>DDK accuracy</i>				
Number of speech sound errors per participant in 40 trisyllable attempts	NS	8.5 (5.9)	<.001	1.43
	RE	22.7 (12.7)		
Number of different incorrect realizations of /pʌtʌkʌ/ per participant in 40 attempts	NS	4.6 (1.8)	.010	1.00
	RE	7.9 (4.3)		
<i>RN speed</i>				
Speed in seconds for RN-1 (letters)	NS	31.3 (7.3)	.182	.36
	RE	33.8 (6.7)		
Speed in seconds for RN-2 (multisyllabic words)	NS	22.7 (3.3)	.003	1.24
	RE	29.4 (6.9)		
<i>RN accuracy</i>				
RN-2 words with speech errors†	NS	1.0 (.99)	<.001	1.88
	RE	4.6 (2.5)		

NS=Normal speech group, RE=Residual error group. * p-values reported are one-sided t-tests using Welch's approximation, assuming unequal variance. (Note that non-parametric Mann-Whitney tests resulted in similar conclusions for all group comparisons reported). † Words with speech errors that (a) were unlike the child's initial production of the word, or (b) could not be accounted for by the child's individual speech error patterns.

/pʌtʌkʌ/ in 40 trisyllable attempts, speed on RN-1, speed on RN-2, and number of words with speech sound errors on RN-2. The MANOVA indicated that the groups were significantly different ($F[7, 19]=4.94, p=.003, \text{partial } \eta^2=.645$). One-tailed independent-samples t-tests were used for follow-up, and p-values for these t-tests are reported below along with effect size estimates (Cohen's d). Note that non-parametric Mann-Whitney rank-sum tests confirmed all t-test results at $\alpha=.05$.

Table IV. Pearson's correlation coefficients for experimental and control variables.

	1	2	3	4	5	6	7	8	9
1. DDK Speed 10 Repetitions									
2. DDK Avg Speed Correct Trisyllables	.83**								
3. DDK Total Errors	.40*	.27							
4. DDK Number Types of Errors	.27	.06	.86**						
5. RN-1 Speed	.43*	.23	.26	.18					
6. RN-2 Speed	.64**	.35	.53**	.31	.48*				
7. RN-2 Words with Speech Errors	.45*	.40*	.58**	.38	.15	.46*			
8. PPVT3	-.26	-.33	-.40*	-.17	-.27	-.43*	-.42*		
9. Recalling Sentences	-.27	-.22	-.28	-.06	-.35	-.41*	-.61**	.72**	
<i>RE Group only</i>									
10. PCC-R	-.25	-.21	-.34	-.15	-.23	-.33	-.54	.74**	.61*

* Correlation is significant at the .05 level (2-tailed); ** Correlation is significant at the .01 level (2-tailed).

DDK speed

The time per 10 trisyllable attempts (averaged across four trials) was computed for each participant, regardless of articulatory accuracy. DDK speed from the NS group is generally in accord with data reported for other samples of typically-developing adolescents (Fletcher, 1972; Kent et al., 1987; Fawcett and Nicolson, 2002). No significant difference was found between the RE and NS groups ($p=.203$; Cohen's $d=.32$). The average time per correct trisyllable was also computed for each participant, considering only instances in which three or more consecutive correct trisyllables occurred. Again, no significant group difference was found ($p=.396$; Cohen's $d=.10$). Thus, the two groups did not differ on either of the DDK speed measures.

DDK accuracy

The total number of speech sound errors produced on all four DDK iterations (based on the classification scheme in Table II) was computed for each participant. There was a significant group difference ($p<.001$), with a large effect size (Cohen's $d=1.43$). This indicates that, even though all participants in the RE group were capable of producing correct trisyllables, they made more errors when their speech production systems were taxed in the DDK task.

There is the potential for a speed-accuracy trade-off. That is, despite being given uniform instructions (being told to produce the trisyllables as rapidly as possible), some participants may have focused on maintaining accuracy at the expense of speed. In an effort to control for this statistically, an Analysis of Covariance (ANCOVA) was used to examine error differences between the groups while controlling for the average speed of production of 10 trisyllable attempts. The groups remained significantly different in the number of speech sound errors (group $F[1, 24]=13.40$, $p=.001$) when average speed of production of 10 trisyllable attempts was controlled ($F[1, 24]=4.26$, $p=.050$).

Finally, the number of different incorrect realizations of the /pʌtʌkʌ/ sequence per participant was compared across groups. The NS group had an average of 4.6 different incorrect realizations of /pʌtʌkʌ/, whereas the RE group produced an average of 7.9 different incorrect realizations. A large group difference was found ($t=2.57$, $p=.010$, Cohen's $d=1.00$), suggesting that the RE group was more variable in their DDK productions than was the NS group.

Rapid naming speed

T-tests revealed that the groups did not differ in their speed on the naming of letters in the RN-1 task ($p=.182$, Cohen's $d=.36$). Because normative data is available for this task from the CTOPP, it was also confirmed that the mean of the scaled scores of the RE group ($M=9.3$, $SD=2.3$) was not significantly different than the mean of the normative sample of the CTOPP ($M=10$, $SD=3$).

In contrast, the RE group was found to differ significantly from the NS group in their speed on the multisyllable RN-2 task ($p=.003$, Cohen's $d=1.24$). Thus, the RE group was slower on naming multisyllabic pictures but not on naming monosyllables (letters).

To explore whether the group difference on RN-2 was due to differences in vocabulary and/or verbal working memory, an Analysis of Covariance (ANCOVA) was performed, analysing group differences while controlling for PPVT-III standard score and the CELF-4 Recalling Sentences scaled score. Although the sample size is limited, if the group

difference is sufficiently large, it would remain detectable when controlling for relevant language-related skills. In this instance, the group difference in RN-2 speed remained significant ($F[1, 23]=7.5$, $p=.012$, partial $\eta^2=.245$) when controlling for vocabulary and working memory, which were non-significant covariates ($p's>.18$). Hence, group differences observed on the RN-2 task could not be readily explained by receptive vocabulary (PPVT-III) or verbal short-term memory differences (Recalling Sentences). It was the case, however, that the RE group had more difficulty on the Recalling Sentences task ($t[25]=1.87$, $p=.037$); this supports Flipsen's (2003) findings that adolescents with RE performed more poorly on this task than their peers whose speech had normalized.

Rapid naming accuracy

To determine if adolescents with RE made more speech sound errors than their NS peers when rapidly naming pictures, the number of words containing speech sound errors on the RN-2 task was tallied for each participant. Words were counted as incorrect only if they contained sound errors that (a) were different from the participant's initial production of the word, or (b) were not accounted for by the RE participants' error patterns. Therefore, this measure reflects the accuracy of a participant's speech production during a rapid naming task that requires retrieval of stored phonological forms. The group comparison indicated significant differences ($p<.001$, Cohen's $d=1.88$), as shown in Table III, indicating that the RE group produced significantly more words with speech sound errors than the NS group during the RN-2 task, even when allowing for their common errors.

Relationships between speed and accuracy

Because there is the potential for a speed-accuracy trade-off, the correlations between speed and accuracy on the experimental tasks need to be considered. As can be seen in Table IV, there was a weak correlation ($r=.40$) between speed of production of 10 DDK trisyllables and total number of errors on the DDK task. This correlation is positive, suggesting that a slower speed (i.e. longer duration) was associated with a greater number of errors on this task. Hence, when considering the 27 participants as a group, a speed-accuracy trade-off was not observed, and, in fact, the opposite trend was found. That is, faster DDK production was associated with fewer errors.

A similar trend was observed on the RN-2 (multisyllabic naming) task. A positive correlation ($r=.46$) indicated that slower performance on the RN-2 task was associated with more errors. Hence, participants tended to be either quick and accurate, or slow and inaccurate. This reflected the possibility of a speed/accuracy 'skill' that may be responsible for general speech production abilities. We therefore investigated how well a combination of these variables would separate the participants from the two groups. A discriminant function analysis was performed using the four variables that were statistically significant and that had large between-group effect sizes: RN-2 speed, RN-2 words with speech errors, total errors on the DDK task, and number of different incorrect realizations of /pʌtʌkʌ/. Thus, a composite score of speed and accuracy was computed based on a combination of these tasks. The results, shown in Figure 1, suggest that all 14 of the NS participants and 10 of 13 RE participants could be correctly identified based on this composite (the four variables from the DDK and RN-2 tasks). That is, when these four variables are considered together, the majority of the RE participants (who are relatively slow and inaccurate) can be distinguished from the NS participants (who are relatively fast and accurate).

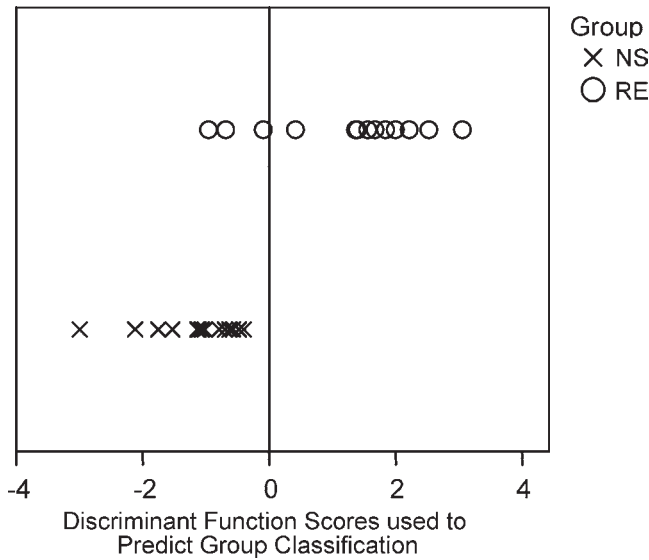


Figure 1. Group separation using a combination of four speed and accuracy measures. Symbols to the left of zero are participants classified as having normal speech (NS); symbols to the right of zero are classified as having residual errors (RE) based on RN-2 speed, RN-2 words with speech sound errors, DDK total errors, and number of incorrect realizations of /pʌtʌkʌ/ on the DDK task. All 14 NS participants are correctly classified and 10/13 RE participants are correctly classified based on these variables.

Speech sound production, DDK, and RN

If speech sound production skills are related to performance on DDK or rapid naming within the RE group, it could lead to better understanding of possible underlying mechanisms responsible for speech sound production difficulties in this population. The bottom of Table IV reports the relationship between performance on the DDK and RN tasks and a measure of speech production for the RE group (PCC-R). PCC-R was derived from a 64-item picture naming task comprised of phonologically complex words (found in Appendix A of Preston and Edwards, 2007). It is evident from the relatively weak correlations that speech sound production accuracy is not uniquely predicted by DDK speed, DDK accuracy, RN speed, or RN accuracy. In examining how speech sound accuracy relates to the speed/accuracy composite score (obtained from the discriminant function), there is an apparent trend for greater speech sound accuracy (as measured by PCC-R) to be associated with relatively 'better' scores on the speed/accuracy composite score (Spearman's $\rho = -.59$, $p = .034$, Figure 2).

Discussion

The results suggest that rapid speech output tasks, which are intended to tax the speech production system, may reveal differences between adolescents with residual errors including rhotics (RE) and their normally speaking peers in both speed and accuracy. In this study, the DDK task, which does not require access to stored (long-term) representations, revealed differences in articulatory accuracy but not speed. Accuracy differences were observed even though all RE participants were capable of articulating correct /pʌtʌkʌ/, and accuracy differences were also found when controlling for speed of

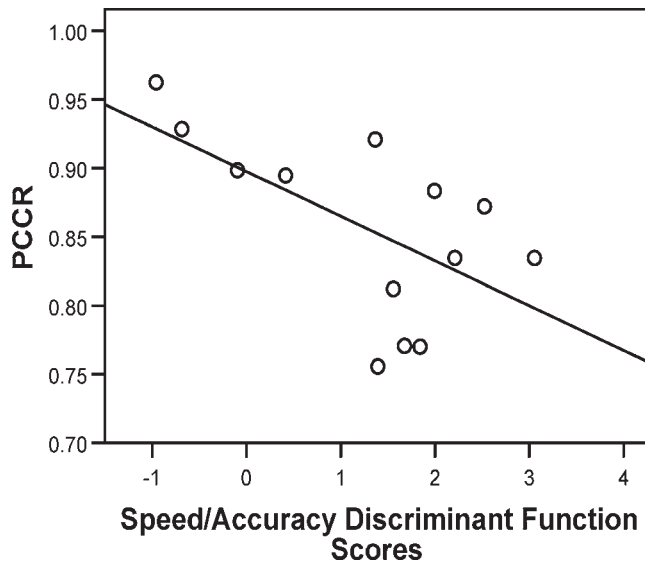


Figure 2. Scatterplot of PCCR from a picture naming task and speed/accuracy composite.

productions. The groups also differed in speed and articulatory accuracy when rapidly naming multisyllabic pictures, but not monosyllables (letters). A combination of speed and accuracy (derived from the measures that were best at identifying group differences) revealed that the majority of participants (24 of 27) could be correctly classified as RE or NS based on this composite. This speed/accuracy combination could be crudely described as a general 'speech skill' that differs in adolescents with RE, as compared to adolescents without residual errors. One possible explanation for this weaker 'speech skill' might be a disrupted central nervous system timing mechanism (cf. Peter and Stoel-Gammon, 2008). Because the current study did not evaluate non-speech processing speed/accuracy, it is unclear whether the deficits observed here are specific to the speech-language systems, or whether more global neural deficits in timing and motor coordination exist (Bradford and Dodd, 1996; Leonard et al., 2007; Peter and Stoel-Gammon, 2008).

DDK tasks have often been used to assess speech motor production, with the standard measure being articulatory speed. However, speed of production was found not to differ between the two groups in this study. This is perhaps a surprising result. If DDK speed is an accurate means of assessing speech motor production, then the group of adolescents with RE in this study were relatively unimpaired in speech motor skills. This is in contrast to studies of younger children with speech sound disorders (e.g. Henry, 1990), and also contradicts results reported by McNutt (1977), who observed slower production of bisyllables in 12–15 year olds with residual /r/ errors. There are several possible explanations for the contradictory results. For example, they may be due to the slight age differences in the samples, the task used (e.g. bisyllables instead of trisyllables), or the method of measurement (McNutt used a strip-chart recorder, rather than digital waveforms, to analyse the number of repetitions in the first 2 seconds of two breath groups, and he used a count-by-time method, rather than a time-by-count method). Alternatively, the different findings may be due to the potentially weak reliability of DDK rate measurements (Gadesmann and Miller, 2008), or they may simply reflect the variability in the RE population.

In the present study, DDK accuracy and consistency were found to be more sensitive to group differences than was speed, with total number of errors and variability of production being higher in the RE group. The findings are in agreement with Williams and Stackhouse (1998; 2000), who report that even typically developing preschool children are quite consistent in their repetitions of real words and nonsense words, whereas some children with speech sound disorders are both less accurate and less consistent. The results also lend support to the suggestion by Williams and Stackhouse (2000) that inconsistent errors on repetition tasks such as DDK could be indicative of pervasive speech processing problems. Variability in production might be indicative of poor motor planning and/or problems with speech automaticity. Although phonetic transcription of rapid productions is labour-intensive, future research should investigate the clinical utility of accuracy and consistency measures of DDK tasks.

Differences in speed were observed when a lexical component was required in the task. Slow performance by the RE group on the RN-2 task (rapid naming of pictures) may reflect relative difficulty accessing stored phonological representations, as retrieval of stored representations was required in the RN task but not in the DDK task (Stackhouse and Wells, 1997). Rapid naming has also been suggested to reflect one's working memory capacity and/or ability to allocate cognitive resources (Troia et al., 1996). In the present study, however, group differences were still found when controlling for short-term verbal memory and vocabulary. Hence, it may be the case that adolescents with RE have weaker phonological representations and/or slower access to representations associated with multisyllabic words, as compared to their NS peers. Additionally, the longer words used in this study were more phonologically complex than the consonant sequences on the DDK task, thus adding greater demands to motor planning. The group differences on the RN-2 task might also reflect slow overall processing speed (Wolf and Bowers, 1999; Vukovic and Siegel, 2006). Whichever the case, there is mounting evidence that slow RN speed constitutes a risk for literacy difficulty, including reading comprehension, reading fluency, decoding, and spelling (Troia et al., 1996; Allor, 2002; Fawcett and Nicolson, 2002; Wolf, O'Rourke, Gidney, Lovett, Cirino, and Morris, 2002; Kirby, Parrilla, and Pfeiffer, 2003; Swanson, Trainin, Necochea, and Hammill, 2003; Cardoso-Martins and Pennington, 2004; Schatschneider, Fletcher, Francis, Carlson, and Foorman, 2004; Savage, Frederickson, Goodwin, Patni, Smith, and Tuersley, 2005). Therefore, future research involving adolescents with RE should include specific assessment of literacy skills (cf. Pascoe et al., 2006; Preston and Edwards, 2007).

For adolescents with RE, phonological accuracy decreased in tasks requiring rapid speech output (including both DDK and RN-2 tasks). Even though the tasks used to assess accuracy in this study either required production of phoneme sequences that the adolescents were capable of producing (DDK) or made allowances for their usual error patterns (RN-2), the RE group was still less phonologically accurate. Hence, tasks that demand rapid performance revealed a reduced 'reserve' of speech production skill in the RE population (Kent et al., 1987).

Group differences in speed were not observed in the RN-1 task (rapidly naming letters), but were found in the RN-2 task (rapidly naming pictures representing multisyllabic words). Possible explanations for this may include (1) word length differences, and/or (2) the nature of the stimuli (cf. Denckla and Rudel, 1976). The former may be reasonable to assume, given the evidence that children with speech sound disorders, as well as children with dyslexia, tend to have difficulty representing the phonological characteristics of multisyllabic words in naming, repetition, and identification tasks (Lewis and Freebairn,

1992; Swan and Goswami, 1997; Sutherland and Gillon, 2005). The latter may also be plausible, given that naming letters involves retrieving representations from a limited category (i.e. 26 letters in English), whereas naming pictures requires retrieving from a much larger set (i.e. picturable words) (Wolf and Bowers, 1999). Future research might address this issue by comparing RE and NS groups in rapid naming of pictures with monosyllabic vs multisyllabic names in order to avoid the confounds of differences in types of stimuli.

The underlying mechanisms for residual speech errors are not well understood. It is unlikely that either a pure linguistic or a pure motoric description will adequately characterize this population. As descriptive data accumulate, more comprehensive linguistic and neuropsychobiological models should be developed. For example, little is known about the possible neural bases for residual speech sound errors. Indeed, there is currently little reason to assume that a single neural deficit is at the root of both the imprecision/incoordination observed on the DDK task and the slow naming observed on the RN-2 task in this study. Additionally, the fact that all of the RE participants for whom data were available had nuclear family members with speech, language, or literacy problems points to the possibility of a genetic predisposition to problems with speech sound normalization (e.g. Shriberg et al., 2005). In sum, there are multiple avenues to pursue in examining specific features that may differ in the RE population (or sub-populations) and that may account for the differences in overt speech production observed.

Additionally, the current study classified all the participants with RE into a single group that shared the characteristic of having problems with rhotics. There has been discussion in the literature of sub-groups of RE (e.g. McNutt, 1977; Shriberg, Lewis, McSweeney, and Wilson, 1997b; Shriberg, Flipsen, Karlsson, and McSweeney, 2001), but there is some debate as to how these sub-groups should be defined (according to aetiology, speech development history, error patterns, etc.). To thoroughly explore sub-group characteristics, replication of the present results in larger samples is needed, along with prospective longitudinal studies that control for intervention. Such studies should also evaluate the speed and accuracy of adolescents with RE in other domains, such as general processing speed, non-verbal skills, and non-speech motor functioning (e.g. Leonard et al., 2007).

As with many studies of clinical populations, we were also limited by sample selection. Having relied largely on clinical referrals, our sample included primarily adolescents who had recently been seen by a speech-language pathologist. Because this population is often under-served in clinical and educational settings (i.e. they may not qualify for therapy services), it is possible that our sample included adolescents with relatively more severe problems. As noted earlier, many participants also had errors on some sounds other than rhotics. Moreover, it is unclear how therapy has influenced the speech production systems of these children, and how it could have influenced performance on the tasks used here.

There is clearly a need for further research concerning the abilities of adolescents with residual speech sound errors on speed and accuracy tasks. It is also critical that we develop a thorough understanding of the longitudinal pathways that result in residual speech sound errors so that preventative measures may be taken at earlier ages, and appropriate interventions can be developed and evaluated. Because RN and DDK tasks were shown here to be useful in identifying children with RE, it will be important to investigate the diagnostic utility of such tasks. That is, can such tasks identify those children who are likely to retain their speech sound errors and/or those who are at risk for other phonologically-based problems such as poor literacy. For instance, future studies should use RN and DDK as potentially predictive measures in younger populations before speech normalization

occurs. Should the RN and DDK measures prove predictive of a speech disordered subtype that is resistant to conventional therapy, this would motivate new clinical research questions.

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Note

1. The /r/ symbol will be used to indicate the American English consonantal rhotic, rather than /ʀ/.

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