The Articulatory Phonetics of /r/ for Residual Speech Errors

Suzanne E. Boyce, Ph.D.[1]

ABSTRACT

Effective treatment for children with residual speech errors (RSEs) requires in-depth knowledge of articulatory phonetics, but this level of detail may not be provided as part of typical clinical coursework. At a time when new imaging technologies such as ultrasound continue to inform our clinical understanding of speech disorders, incorporating contemporary work in the basic articulatory sciences into clinical training becomes especially important. This is particularly the case for the speech sound most likely to persist among children with RSEs–the North American English rhotic sound, /r/. The goal of this article is to review important information about articulatory phonetics as it affects children with RSE who present with /r/ production difficulties. The data presented are largely drawn from ultrasound and magnetic resonance imaging studies. This information will be placed in a clinical context by comparing productions of typical adult speakers to successful versus misarticulated productions of two children with persistent /r/ difficulties.

KEYWORDS: Articulation, speech production, speech sound disorders, tongue configurations

Learning Outcomes: As a result of this activity, the reader will be able to (1) describe the primary, secondary, and tertiary constrictions for the vocal tract for /r/ and describe variation in tongue shapes for /r/ in typical adult speakers, and (2) discuss and critically appraise the differences between error and correct /r/ for children with residual speech errors.

[1]Department of Communication Sciences and Disorders, University of Cincinnati, Cincinnati, Ohio.

Address for correspondence: Suzanne E. Boyce, Ph.D., Department of Communication Sciences and Disorders, University of Cincinnati, French East Building 345b, 3202 Eden Ave, Cincinnati, OH (e-mail: boycese@ucmail.uc.edu).

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Most speech production difficulties in children resolve before the age of 7 years. Accordingly, the vast bulk of therapy for speech sound disorders is aimed at children in this age group. As other articles in this issue make clear, however, there is a group of children whose speech production difficulties persist beyond this age. For purposes of this article, the diagnostic category for these children will be termed *residual speech errors* (RSEs; although see Flipsen in this issue for discussion of persistent vs. residual sub-category distinctions). It is a relatively small group—between 1 and 2% of children.[1] This group, however, is responsible for a significant amount of frustration on the part of clinicians and for a significant secondary market in remediation advice directed to clinicians looking for improved intervention approaches.[2,3] The issue is particularly important because poor phonetic production skills in children with RSEs are associated with reduced phonological processing and reading skills.[4]

Naturally enough, phonetic training in the typical speech-language pathology program tends to concentrate on those aspects of phonetic knowledge most applicable to younger children. However, treating children with RSEs requires deeper knowledge of articulation than is typically provided as part of clinical education. This may be because, unlike children who respond to therapy at earlier ages, children with RSEs have effectively become enmeshed in ineffective articulatory habits that must be "unwound" and rebuilt. Because these habits are deeply ingrained in speech, they must be carefully analyzed from three points of view: (1) phonological, (2) phonetic, and (3) physiologic. The issue of phonetic knowledge is particularly important for clinicians treating RSEs, because the increasing availability of imaging data, and in particular ultrasound imaging, is creating an opportunity for clinical strategies to be refined and refocused.[3,5–8]

Although children with RSEs may present with misarticulations of several different sounds, perhaps the most numerous, and most frustrating, are children with misarticulations involving the English rhotic phoneme /r/.[2] Accordingly, this article will concentrate on the phonetics of /r/. In particular, it will emphasize the acoustic and articulatory role of tongue configurations in the pharyngeal portion of the vocal tract. The initial portion of this article will review linguistic and phonetic background information for this sound, including the use of phonetic symbols. The second portion is devoted to a short review of what is known about the articulation of /r/ in typical adult speakers, along with illustrations from magnetic resonance imaging (MRI) and X-ray. In the final portion, we discuss specific differences between successful and misarticulated productions by two children with a history of RSE for /r/, as shown by MRI data, in the context of ongoing treatment.

LINGUISTIC BACKGROUND

Linguists agree that the rhotic liquid of English is a single phoneme and that certain articulatory movements must occur for a typical acoustic profile and an acceptable percept to occur.[9] In the International Phonetic Alphabet's notation, this sound is represented by /ɹ/, which specifies that the sound is an approximant with a primary constriction at a point along the palate that may range from alveolar to postalveolar to palatovelar. The American phonetic tradition, which is followed by most clinicians, is to use the Roman alphabet symbol /r/. American phoneticians have a strong tradition of distinguishing between cases where /r/ is used as a syllable onset or coda (i.e., a consonant), versus when it is used as a syllabic nucleus (i.e., more like a vowel). One method is to use a single symbol with a syllabic diacritic, /r̩/. An alternate tradition is to use the /ɚ/ and /ɝ/ symbols for unstressed and stressed syllabic nuclei. This usage is historically linked to attempts among phoneticians to document similarities and differences across the different rhotic and nonrhotic, or "r-less," dialects of English but has lingered in descriptions of rhotic dialects as a means of indicating situations where the rhotic liquid acts phonologically as a syllable nucleus.

In general, clinical practice has followed the more common American tradition of multiple symbols for /r/. This preference has gained traction from the convenience of marking a very real clinical phenomenon. Children with RSEs frequently show an asymmetrical pattern of ability to produce positional variants of /r/. In other words, many children with RSEs have difficulty with /r/ in postvocalic position but find syllable-initial position easier. Others have more difficulty with syllable-initial position than postvocalic position.[10] Clinicians have typically responded to this asymmetrical pattern by organizing therapy protocols and strategies according to a "consonantal" versus "vocalic," or "syllable-initial" versus "postvocalic" schema.[11] Notably, however, these clinical schemas differ largely in the determination of which phonetic contexts, words, and larger sequences are most important for stimulation and practice and in methods for encouraging children with an acceptable variant in one position to generalize to the other position. Because the phoneme is the same, the acoustic profile is internally consistent, and the same articulatory movements must occur for the same acoustic profile to be generated; the clinical instructions for shaping vocal tract postures are similar across different positional variants.[11]

Because this article is focused on the basic phonetics, and in particular the articulatory phonetics, of late-acquired sounds, we will emphasize the articulatory sameness of the rhotic phoneme across different syllable positions by using the symbol /r/ rather than the two symbols /r/ and /ɚ/. The symbol is shown with slashes rather than brackets to indicate the status of /r/ as a single phoneme. A full treatment of the phonetics of positional variants of /r/ is beyond the scope of this article.

PHONETIC REASONS FOR RESISTANCE TO THERAPY IN CHILDREN WITH RESIDUAL SPEECH ERRORS

Most clinicians have an arsenal of techniques for teaching sounds to children. These typically focus on the tongue shapes illustrated in textbooks, or on introspective analysis of their own productions. A common approach for teaching /r/, for instance, is to instruct the child to position the tongue dorsum so as to feel the molar teeth.[11–13] Other clinicians may instruct the child to feel the alveolar ridge with the tip of the tongue and then curl the tip of the tongue backward.[11,14] In many cases, however, children with RSE have not responded to these or other standard techniques. Although there are many possibilities for why these children do not respond (e.g., difficulty following instructions, reduced auditory perception, etc.[15]), one major possibility is that the tongue configuration inherent in the instructions does not work for that child's vocal tract. It is therefore essential that clinicians possess articulatory knowledge of /r/ (and other sounds) at a level of detail required to provide articulatory alternatives when particular clinical techniques are not effective.

VARIABILITY OF TONGUE SHAPES

Phonetics textbooks generally describe sounds in terms of their primary "place of articulation." For acoustical purposes, this is better described as "primary place of constriction"—that is, the primary place where the vocal tract airspace is narrowed to produce the desired acoustic result. However, for many sounds the vocal tract airspace is also narrowed in more than one location. These sounds are referred to as "doubly" or even "triply" articulated. The designation of places of articulation as "primary," "secondary," or "tertiary" follows the degree of constriction; the primary place of articulation is the location where the constriction is narrowest. The secondary or tertiary locations are necessary for production of an acceptable acoustic version of the phoneme, but their degree of constriction is either less or more variable across different prosodic or phonetic contexts.[16,17] One example is the vowel /u/. Although /u/ is typically listed as a back vowel, and the raising of the tongue dorsum in the vicinity of the velopalate is considered the primary constriction, a secondary constriction in the form of lip-rounding is generally present as well.[18]

With regard to /r/, introductory phonetics courses may focus on a single place of articulation in the alveolar/postalveolar region. Most textbooks mention two alternative configurations: (1) a "bunched" configuration with the tongue dorsum raised toward the middle portion of the palate and the tongue tip lower than the dorsum, and (2) a "retroflex" configuration with the tongue tip raised toward the front

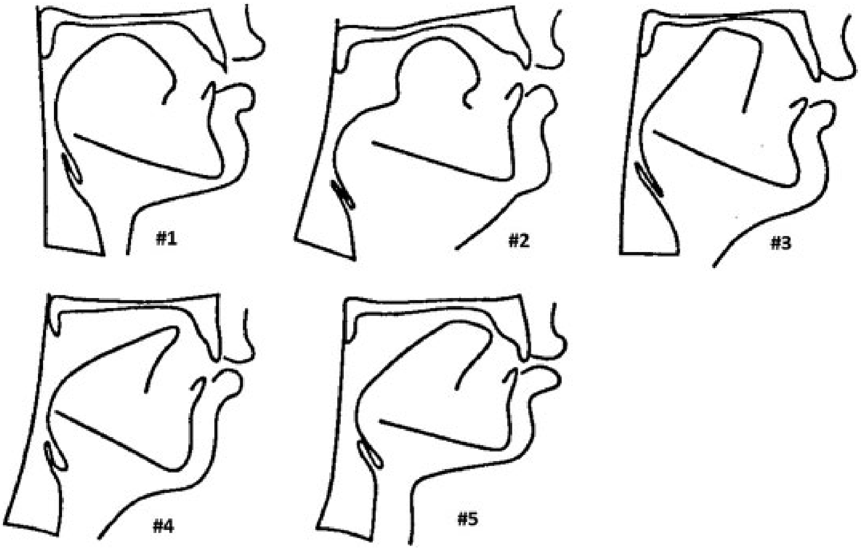

Figure 1 Types of American English tongue configurations for /r/ as identified by Delattre and Freeman from X-ray tracings of 43 subjects.[9] Only types seen in "rhotic" dialects are shown. All types were found in both prevocalic (syllable-onset), syllabic (nucleus), and postvocalic (syllable rime) positions. Tongue configuration types have been renumbered for purposes of this article. Figure adapted with permission from Hagiwara (1995).[44] Types 1 and 4 are examples of configurations typically called bunched (1) and retroflex (4). They correspond roughly to images shown in Fig. 2 for speakers 22 and 5.

portion of the palate and the dorsum lower than the tongue tip. These configurations are illustrated in the stylized X-ray tracings on the left side of Fig. 1.[9,18] However, tongue configurations for /r/ are significantly more variable, spanning a continuum from "bunched" to "retroflex" and including several types with both tongue tip and dorsum raised. This variability is illustrated in Fig. 2, which shows midsagittal MRIs of 22 different typical speakers producing sustained /r/ in the context of the word *pour*. The figure shows 23 images because one individual (speaker 5) was able to produce a perceptually "correct" /r/ using two different tongue configurations. Each speaker's production(s) were judged perceptually "correct" by trained listeners. Because the MRIs of Fig. 2 were obtained from sustained /r/ in the word *pour*, one question that might arise is whether the same tongue configurations also occur in syllable-onset position. In the same study, a parallel set of ultrasound images was collected from each speaker producing words with onset /r/ in the word "role." Each of the tongue shapes shown in Fig. 2 also occurred in syllable-onset position. A similar range of variability across speakers has been noted by other investigators.[9,19–21]

Looking at Fig. 2, several points are apparent. First, the variability across typical speakers suggests that there are several different ways to shape the vocal tract to produce the acoustics of /r/. The different tongue shapes in the figure are arranged roughly according to their similarity to each other and to illustrate the continuum from "bunched" configurations with the tongue dorsum raised and the tongue tip down to "retroflex" configurations with the tongue dorsum lowered and the tongue tip raised, continuing through configurations with both tip and dorsum raised. Although logically a single shape could work for all vocal tracts, the variability we see suggests that some shapes work better with some vocal tracts than others, and different speakers find a shape that works for their individual vocal tract. For instance, although speaker 5 was able to produce a perceptually correct /r/ using both a raised and lowered tongue tip, his natural tongue configuration was that of the classic bunched shape shown in the second column. Significant coaching was required to achieve the tip-up shape illustrated

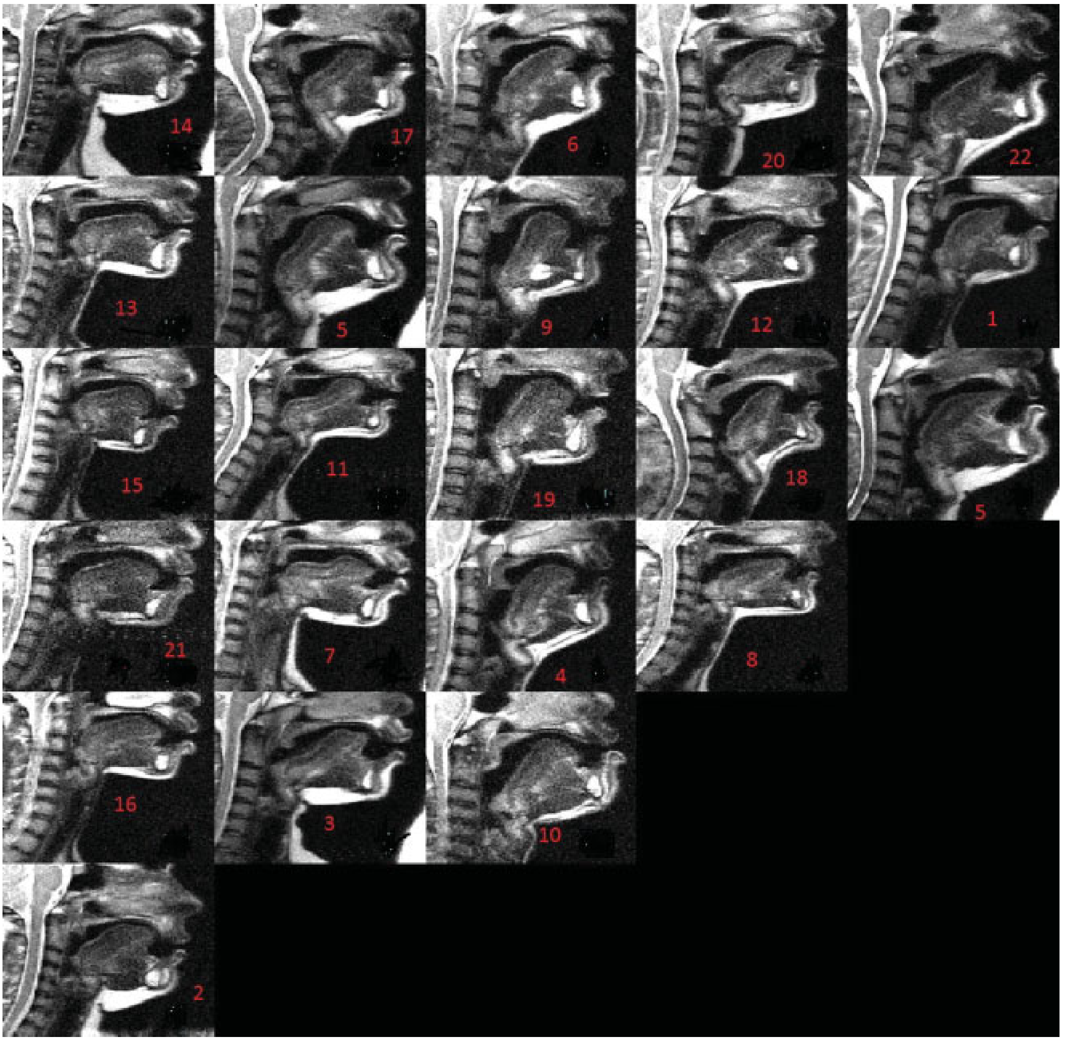

Figure 2 Midsagittal magnetic resonance images of 22 different typical adult native speakers of rhotic dialects of American English, producing sustained /r/ as in the word *pour*. All images are shown in the midsagittal plane facing right. As noted in the text, similar vocal tract shapes have been recorded dynamically from the same set of speakers in prevocalic positions using ultrasound. There are 23 images because speaker 5 was trained to produce a retroflex shape similar to that of no. 4 in Fig. 1, as well as his natural bunched shape, similar to that of no. 1 in Fig. 1. Note that magnetic resonance images reflect the density of hydrogen atoms in tissue versus air. Bone, air, and teeth all appear as dark areas on the image, meaning that it is not possible to separate teeth from air when they are contiguous. Codes identifying each speaker are numerical and appear at the bottom right edge of each image.

in the column on the far right and to sustain it for the 20 seconds required for the MRI scan. From an intervention point of view, this means that teaching a single tongue configuration for /r/ may not prove to be a successful strategy for all vocal tracts.

Second, the different tongue configurations in Fig. 2 show a range of locations for the primary "place of articulation"—that is, the point of greatest vocal tract narrowing along the palate. For some speakers, this point is closer to the alveolar ridge. For other speakers, it is in the velar region, very close to the location of narrowing for the /u/ vowel, the homorganic glide /w/, and velar stops /k/ and /g/. Thus, although many textbooks refer to /r/ as having an alveolar place of articulation, it is more accurate to say that it has a relatively undefined "palatal" or "postalveolar" primary place of articulation. As noted previously, this is in fact the current stance of the international phonetic association for the IPA symbol /ɹ/.[22]

Third, and perhaps most importantly, each of the tongue configurations shown in Fig. 2 illustrates an aspect of /r/ production that has been given relatively little attention in clinical training to date. This is the existence of a secondary place of constriction in the pharynx as an obligatory feature of the /r/ phoneme. The existence of a pharyngeal constriction was noted in Delattre and Freeman's study,[9] but it has not typically been emphasized in textbooks or educational materials directed to clinicians. The mechanism for this pharyngeal narrowing is a movement of the tongue root toward the back pharyngeal wall, independent of the movement of the tongue dorsum or tongue blade/tip toward the palate. (Note that when the tongue root moves backward it can sit flush with the epiglottis, and the narrowest point of the vocal tract in the pharynx may in fact include the projection of the epiglottis into the pharyngeal space.) Separate acoustic investigations have also shown that for attested vocal tract configurations this pharyngeal constriction is a major contributor to the acoustic profile of /r/.[3,23–26] Theoretically, it is possible to produce the characteristic acoustic profile of /r/ using movements of the anterior tongue alone,[26–28] but /r/ productions without a pharyngeal constriction have not been discovered in actual speakers.[23,24,28] The degree of pharyngeal constriction is not the same for all speakers. As noted from X-ray observation,[9] MRI data, and acoustical modeling data,[24] the pharyngeal constriction in American English speakers tends to be narrower for tongue configurations with a raised tongue tip and wider for tongue configurations with a "bunched" configuration and a lowered tongue tip.

ROLE OF TONGUE GROOVE AND SIDES

The coronal (i.e., cross-sectional) profile of the front part of the tongue for /r/ is either relatively flat or shows a mild groove.[11] This profile is illustrated in Fig. 3, which shows coronal MRIs of the tongue blade during /r/ from two typical adult speakers, along with midsagittal images showing the location of these slices along the vocal tract.

It is important to note that for /r/, the midsagittal groove continues along the length of the tongue through the tongue dorsum and root. Furthermore, if the tongue dorsum, the tongue blade, or both are lifted toward the palate while the tongue root is retracted toward the back pharyngeal wall, the midsagittal shape of the tongue along the groove will often show a dip or dimple at the point of separation between the tongue dorsum and tongue root. This dip between the tongue dorsum and root is particularly noticeable for productions in the second column from the left of Fig. 2 (speakers 3, 7, 11, 5, and 17). This aspect of the tongue configuration is important for understanding images of the tongue, because different impressions of tongue configuration can be gained depending on whether the image is derived from a slice along the midline groove, along one or the other side of the tongue, or some combination. Thus, imaging modalities such as ultrasound and MRI, which effectively slice the vocal tract into sections, will show a different view of the sagittal tongue shape depending on the thickness of the slices, and for narrow slices, whether they are imaging the tongue down the middle or along the sides.

This issue is illustrated best by modern X-ray imaging technology using a radiographically opaque medium such as barium to outline the tongue groove. An example is shown in Fig. 4, which depicts the tongue outline during a production of *year* in the sentence "Where were you a year ago?" The speaker was an elderly man with normal speech who was imaged during a routine clinical swallowing evaluation.[29] His production of /r/ in *year* was typical for speakers of a rhotic dialect of North American English. In this figure, the left-hand panel shows the original image. The tongue sides are visible against the airspace of the vocal tract, and the shape of the groove through the tongue midline is shown by the darker line where barium pooled and clung. The right-hand panel shows a hand-drawn outline of the different contours of the tongue sides and groove, along with anatomical landmarks.

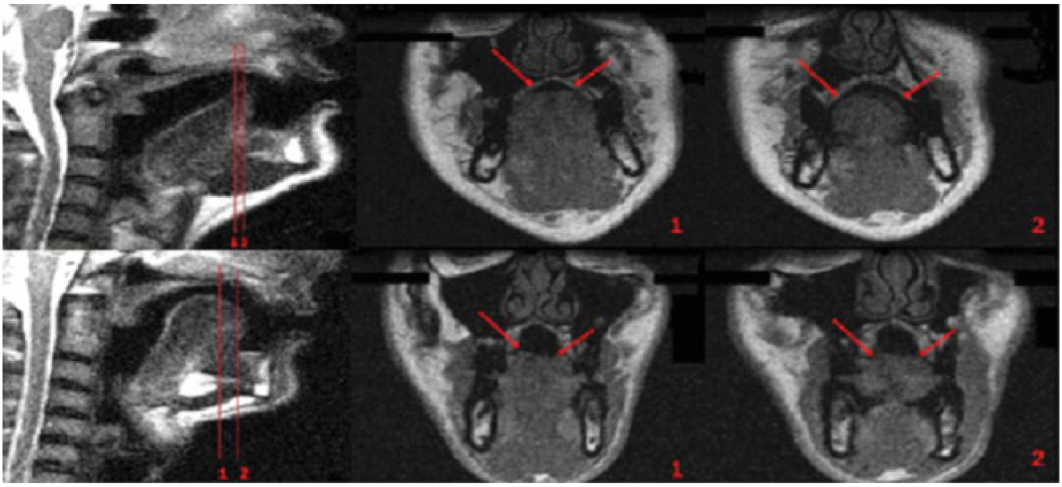

Figure 3 Corresponding midsagittal (left) and coronal (middle and right) plane images of speakers 22 and 5 from Fig. 2. Red lines labeled 1 and 2 on the midsagittal image indicate the location of the coronal slice. The lateral edges of the tongue at this point along the vocal tract are shown by red arrows on the coronal slice images. As with Fig. 2, both air and teeth are shown as dark spaces and tissue is shown as gray or white depending on hydrogen atom density. The palate is shown as a bony ridge above the tongue.

Note that the shape of the groove includes a dip between the tongue dorsum and the tongue root, similar to that shown by speakers 3, 7, 11, 5, and 17 in Fig. 2. The shape of the tongue configuration along the sides shows the tongue tip lower than the tongue dorsum. The point of greatest constriction is in the vicinity of the midpalate. The shape of the palate is cut off in the image at its highest point, but the shape of the tongue itself is clear.

It is important to note that because all of the 23 images of Fig. 2 were made along a midsagittal plane, they represent the midline portion of the tongue and thus are a reasonable guide to the shape of the groove from tongue front to tongue root. At the same time, an observer looking only at a midsagittal image may underestimate the degree to which the sides of the tongue projects into the pharyngeal airspace and may thus underestimate the degree

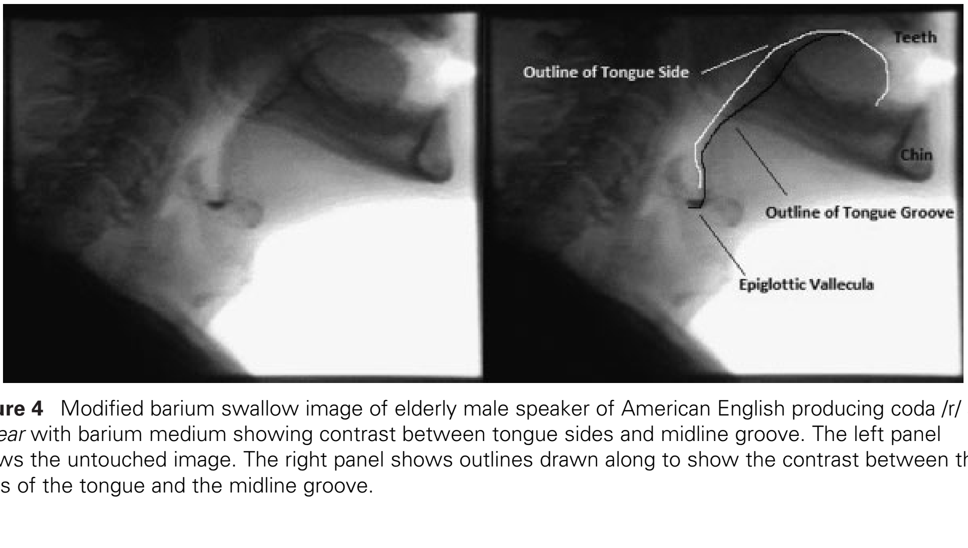

Figure 4 Modified barium swallow image of elderly male speaker of American English producing coda /r/ as in *year* with barium medium showing contrast between tongue sides and midline groove. The left panel shows the untouched image. The right panel shows outlines drawn along to show the contrast between the sides of the tongue and the midline groove.

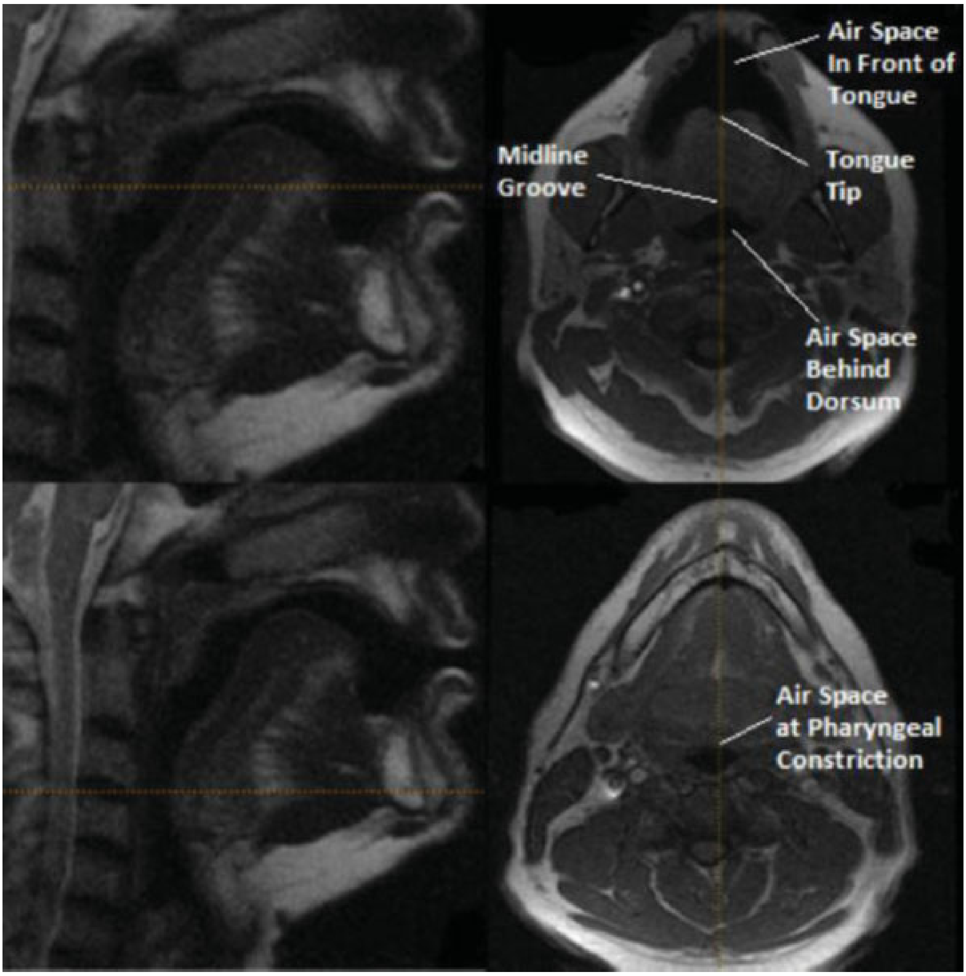

Figure 5 Corresponding magnetic resonance imaging in midsagittal and axial (horizontal) planes from typical adult speaker 5 of Fig. 2 at level of tongue tip (left) and level of narrowest constriction between tongue root and back wall of pharynx (right). Note that a section of the velum hanging in the airspace behind the tongue dorsum can be seen as a bar of flesh bracketed by dark areas before and behind.

of pharyngeal narrowing. This point is illustrated in Fig. 5, which shows two horizontal (axial) slices through the vocal tract (right-hand panels) along with the locations of these slices in the midsagittal plane (left-hand panels) for speaker 5. The two axial slices show the midline tongue groove at the level of the tongue tip and at the narrowest portion of the pharynx.

CLINICAL RELEVANCE OF PHARYNGEAL CONSTRICTION AND TONGUE GROOVE

Clinicians can use knowledge of these aspects of typical production to evaluate their favorite strategies for eliciting /r/, or to devise new strategies. To take an example, a well-known strategy for eliciting /r/ is to instruct a child to "make a boat shape with the tongue."[30] This instruction may encourage the child to form a groove along the midline of the tongue dorsum and root, while maintaining a constriction along the palate. Because forming a groove requires depression of the tongue along the midline, the effect may be to move the tongue root toward the back pharyngeal wall, producing a pharyngeal constriction.

Some instructors or clinical resources might suggest that /r/ has an alveolar constriction alone, and that children with /r/ misarticulations should be discouraged from making a constriction at the lips. In our clinic, it is common to find that children with RSEs have been instructed to spread or pull back their lips when attempting to produce /r/. This admonition probably stems from the fact that many /r/ misarticulations sound like /w/ or /u/, which have relatively extreme and visible lip constrictions involving protrusion as well as narrowing. However, typical adult /r/ also involves a narrowing of the vocal tract at the lips. The lip movement involved is mild compared with constrictions common to sounds such as /u/ and /w/, and it is typically more extreme in syllable-initial position.[9,31–33] Acoustically and perceptually, however, lip constriction is the least relevant contributor to a correct /r/. In other words, if the tongue configuration is appropriate for /r/, adding a lip constriction may affect its naturalness but not its phonemic identity. Conversely, if the tongue configuration is not appropriate, changing the lip constriction cannot substantially improve it.[23,24]

Although some textbooks suggest that the retroflex tongue configuration with tongue tip raised and dorsum lowered (shown for speakers 5, 1, and 22 in Fig. 3) is the most prevalent version of /r/, larger studies have found this to be the rarest type.[9,20,21] Speakers who use this extreme retroflex configuration tend to use it only in syllable-initial position, and many speakers switch to a more bunched configuration depending on phonetic context.[9] Similarly, in a study of 27 adults using ultrasound imaging, Mielke and colleagues found that a significant fraction of adult typical speakers switch configurations across contexts.[20] These facts are very relevant to intervention. It is likely that retroflex tongue positions are more rarely used as a speaker's natural /r/ and/or are more likely to be switched out, because the anatomy that favors them is rarer. Possibly, coarticulation with other sounds and/or prosodic conditions is more difficult. As indicated above, it is likely that children with RSEs need explicit instruction and target structuring to generalize newly learned articulatory strategies across different syllables, words, and sentences. Thus, even if a child is successful at producing /r/ with a retroflex tongue configuration in some contexts, they may not be able to use it in all contexts. If progress in therapy has ground to a halt, it may be helpful to teach a different tongue configuration and to explore its use across contexts.

One question that arises is whether the most appropriate /r/ tongue shape for a particular child can be predicted from anatomy. If so, clinicians might be able to predict the most appropriate tongue configuration for /r/ from observations gained in an oral mechanism examination. There is strong evidence that vowel articulation is influenced by palate shape and by pharyngeal cavity space.[34,35] Although these findings apply to vowels rather than /r/ specifically, they do suggest that, for any one speaker, anatomical influences such as palate shape, pharyngeal space, and oral cavity length limit the range of tongue configurations that will produce a "correct" /r/. On the other hand, Westbury and colleagues did not find a correlation between palate length and /r/ configuration types.[19,36] It is clear that many vocal tracts are broadly compatible with both shapes, because many typical speakers use different tongue configurations across different phonetic and prosodic contexts,[20,37,38] and some vary tongue shape in response to a palatal prosthesis.[39] Furthermore, the typical oral mechanism evaluation does not include an analysis of oral cavity length or pharyngeal area. More research is needed to provide clinical guidance of this nature. Given the degree of variability in typical adult speakers, it should not be assumed that the tongue configuration that will work best for a particular child can be determined a priori. Instead, a child's most workable tongue configuration should be determined by trial and error.[10]

PHONETICS OF MISARTICULATIONS IN CHILDREN WITH RESIDUAL SPEECH ERRORS

The preceding sections of this article dealt with typical adult patterns of producing /r/. In the following sections, we will discuss three types of commonly found patterns of misarticulation. These error productions will be contrasted with typical child and adult productions of related sounds. The data will be drawn from an MRI

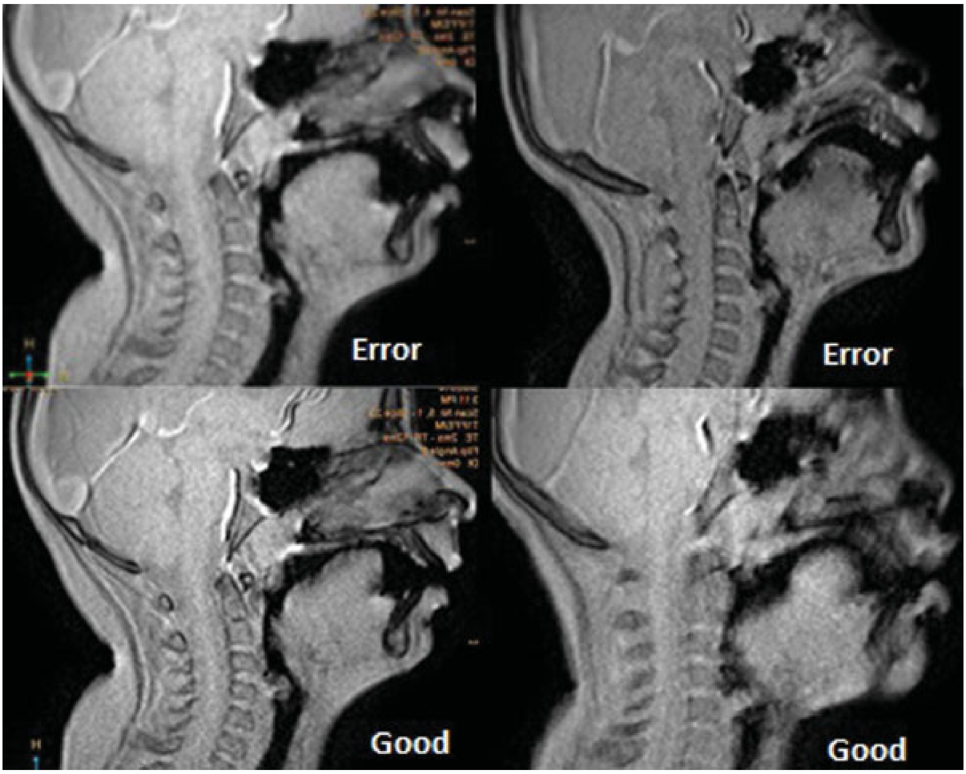

Figure 6 Magnetic resonance imaging of two children in therapy for residual speech errors. Child speaker 1 (age 10;5) is shown on the left and child speaker 2 (age 9;0 years) is shown on the right. Sustained misarticulated versions of /r/ are shown above versions judged to be "good."

study of children with RSEs between 8;2 to 11;10 (years; months) of age. Each child produced /r/ in a target word and sustained that production for 8 seconds. Children with an RSE diagnosis were imaged producing both a typical misarticulated version of /r/ and their "best" /r/. This was accomplished by asking children to identify words they had trouble with in terms of /r/ articulation and words they were most successful with. They were instructed to start to say the word in question and then to sustain the /r/. Children were familiarized with the task in a training session using ultrasound before they undertook the MRI session. During the MRI session itself, if movement artifacts in the image were identified, the production trial for that sound was repeated. Images with significant movement artifacts were discarded. To ensure that the children's misarticulated and correct productions in MRI sessions were typical of their utterances under more normal circumstances, the midsagittal MRIs were compared with midsagittal ultrasound images collected during the children's productions of the same target words during therapy sessions. A trained clinician with experience of the children's performance during therapy was also present for the MRI sessions and determined that the children's productions were impressionistically similar to their misarticulated and corrected productions in therapy sessions. Note that this could be done for the MRI sessions only at the very beginning of the 8-second sustained interval, because the onset of noise from the magnet masked the subsequent sound from the child. Fig. 6 shows examples from two children who each produced a clearly misarticulated and an acceptably "correct" version of /r/ . The misarticulated version is labeled "error" and the more acceptable version "good."

Child speaker 1 originally came to the clinic for ultrasound therapy after many years of conventional therapy in his school setting. He was unable to produce an acceptable /r/ in any context. In word-initial and cluster contexts, his productions were transcribed as /w/ but were sometimes heard as /l/. In all other contexts, his productions were typically transcribed as sounding like /ʊ/. He had been instructed to use an exaggerated retroflex tongue configuration but more frequently used a tongue configuration with a high, humped dorsum and a lowered tongue tip with no sign of a separate tongue root movement toward the back pharyngeal wall. Therapy focused on suppressing the exaggerated retroflex tongue configuration and on finding an alternative configuration for the tongue blade/tip or dorsum that he could combine with tongue root movement in a backward direction. After four sessions of therapy with ultrasound, he could produce a good /r/ in most words if prompted to remember his best tongue shape. During good tokens of /r/, he showed consistent tongue root retraction. His incorrect /r/ productions showed inconsistent tongue root retraction, along with inconsistent control of the sides of the tongue. The MRI session was held during this phase in his treatment.

The tongue shapes shown in Fig. 6 for child speaker 1 (left side) are representative of the tongue configurations he showed with ultrasound in therapy. The error versus good /r/ tongue configurations are clearly different in both overall shape and in the location of vocal tract constrictions. For both, the primary constriction is made by the tongue blade in the vicinity of the alveolar ridge. For both, there is an apparent secondary constriction in the region of the pharynx. For the error /r/, however, the tongue tip is lower and the entire front of the tongue, including the tongue blade and tip, is more retracted. In contrast, for the good /r/, the tongue tip is raised to be closer to the alveolar ridge itself, and the entire blade/tip complex is stretched to be more forward in the mouth. This causes the primary constriction itself to extend for a longer distance, to encompass a more forward location, and to be notably narrower along its length. Although it is hard to see from this midsagittal view, the retraction of the tongue root is more pronounced in the good /r/. Perhaps the most notable aspect of the good /r/ tongue configuration is the suggestion of a dip in the midline groove between the tongue front and tongue root. This dip is not present in the error /r/ tongue configuration.

It is also worth pointing out that although this child's error tongue shape resembles that of many adult typical speakers shown in Fig. 2 (e.g., speaker 5), the similarity breaks down when the total shape of the vocal tract is taken into account. Relative to the adult vocal tract shape, the child error production shows a palatal constriction that is slightly further back. Furthermore, his error production featured a reduced pharyngeal constriction. The child's good /r/ more closely resembles the typical adult vocal tract configurations shown in the two left-most columns of Fig. 2, both in terms of constriction location and degree.

Although the good /r/ configuration was elicited for this child using ultrasound biofeedback, similar results may be obtained with clinical strategies that encourage separation of these two parts of the tongue, or enhancement of the midline groove. An example of the former is the instruction "Say 'ah' and raise the tip of your tongue without moving the rest of your tongue." This works because the vowel /ɑ/ involves pharyngeal constriction. An example of the latter is the previously mentioned "Make a boat with your tongue" instruction.[11,30]

Child speaker 2 also came to the clinic for ultrasound therapy after many years of conventional therapy, and he was originally unable to produce an acceptable /r/ in any context. In word-initial and cluster contexts, his productions were transcribed as sounding like /w/, but in other contexts they were transcribed as sounding like /ɔ/. The evaluating clinician also noticed that his /r/ sounds were accompanied by what she called "gurgling." This clinical observation is commonly noted when native English speaking clinicians hear something like a uvular fricative or trill. Sounds with a uvular place of articulation are common in languages such as French and German. The place of articulation for such sounds is the upper pharynx.[40]

When he came to the clinic, this child used a tongue configuration with the tongue tip raised and curled back in an exaggeratedly retroflex posture. Although encouraging a tongue curl posture is a popular remediation strategy, the posture itself has not been observed in typical speakers of American English.[9,11,37] There was no sign of a separate tongue root movement toward the back pharyngeal wall. Because the child had not succeeded in generalizing correct /r/ to a variety of phonetic contexts, therapy focused on experimentation with different tongue shapes that allowed him to maintain a constriction along the palate along with simultaneous tongue root retraction. This was done using ultrasound and the MRIs seen in Fig. 2 as a guide for reference. This child's error /r/ and good /r/ tongue configurations are shown on the right side of Fig. 6. The MRI session was held during a phase in his treatment where he managed to separate the tongue front from the tongue root movement, but still inconsistently produced a "gurgling" sound when his palatal constriction was too far back. They are representative of his ultrasound tongue configurations during therapy.

Unlike child speaker 1, the general tongue shapes for child speaker 2 are similar for both error and good /r/ sounds. Both show a clear dip in the midline groove and resemble tongue shapes shown in Fig. 3 for adult typical speakers. Both show pharyngeal constriction by the tongue root, as well as palatal constriction with a raised tongue blade and a lowered tongue tip. For his error /r/ sounds, however, this child has positioned his tongue front and tongue root constrictions in the wrong part of the vocal tract. In particular, the location of the palatal constriction is too far back along the palate, and there is too much air in the front cavity under the alveolar ridge. Furthermore, the pharyngeal constriction appears to be too narrow. This vocal tract configuration used by child speaker 2 for /r/ is similar to that described for uvular trills in languages that use them.[41] It is likely that the impression of "gurgling" derives from the child's attempt to move the entire tongue backward rather than to separate movements of the tongue front and tongue root, causing the aerodynamic conditions compatible with trill or fricative vibration in the upper pharynx.

The good /r/ production corrects this problem by moving the front of the tongue (i.e., the blade/tip) forward along the alveolar ridge so that the narrowest part is directly below the highest portion of the palate. Note that in the good /r/, the tongue root remains very close to the back wall of the pharynx, meaning that the two parts of the tongue are stretched away from one another. Because the good /r/ does not include any gurgling or frication noise, we can conclude that the constriction is wide enough to eliminate aerodynamic conditions for a fricative or trill.

In our clinic, access to the MRI for this child was extremely helpful in explaining why his progress in therapy had halted. From an ultrasound image, it is not possible to determine exactly where the parts of the tongue are with respect to other structures of the vocal tract that are not imaged, such as the palate or the pharyngeal walls. In the case of child speaker 2, both his error and his good /r/ productions showed what looked like the same tongue shape on the ultrasound screen. The MRIs, however, showed that he needed to increase the distance between his tongue root and tongue front, stretch the front part of the tongue further forward along the palate, and pull the tongue root slightly away from the pharyngeal wall. This observation suggests that a child who presents with a "gurgling" or uvular-sound error productions may be showing the maladaptive behavior of moving the tongue backward as a single unit.

SUMMARY AND CONCLUSIONS

Remediation for children with RSEs requires the development of new articulatory habits and the development of new interactions between the phonetic and phonological components involved in speech. Careful consideration of imaging and other phonetic data from typical speakers can elucidate the maladaptive behaviors behind misarticulations and suggest alternative intervention strategies. For instance, data from multiple sources indicate that accurate production of /r/ requires a tongue root movement toward the back pharyngeal wall along with a movement of the tongue front (i.e., either blade/tip or dorsum/blade) toward the palate. Although they showed different types of misarticulations, in both child speakers investigated in this study, improvement in /r/ production was accompanied by clear separation of the tongue front and tongue root. Typical speakers use several different tongue configurations to produce /r/, and many speakers switch back and forth between tongue configurations according to different prosodic and/or phonetic contexts.[3,7,42,43] Incorporation of this knowledge, as well as additional knowledge derived from articulatory imaging techniques, could prove highly beneficial to clinicians treating children with RSE.

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