LSHSS

Tutorial

Tutorial: Motor-Based Treatment Strategies for /r/ Distortions

Jonathan L. Preston,[a] Nina R. Benway,[a] Megan C. Leece,[a] Elaine R. Hitchcock,[b] and Tara McAllister[c]

Purpose: This tutorial summarizes current best practices in treating American English /r/ distortions in children with residual speech errors.
Method: To enhance the effectiveness of clinicians' cueing and feedback, the phonetics of /r/ production is reviewed. Principles of acquisition, which can inform how to practice /r/ in the early stages of therapy, are explained. Elements of therapy that lack scientific support are also mentioned.
Results: Although there is significant variability in /r/ production, the common articulatory requirements include an oral constriction, a pharyngeal constriction, tongue body lowering, lateral bracing, and slight lip rounding. Examples of phonetic cues and shaping strategies are provided to help clinicians elicit these movements to evoke correct /r/ productions. Principles of acquisition (e.g., blocked practice, frequent knowledge of performance feedback) are reviewed to help clinicians structure the earliest stages of treatment to establish /r/. Examples of approaches that currently lack scientific support include nonspeech oral motor exercises, tactile cues along the mylohyoid muscle, and heterogeneous groupings in group therapy.
Conclusion: Treatment strategies informed by phonetic science and motor learning theory can be implemented by all clinicians to enhance acquisition of /r/ for children with residual errors.
Supplemental Material: https://doi.org/10.23641/asha.12771329

For some children with speech sound disorders, distortions of American English /r/[1] can be difficult to correct and may persist for years (Flipsen, 2015). A number of child and clinician factors may play a role in treatment outcomes for these residual speech errors (e.g., Kwiatkowski & Shriberg, 1998); however, implementing scientifically informed cueing and practice strategies for /r/ may help remediate these errors during therapy. A host of research has used instrumental approaches to elucidate the complex articulatory actions of correct and misarticulated /r/ through technologies such as ultrasound imaging of the tongue (e.g., Klein et al., 2013; Modha et al., 2008; Preston, McAllister Byun, et al., 2017), cineradiography (Delattre & Freeman, 1968), electropalatography (EPG; Hitchcock et al., 2017; Schmidt, 2007), magnetic resonance imaging (MRI; Boyce, 2015; Tiede et al., 2004), and electromagnetic articulography (van Lieshout et al., 2008). Although those technologies are not readily available to all clinicians, the information gained from these and other sources contributes to a deeper understanding of the articulatory actions required for /r/, which can in turn inform clinicians' phonetic cues and elicitation strategies. Furthermore, appropriately structured practice and detailed feedback may help stabilize /r/ production. In this tutorial, therefore, we focus on scientifically rooted strategies that all clinicians can implement to enhance their therapy without the aid of technology.

We begin with a review of the clinical need to address /r/ errors, followed by an explanation of the articulatory features of correct /r/ production. Next, we translate this information to specific cueing strategies derived from clinical and phonetic research on /r/ production. We then discuss the importance of pre-practice and acquisition training in the early stages of treatment, broadly derived from schema-based models of motor learning (Maas et al., 2008) to guide clinicians in establishing correct /r/. The focus of this tutorial

[a]Department of Communication Sciences & Disorders, Syracuse University, NY
[b]Department of Communication Sciences and Disorders, Montclair State University, NJ
[c]Department of Communicative Sciences and Disorders, New York University, NY
Correspondence to Jonathan L. Preston: jopresto@syr.edu

Editor-in-Chief: Holly L. Storkel
Received January 30, 2020
Revision received June 16, 2020
Accepted June 16, 2020
https://doi.org/10.1044/2020_LSHSS-20-00012

[1]Although the American English rhotic is most accurately represented with the symbols /ɹ/, /ɝ/, and /ɚ/ for different allophonic variants, we follow the clinically common convention of using /r/ to represent the various allophones.

Disclosure: *The authors have declared that no competing interests existed at the time of publication.*

is on the stages of treatment that are intended to elicit perceptually correct productions of /r/ and establish successful productions at simple levels of linguistic complexity (i.e., syllables and words) with clinician support prior to a focus on generalization and retention. Therefore, the target clinical population we address includes children who produce distortions and who evidence little or no stimulability for /r/,[2] not children who are unable to generalize an established rhotic production, which would require a different emphasis in treatment (Hitchcock & McAllister Byun, 2015; Maas et al., 2008; Preston, Leece, & Storto, 2019). We have studied the strategies described in this tutorial with children aged 6 years through adults who have typical receptive language skills, although modifications or simplifications of the strategies may be applicable at younger ages or with clients with additional impairments.

The Need to Address /r/ Production

Residual speech errors persist into adolescence or adulthood in about 1%–2% of the population (Culton, 1986; Flipsen, 2015), and more than half of individuals with residual errors have /r/ distortions (Lewis et al., 2015; Shriberg, 2009). Furthermore, about 25% of children with a history of speech delay as preschoolers continue to have /r/ distortions at 9–12 years of age (Shriberg, 2009).

The rhotic liquid /r/ is one of the most common phonemes in American English (e.g., Mines et al., 1978), and therefore, a distortion of the sound can have a significant impact on the intelligibility and naturalness of speech production (Cronin et al., 2014; Silverman & Paulus, 1989). Across English dialects, /r/ can be present in prevocalic position as a singleton (e.g., "red") or in a consonant cluster (e.g., "tree"). Furthermore, in American English, the rhotic can act as the nucleus of a stressed syllable (/ɝ/, e.g., "earth") or an unstressed syllable (/ɚ/, e.g., "father"). Finally, /r/ can occur in postvocalic position following a vowel (e.g., "ear," "air"). Although the duration and timing of articulatory movements may differ among these variants (Campbell et al., 2010; Gick & Campbell, 2003), the articulatory/gestural targets are very similar (Zhou et al., 2008), and therefore, the cueing strategies to evoke correct production will be similar.

There is clear evidence that errors in /r/ production can result in negative social and emotional consequences, including negative peer perceptions and bullying (Hitchcock et al., 2015; Silverman & Paulus, 1989). The naturalness of the speech of children with /r/ errors may be impacted, and peers may perceive children's speech as "disfluent" or "unpleasant" (Silverman & Paulus, 1989). Participation in curricular and cocurricular activities (e.g., theater, debate clubs) may also be limited by /r/ distortions. As adults, there can be negative, long-term educational and employment consequences as well (Felsenfeld et al., 1994). As described elsewhere, clinicians should be mindful that children with single sound errors such as /r/ distortions *can* be eligible for speech-language therapy services in schools in the United States, as eligibility need not rely on low academic performance (Dublinske, 2002; Farquharson, 2019; Hitchcock et al., 2015; Whitmire, 2007).

Typical /r/ Production Versus Common Distortions

To understand the articulatory features of /r/, it may be beneficial for clinicians to have a detailed understanding of the anatomy of the tongue and its functionally distinct parts, as summarized in the four examples of correct /r/ productions in Figure 1. The tip is the anteriormost part of the tongue. Behind the tip is the blade. Posterior to the blade is the body (dorsum),[3] which is the largest portion of the tongue. The posteriormost aspect of the tongue, which is in the pharynx, is the root. Unfortunately, there are no clear anatomical landmarks distinguishing these parts of the tongue, and they are described primarily by their functional movement. Therefore, the labels in Figure 1 are approximated. In addition to the distinctions in the front-to-back dimension, it should be noted that the sides of the tongue should be differentiated from the midline of the tongue (particularly along the tongue body) because the sides are often raised while the midline is lowered for /r/. Referring to the tongue tip, blade, body, root, and sides may increase the specificity of cues, as described below.

Cueing correct /r/ production typically involves contrasting articulatory movements for distorted /r/ with movements associated with correct /r/. Therefore, we begin with a review of the primary articulatory requirements of /r/. Although Gick and Campbell (2003) define three vocal tract constrictions for /r/, we find it more clinically useful to characterize /r/ in terms of five (not entirely independent) elements, as these five elements align well with the cues that clinicians may provide to elicit /r/: (a) an oral constriction that requires some portion of approximately the front half of the tongue raised, (b) a pharyngeal constriction that requires the tongue root to retract, (c) lowering of the midline of the posterior tongue body, (d) contact of the sides of the tongue body against the back teeth or gums, and (e) slight lip rounding. Importantly, tongue and lip positions for correct /r/ can be highly variable from speaker to speaker and even across phonetic contexts within a speaker (Delattre & Freeman, 1968; Guenther et al., 1999; Mielke et al., 2016). Therefore, the relative emphasis placed on any of these five elements during treatment is likely child dependent, and exact cues will vary with each child.

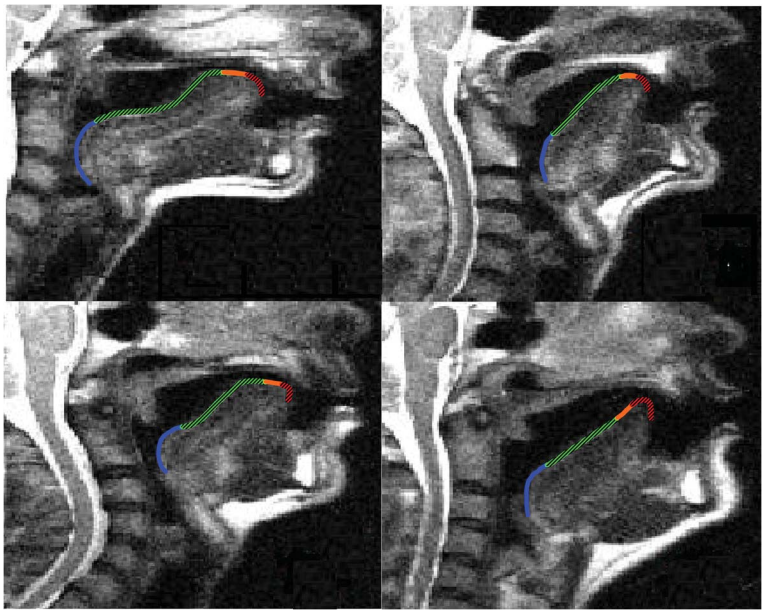
Oral Constriction

With respect to the first element, the oral constriction, all correct /r/ productions include some form of narrowing

[2]Note that children who are stimulable and who produce phonemic substitutions, such as /w/ for /r/, would likely be candidates for other approaches, such as minimal pairs therapy.

[3]Although the term *tongue dorsum* is common in the literature, we instead use the term *tongue body*, as it is likely more familiar to speech-language clinicians and it is a term that might be easier to teach children.

Figure 1. Midsagittal magnetic resonance images of correct /r/ from four adult speakers. Tongue contour markings were added to highlight the different aspects of the tongue, which may be referenced when cueing /r/. The tongue tip is in red, with striations. The blade is in orange. The body is in green, with striations. The root is in blue. The two images on the left represent "bunched" tongue shapes, whereas the two images on the right represent more "retroflex" tongue shapes. Magnetic resonance images are from Boyce (2015), reprinted with permission. © Georg Thieme Verlag KG.



in the oral cavity in the palatal or palato-alveolar region. All of the images of correct /r/ in Figure 1 show the tongue tip, blade, or anterior tongue body raised toward the palate. However, there is substantial variation, both across and within individuals, in the tongue shape used to achieve a narrowing in the oral cavity. There are two commonly described tongue shapes that can result in correct productions. The "retroflex /r/" shape involves the tongue tip pointing up toward the hard palate or alveolar ridge (see images on the right side of Figure 1). The "bunched /r/" shape involves the anterior tongue body raised toward the palate with the tongue tip pointed forward or angled down in front of the lower incisors (see images on the left side of Figure 1). Bunched /r/ is more common than retroflex /r/ among speakers of American English (Delattre & Freeman, 1968; Mielke et al., 2016). However, there are numerous tongue shapes that can result in acoustically and perceptually "correct" productions, some of which are neither classically "retroflexed" nor "bunched" but all of which include the tongue tip, blade, or anterior body raised toward (but not touching) the hard palate or alveolar ridge (Boyce, 2015; Espy-Wilson et al., 2000; Tiede et al., 2004). In contrast, distorted productions of /r/ may lack elevation of the front of the tongue (Gick et al., 2007; Klein et al., 2013; Preston, McAllister Byun, et al., 2017). It is important to note that elevation of the front of the tongue does not in itself guarantee perceptually accurate /r/, because the of the constriction along the palatal region is not appropriate for the child's vocal tract size/shape (Boyce, 2015; see also Figure 2, top-right panel) and/or because some of the other four elements of /r/ articulation are incorrect.

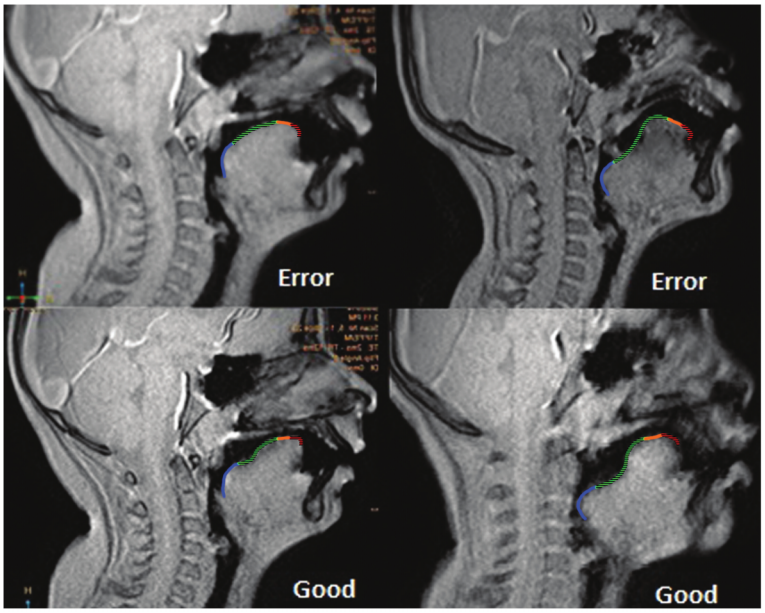
Tongue Root Retraction

The second articulatory element of correct /r/, tongue root retraction, requires posterior movement of the tongue root toward the back wall of the pharynx. Although there is significant variability in the tongue shape used to achieve the oral constriction, there is relative less variability from speaker to speaker in the posterior tongue movement to achieve the pharyngeal constriction (Alwan et al., 1997; Delattre & Freeman, 1968). Tongue root retraction can be evident in images of the tongue as a slope or an angle toward a "bump" in the tongue root that retracts toward the pharyngeal wall (see Figure 1). Failure to achieve this tongue root retraction can result in a distorted production of /r/ (Boyce, 2015; Klein et al., 2013; Preston, McAllister Byun, et al., 2017). Imaging of such distortions reveals a more vertical orientation of the tongue root, as seen in the top-left panel of Figure 2, contrasted against a correct production of /r/ from the same child in the bottom-left panel (Boyce, 2015).

Lowering of the Posterior Tongue Body

The third element, lowering of the midline of the posterior tongue body (dorsum), is perhaps not its own unique characteristic of correct /r/ but is a consequence of a proper oral and pharyngeal constriction (Elements 1 and 2). That

Figure 2. Midsagittal magnetic resonance images of distorted /r/ (top) and correct /r/ (bottom) from two children before and after speech therapy. Tongue contour markings were added to highlight the different aspects of the tongue, which may be referenced when cueing /r/. The tongue tip is in red, with striations. The blade is in orange. The body is in green, with striations. The root is in blue. Magnetic resonance images are from Boyce (2015), reprinted with permission. © Georg Thieme Verlag KG.

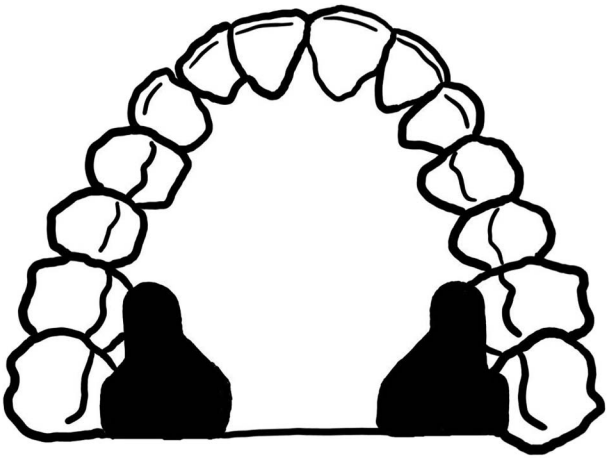


is, as seen in Figure 1, the posterior tongue body should be lowered behind the oral constriction, resulting in evidence of a slant or slope along the tongue from the anterior oral constriction to the posterior tongue root retraction (Gick & Campbell, 2003). Stated differently, the midline of the posterior tongue body ("back of the tongue") should *not* be raised toward the velum but, instead, should be lowered toward the pharynx; this creates a relatively large space for acoustic resonance between oral and pharyngeal constrictions (Espy-Wilson et al., 2000; Zhou et al., 2008). In contrast, many children with /r/ distortions raise the posterior tongue body toward the soft palate (Adler-Bock et al., 2007; Klein et al., 2013; Preston, McAllister Byun, et al., 2017; van Lieshout et al., 2008). Speakers whose productions of /r/ involve an excessively high tongue body have been described as exhibiting a merger of the oral and pharyngeal constrictions, resulting in one single (velar) constriction (Gick et al., 2007).

Lateral Bracing

The fourth element for /r/ production, lateral bracing, is achieved with contact of the lateral margins of the tongue body against the gums or molars (Alwan et al., 1997; McLeod & Singh, 2009; Schmidt, 2007). Figure 3 shows where the sides of the tongue typically make contact for /r/. This action is important for tongue stability in many lingual sounds including /r/ (Gick et al., 2017). Whereas the sides the tongue body are raised, the center of the tongue body must be lowered (see Element 3), resulting in a concave shape or "pitlike cavity" behind the oral constriction (Alwan et al., 1997). Thus, a cross-sectional view of the tongue body reveals a central groove with raised sides, creating a U-like shape. Lateral bracing is typically the only tactile feedback that is available during correct /r/ production (and can therefore be highlighted when cueing /r/). However, it has been speculated that lateral bracing may not be obligatory for all correct /r/ productions, and therefore, the amount of lateral contact might vary from child to child (Hitchcock et al., 2017).

Figure 3. Image of the palate and upper dentition showing regions of lateral tongue contact of the tongue during typical /r/ production (black filled regions near molars) modeled after electropalatography images.



Lip Position

The fifth element, slight lip rounding, is present in many correct /r/ productions (Delattre & Freeman, 1968; Espy-Wilson et al., 2000; Gick & Campbell, 2003). However, lip rounding may be quite minimal for some speakers, particularly in syllable-final position (e.g., "car"; Campbell et al., 2010; Gick & Campbell, 2003). Excessive lip rounding is present in some perceptually inaccurate /r/ productions, which may be described as substitutions of [w] or the labiodental glide [ʋ]. On the other hand, correct /r/ can be produced with extensive lip rounding in certain coarticulatory contexts, such as before a rounded vowel in words like "rude" /rud/. This suggests that excessive lip rounding only results in perceptually inaccurate /r/ when it occurs in conjunction with tongue positioning errors. In total, lip position appears to play a relatively small role in distorted /r/ for many children, and solely cueing lip position is unlikely to impact the perceived accuracy of the /r/ sound if there are incorrect oral and pharyngeal constrictions.

It may be noted that our focus has primarily emphasized articulatory actions of the tongue and, secondarily, the lips. This is not to imply that other articulators are unnecessary for /r/ production. For example, appropriate jaw opening is needed, and either an overly clenched jaw or an excessively open jaw position can inhibit correct production. However, the jaw is a supportive articulator for the tongue and lips and does not form a vocal tract constriction in and of itself. Furthermore, proper velopharyngeal closure is needed for /r/; instances in which a child produces significant hypernasality *only* during production of /r/ (and no other phonemes) may suggest an impaired motor plan for this phoneme. Similar treatment strategies targeting the five elements of /r/ would still be warranted, in addition to cues pertaining to nasality.

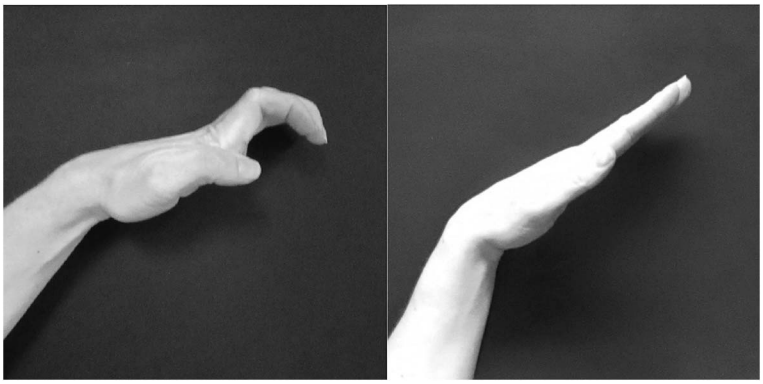
In sum, correct /r/ typically involves elevation of the front of the tongue, retraction of the tongue root, lowering of the tongue body, elevation of the sides of the tongue, and slight lip rounding. In contrast to the complex tongue shapes associated with correct /r/ production, distortions of /r/ often involve more simplified tongue shapes. For example, distorted /r/ may be characterized as having a low tongue tip/blade, a high tongue body, a tongue root that is forward, and a lack of lateral bracing. Correct /r/ requires differentiated movement of the anterior and posterior parts of the tongue, resulting in multiple curves or "bends" in the tongue (Preston, McCabe, et al., 2019), whereas distorted /r/ tends to be simpler in shape. In its most extreme form, distorted /r/ can involve a near-total lack of differentiation among the distinct parts of the tongue, resulting in a simple "rainbow" shape of the tongue from back to front in sagittal section (Gick et al., 2007; Klein et al., 2013; Preston, McCabe, et al., 2019). Supplemental Material S1 (sagittal ultrasound images of the tongue depicting distorted /r/ and correct /r/ productions from children) provides examples of tongue shapes of correct and distorted /r/ productions using ultrasound imaging.

Cueing /r/

To achieve correct productions, children with /r/ distortions may need to be taught some basic anatomy of the tongue (e.g., tip, blade, body, root, sides). Overly broad concepts such as "lift your tongue up for /r/" may not be helpful because, as described above, the tongue has functional parts that can move quasi-independently; that is, lifting the middle of the tongue body high for /r/ is commonly associated with a distortion, but lifting the tongue tip, blade, or anterior body high is more likely to be associated with correct /r/. Therefore, teaching children the distinct parts of the tongue and using specific terminology during treatment may improve the effectiveness of cues. Age-appropriate activities, such as drawing/labeling images or shaping a model of the tongue in various configurations (e.g., using a paper cutout, Play-Doh, or a rubber model to represent the tongue), may be useful in the early stages of therapy to ensure the child has an understanding of the distinct parts of the tongue that will be cued during practice. Images such as those in Figure 1 may help children understand basic anatomy, which may include the tongue tip, blade, body, and root. MRI images highlighting various vocal tract configurations for /r/ may also be useful in depicting the variability of /r/ tongue shapes (Boyce, 2015; Tiede et al., 2004). Another helpful resource for visualizing articulatory movements is the website Seeing Speech (https://www.seeingspeech.ac.uk/ipa-charts/), which includes dynamic MRI, animations, and ultrasound images of the tongue during production of /r/ as well as other speech sounds. Finally, gestures in which the clinician's hand shape represents the tongue shape may also be a helpful visual aid to facilitate children's understanding of the lingual complexity required for /r/ (Rusiewicz & Rivera, 2017). For example, as shown in Figure 4, a bunched /r/ shape may be represented with low fingertips (representing the tongue tip), elevated distal knuckles (representing the tongue blade), lowered base knuckles (representing the tongue body), and a cocked wrist (representing the tongue root), but a retroflex /r/ shape may be cued with the palm facing down, raised fingertips (higher than the knuckles), and a cocked wrist (representing the tongue root).

Once the child is familiar with basic lingual anatomy, effective cueing may focus on the idea that different parts of the tongue need to move in different directions for perceptually accurate /r/ (e.g., "Lift the *front* of your tongue up off the floor of your mouth; don't lift the *back* of your tongue"). With respect to the oral constriction, in the early stages of treatment, elevation of the front of the tongue can be cued by encouraging the child to move the tongue tip up as if attempting a /t/ without actually producing the /t/ (Hoffman, 1983), which likely will elicit retroflex /r/. Other cues for retroflex may include instructions to point the tip up toward the roof of the mouth or to curl the tip of the tongue up slightly (retroflex /r/ does not require excessive tongue tip curling). Bunched /r/ may require more complex instructions, such as lifting the blade or anterior body ("Lift the part of the tongue that is just behind the tip, but

Figure 4. Examples of hand gestures to cue bunched (left) and retroflex (right) /r/.



don't point the tip up and don't raise the back too high"). As such, clinicians may find the retroflex /r/ easier to describe to children (e.g., Ball et al., 2013). However, numerous verbal and visual instructions should be leveraged to convey the complex tongue movements, and clinicians should encourage children to explore various tongue shapes to evoke /r/, rather than focusing on one tongue shape (McAllister Byun et al., 2014).

Tongue root retraction may sometimes be cued by instructing the child to pull the back of the tongue back into the throat, or it may be characterized as tension or tightness (McAllister Byun & Hitchcock, 2012). The oral and pharyngeal constrictions may be introduced separately to begin with (Bacsfalvi, 2010; McAllister Byun & Hitchcock, 2012). However, eventually, it may be helpful to convey both of these simultaneous actions while cueing /r/ (e.g., "Lift the *front* of your tongue up toward the roof of your mouth, but not touching the roof. At the same time, make the *back* of your tongue tight and pull it backward toward your throat."). Images of the tongue (e.g., Figure 1) or hand gestures (e.g., Figure 4) may also help convey tongue root retraction.

In between the oral and pharyngeal constrictions, the midline of the tongue body should stay low to allow an open space behind the oral constriction for sound to resonate (Alwan et al., 1997; Gick & Campbell, 2003); however, the sides of the tongue are typically raised to brace against the back molars. Therefore, the shape of the tongue body may be described as a "boat" shape such that the sides are raised up but the center is down (Boyce, 2015). Other analogies may also be appropriate, such as characterizing the elevation of the sides of the tongue as a taco or as a bird or butterfly shape with the "wings" raised up (e.g., "butterfly bite"; McAllister Byun et al., 2014). While these analogies may not be perfectly anatomically correct, they may help the child build a conceptual representation of the movements that need to occur. Contact of the lateral margins of the tongue against the back teeth is the only tactile feedback that is normally available for correct /r/ production, and therefore, this contact may be emphasized when cueing /r/. Images such as Figure 3 reveal the contact of the sides of the tongue against the upper molars. Such visual information may be a useful supplement to verbal cues (e.g., "Feel the *sides* of your tongue lifting up and pushing against your back teeth, like in this picture").

With respect to cueing the position of the lips, recall that only minimal lip movement is needed to achieve correct /r/ (Campbell et al., 2010). Therefore, for children who excessively round the lips, suggested cues include "keep the lips steady," "don't push the lips too far forward," or "keep the corners of your lips tight." In general, we do not advocate for cues to "smile big" to inhibit lip rounding because correct /r/ does not require lip spreading, and excessive spreading of the lips may result in unnatural productions.

Table 1 contrasts articulatory features of typical and distorted American English /r/ productions, along with suggested cues to help focus the child's attention on the elements that may facilitate correct production. Supplemental Material S1 contains ultrasound images of tongue shapes for /r/ productions, highlighting various ways in which correct and distorted productions may be achieved with the tongue tip, blade, body, and root. Supplemental Material S2 (electropalatography images showing tongue–palate contact during distorted /r/ and correct /r/ productions from children) contains examples of accurate and distorted /r/ productions with EPG, which highlights lateral bracing. It is important to note that, in most cases, the specific articulatory actions that a child executes cannot be fully identified without instrumental methods (e.g., ultrasound, EPG, MRI). That is, when a child produces a distortion, it may be challenging to "hear" whether the production features sufficient tongue root retraction, lateral bracing, anterior tongue elevation, and/or tongue body lowering. Therefore, the clinician may need to attempt many different cues, such as those in Table 1, until the cues that seem to be most facilitative are discovered. Clinical observation should then continue throughout future practice with the child in order to hone in on the cues that yield the greatest success. It is also important to be aware that, regardless of the specific articulatory configuration a child is producing for /r/, the critical element is whether the production *sounds* acceptable. Moreover, a single speaker can use multiple different articulatory configurations depending on factors such as syllable position or vowel context;

Table 1. Contrast between a typical /r/ production and distorted /r/, with suggested articulatory cues to elicit the target movement.

Articulator	Features of typical /r/ production	Common errors in distorted /r/ production	Suggested cues
Tongue tip, blade, or anterior body	Raised off the floor of the mouth toward the alveolar ridge or hard palate. Tip pointed up (retroflex) or angled straight or pointed down (bunched)	Low, near the floor of the mouth	• Point the tip of your tongue toward the bump behind your top teeth, but not touching it. • Make sure the front of the tongue is raised up near the roof of your mouth. • Lift the tip and blade of your tongue up off the floor of the mouth—not touching the roof. • Lift the front as if you were going to make /t/ but don't raise it quite high enough to touch the roof. • Raise the part of the tongue that is just behind your tongue tip.
Posterior tongue body	Low, grooved in the center	Raised high and back	• Keep the body of the tongue low while you lift the front. • Try to keep the middle of your tongue low, so there is a groove down the middle. • Don't let the back of the tongue be raised up when you say /r/. • The back should be lower than the front.
Lateral margins of the tongue body	Sides up, braced against back molars	Sides are typically lower than the middle	• Make the sides of your tongue go up for a butterfly bite. • Keep the sides of your tongue up the way you do for the /ʃ/ sound. Make that sound and then pull the tongue a little further back. • Make the /i/ sound and feel the sides of the tongue up and then slide your tongue back and try the /r/ sound. • Feel the sides of your tongue against your farthest back top teeth (molars). • Try to make your tongue shape like a canoe or a taco—sides up high, but a dip in the middle. • Lift the sides up high like the wings of a bird.
Tongue root	Pulled back toward the pharyngeal wall	Lacking retraction	• Let's work on moving the very back part of your tongue—the root—back and forth. /i/ is a sound you say with the root of your tongue pretty far forward, and /ɑ/ is a sound you say with the root of your tongue far back. Let's go back and forth between /i/ and /ɑ/. /i/–/ɑ/. Try to stay back for /ɑ/ and then keep it back there while you lift the front of the tongue up for /r/. • Try to really feel the back part of your tongue (the root) moving back. When you say /r/, try to make the root of your tongue go back, like for /ɑ/. • (Put hand on the back of the child's neck) Try sliding your tongue back this way toward the back of your neck. • Pull the back of your tongue straight back, not back and up. • Pull the back of your tongue backward, like you are trying to hold a pill or a marble in the back of the throat.
Lips	Slightly round	Excessively round	• Try rounding your lips just a bit while you say /r/. • Your lips should feel a little tight in the corners with an opening in the middle. • Keep the lips steady. Don't round your lips too much. Just a little bit.

Note. These are only examples. Paraphrasing and combining these cues will likely be necessary to achieve correct /r/ for many clients. It may not be necessary to use all cues with a client, but instead identify the cues that are most facilitative for that individual.

for example, retroflex tongue shapes are uncommon after /i/ vowels (Mielke et al., 2016), so clinicians should consider cueing a bunched /r/ instead of a retroflex /r/ for a word such as "ear" or "hear." The clinician must be adaptive and recognize that different cues may be required depending on the child's needs and the phonetic contexts being practiced.

Shaping Strategies

In addition to the cueing strategies described above, /r/ may be elicited by shaping from other phonetically similar sounds, such as /ɑ/, /l/, or /i/. Shaping /r/ from /ɑ/ leverages the low position of the tongue body and retraction of the tongue root that are characteristic of the low back vowel (Boyce, 2015). Instructions such as the following may be useful: "Say /ɑ/ and hold it. Feel the back of the tongue stay low and back. Now say /ɑ/ and while you hold the back of the tongue low and back for /ɑ/, lift the front of the tongue up off the floor of the mouth, lifting up and back" (Ball et al., 2013). The clinician may also wish to emphasize lateral contact while shaping /r/ from /ɑ/. For example, "Say /ɑ/ and hold it. Feel the back of the tongue stay low and back. Now say /ɑ/ and while you hold the back of the tongue low and back for /ɑ/, lift the sides of your tongue up against your back teeth."

Shaping /r/ from /l/ may also be useful for children who can sustain a perceptually accurate alveolar /l/ sound. As described by Shriberg (1975), the child should be instructed to first identify the tongue tip and the alveolar ridge ("bump behind the top teeth"). Next, instruct the child to say and hold /l/ on command several times, then "Say a long /l/, but this time as you're saying it, drag the tip of your tongue slowly back along the roof of your mouth – so far back that you have to drop it" (Shriberg, 1975, p. 105). These instructions, along with a gesture representing the tongue tip sweeping back along the roof of the mouth, should encourage a retroflex tongue shape.

Shaping from /i/ (as in "eat") is intended to achieve a bunched tongue configuration. The /i/ vowel and /r/ both share the property of lateral bracing, but they differ in that /r/ also requires tongue root retraction. Therefore, instructions to elicit /r/ may include, "When you say /i/, the front part of your tongue is in a spot that's pretty close to a good position for an /r/ sound. The back part of your tongue looks different, though. /i/ is a sound you say with the root of your tongue really far forward, but for /r/, you need the root of your tongue to go back. I want you to make an /i/ sound and try to pull only the back part of your tongue back. You can try lifting your tongue tip up just a bit to make an /r/."

Tactile Cues

Tactile cues for articulator placement, sometimes described as moto-kinesthetic training (Secord et al., 2007; Young & Hawk, 1955), can include the use of tongue depressors, lollipops, or other appropriate tools specifically to enhance the child's understanding of the parts of the tongue that are cued by the clinician. For example, if cueing elevation of the tongue tip, the tongue depressor may be used to stroke or tickle the tip in conjunction with verbal instructions such as, "This is the tip of your tongue. I want you to lift it up off the floor of your mouth." Or if cueing elevation of the sides of the tongue, the tongue depressor may be used to stroke or tickle the sides and/or to tap the back molars, in conjunction with verbal cues such as, "Here are the sides of your tongue. Here are your back teeth and gums. I want you to lift the sides of the tongue up to touch the back teeth and gums." Thus, to the extent that external implements are used, they should enhance the verbal and visual cues provided for specific movements for /r/ (see Table 1), not to generically "wake up" the mouth. We return to this topic below in the Cautions in Treatments for Residual /r/ Distortions section.

Practicing /r/ in the Early Stages of Therapy

The cueing and shaping strategies described above are appropriate for use during pre-practice. Within a motor learning framework, *pre-practice* is the time during which children learn the concept of what is needed for a "correct" response (Maas et al., 2008). That is, children must learn to achieve an articulatory configuration that yields a perceptually accurate /r/ in order for the sound to be implemented in practice. Substantial cueing and instruction may be necessary to evoke a correct response from some children. In the early stages of treatment, children's productions may progress from significantly off-target to mild distortions, a change that is sometimes described as "successive approximations" (Elbert & McReynolds, 1975). For example, clinicians may help children learn that they are getting closer to a correct /r/ despite still being in error by "grading" their productions, such as indicating that their /r/ productions have progressed from a C+ to a B but that only an A+ will be rated as "completely correct."

As children become minimally successful at producing /r/ during pre-practice, they may then engage in practice that initially invokes principles of *acquisition*. That is, when the child's accuracy is just minimally above 0% in syllables, they may require a structured type of practice that includes significant support. This section therefore focuses on principles of acquisition that can guide practice in this early stage. Note that the conditions of practice recommended for this acquisition phase contrast the conditions recommended to facilitate generalization and retention later on in the therapeutic process (Maas et al., 2008).

Feedback

Variations of the cues described in Table 1 can be applied as cues during the acquisition phase of practice, provided prior to each production of /r/. They can also be integrated into knowledge of performance feedback, which is detailed feedback about specific aspects of a movement that was just executed (Maas et al., 2008). Thus, when a child produces a distorted /r/, knowledge of performance

feedback may reference how the child was perceived to deviate from the desired articulatory configuration, such as "I think you need to lift the front of the tongue a little higher off the floor of the mouth" or "Let's try to get the sides of the tongue up a little higher so they are against those back molars." Some elements of /r/ distortions may be readily perceptible to the clinician, such as an excessively high and back tongue position, which may manifest as an /u/-like sound. (In this case, the clinician might provide knowledge of performance feedback such as "Try to keep the back of your tongue low and pulled back into the throat.") In other cases, it may be challenging to ascertain the child's articulatory posture based on the perceptual quality of the sound produced. In such cases, the clinician may provide knowledge of performance feedback reflecting their best guess about the child's articulatory configuration and then try different variations until finding a cue that is generally successful. We recommend that the feedback focus on not only the /r/ production but also the accuracy of the transition into or out of the /r/. Thus, when practicing contexts such as /ɑr/ or /rɑ/, the clinician should not reinforce productions as accurate if they involve a distortion during the transition before or after the /r/. Furthermore, as children acquire productions that include a more acceptable rhotic quality, feedback may also be directed toward achieving more natural timing to avoid excessively lengthened productions.

Stimuli

During the early stages of acquisition or establishment of /r/, simple syllables are typically targeted. A small stimulus set may be relied on initially (e.g., just two to four different syllables), typically with a focus on facilitating contexts that leverage some aspects of coarticulation. For example, positioning /r/ next to /ɑ/ may be facilitative because of the tongue root retraction present for /ɑ/. Positioning /r/ before /æ/ may be facilitative because of anticipation of the low tongue body for /æ/. Positioning /r/ after /i/ may be facilitative because both contain lateral bracing and because /i/ may inhibit lip rounding (Kent, 1982). Positioning /r/ after alveolar plosives, such as /tr/ or /dr/, may be facilitative because the front of the tongue is elevated (Curtis & Hardy, 1959). Thus, some initial syllable targets may include /ɑr/ ("are"), /ræ/ (as in "rat"), /ɪr/ ("ear"), /tri/ ("tree"), /træ/ (as in "trap"), and /dræ/ (as in "drag"). Positioning /r/ between low vowels and alveolar consonants may also be helpful, using target words such as "pardon" or "Carla." Syllables in which /r/ is positioned adjacent to phones with a high back tongue body or lip rounding, such as /u/ or /o/, may be less facilitative and should initially be avoided. Finally, because the schwar /ɚ/ (as in "feather") is unstressed, the short duration and reduced magnitude of movement may increase the difficulty of this sound; /ɚ/ may require separate training after other /r/ allophones have been learned (Hoffman, 1983). Thus, the use of trade materials or curricular words as stimuli may be counterproductive in the acquisition process if phonetic context is not carefully considered. While these suggested stimuli may be helpful as a starting point, they cannot replace careful assessment of each individual child's facilitative contexts.

Practice

In the early stages of therapy targeting acquisition of successful /r/ production, it is recommended that practice follow a blocked schedule. Blocked practice involves repeating the same target many times in a row, such as producing the /ɑr/ syllable 10 or more times consecutively before moving on to a different syllable (e.g., Hitchcock & McAllister Byun, 2015; Ruscello & Shelton, 1979). Blocked practice simplifies the cognitive task by requiring planning of only one target utterance many times in a row (vis-à-vis planning many different movements).

Children vary in the amount of practice required to show signs of acquisition of /r/, with some individuals with low stimulability requiring extensive practice. For example, Preston, Leece, and Maas (2017) reported on six children with residual /r/ distortions who were treated with a motor-based approach that implemented many of the strategies reported here; four of the six children achieved the criterion for stimulability in the first session, one met the criterion in the second session, and one failed to meet the criterion in any of the seven sessions. Similar results were reported in Shriberg's (1975) training program to shape /r/ from /l/. Out of 65 children, 70% of children successfully produced /r/ in isolation within one session, 10% achieved correct /r/ in a second session, and 20% were unable to achieve correct /r/ by the end of the study. In contrast, McAllister Byun and Hitchcock (2012) described a study in which 480 trials of /r/ were elicited over 4 weeks, and just one of nine children achieved a correct /r/ (defined as producing 15% or more of the trials correctly). These findings suggest that it can be difficult to predict how individual children will respond to treatment, and frequent individualized practice may be needed to achieve early success. In general, for children who are not yet stimulable for /r/, individual treatment sessions are recommended to allow sufficient intensity of practice and customization of cueing.

Interim Summary on Cueing and Acquisition of /r/

We have reviewed a number of cueing and shaping strategies. At present, there is no clear evidence to guide clinicians regarding which cues to start with. However, if no facilitating context has been identified, we find that shaping from /ɑ/ or /l/ as described above can be initially successful for many children. Core syllables such as /ɑr/, /ræ/, /re/, /ɪr/, /tri/, /træ/, and /dræ/ may be early targets as the coarticulatory characteristics of these sounds may facilitate correct /r/ production. Initially, spending more time reinforcing the successful syllables may be preferred over achieving just one or two correct productions of a syllable before moving on to a new syllable. Frequent and specific cueing and feedback, as outlined in Table 1, is recommended in conjunction with instructions on functional

movements of the different parts of the tongue. However, the clinician is reminded that not all of these cues will always be necessary; attention should be paid to the specific cues that are most successful for a particular child (yielding correct or slightly more acceptable successive approximations) in order to hone in on the cues to emphasize as therapy progresses. Clinicians are also reminded that cueing and feedback should be direct and concise to allow clients to reach a critical mass of practice trials during the session.

The Appendix provides an example of how to introduce /r/ production to a child with an /r/ distortion. This script has been developed with the aforementioned principles in mind. Additionally, Supplemental Material S3 (examples of cueing and feedback strategies implemented in treatment with children with /r/ distortions) provides examples of treatment sessions implementing some of these cues and feedback used to facilitate acquisition of /r/ in the early stages of treatment.

The Next Steps: Adjusting Practice and Feedback to Facilitate Generalization

Once children can successfully produce target syllables and words with /r/, treatment may gradually shift from an emphasis on acquisition to an emphasis on motor learning (i.e., generalization and retention). As described by Maas et al. (2008), motor learning may potentially be enhanced by reducing the frequency of feedback (e.g., from 90%–100% of trials to 40%–50% of trials), delaying feedback (e.g., by 2–3 s), or providing less specific feedback in the form of knowledge of results (e.g., "Good /r/" or "Not quite").

As the child achieves some success, the stimulus set of /r/ target words should be expanded to increase practice variability, which is considered another means to enhance motor learning. Variable practice can be achieved by increasing the number of target words, targeting /r/ across multiple word positions, and practicing target words with variations in rate, intonation, and loudness (Preston, Leece, McNamara, & Maas, 2017; Preston, Leece, & Storto, 2019; Preston et al., 2014). More complex stimuli may be addressed, such as curricular words in which the phonetic context is uncontrolled, words with a competing phoneme (i.e., a phoneme that shares a major articulatory gesture with /r/, such as /w/ or /l/), words with multiple /r/ sounds, multisyllabic words, and words embedded in phrases or sentences. Stimuli may also be practiced in random rather than blocked order (i.e., practicing a target only once before moving on to the next item). Once /r/ can be produced in a structured setting, generalization strategies may include self-monitoring of productions by encouraging children to rate their own accuracy (L. K. Koegel et al., 1986; R. L. Koegel et al., 1988; Ruscello & Shelton, 1979). Because the focus of this tutorial is on early rather than later stages of /r/ therapy, we will not go into more detail here on strategies to enhance generalization learning. However, the interested reader may consult other tutorials that have highlighted relevant aspects of speech motor learning (e.g., Maas et al., 2008), as well as clinical protocols that facilitate a transition from acquisition-focused to learning-focused treatment, including the Challenge Point Program for /r/ treatment (Hitchcock & McAllister Byun, 2015; McAllister et al., n.d.) and Speech Motor Chaining (Preston, Leece, & Storto, 2019).

Cautions in Treatments for Residual /r/ Distortions

This tutorial has focused on how to teach correct movement patterns for /r/ following the logic that children need to learn to appropriately shape and position the articulators. The elicitation strategies described above are informed by phonetic and clinical science, and the principles of acquisition referenced have theoretical and empirical support. In this section, we address a few practices that may be popular or well marketed but lack theoretical and empirical support.

For example, nonspeech oral motor exercises are emphasized in some trade materials (e.g., Marshalla, 2005; Strode & Chamberlain, 1997) and remain commonly used by some clinicians (Brumbaugh & Smit, 2013; Lof & Watson, 2008), despite a lack of evidence of efficacy in improving production of /r/ or other speech sounds (Lass & Pannbacker, 2008). Nonspeech oral motor exercises take the form of nonspeech tasks, such as wagging the tongue, sucking straws, blowing horns and whistles, licking lollipops, or pushing the tongue against tongue depressors. While these exercises are sometimes purported to increase tongue strength, research evidence indicates that tongue strength does not appear to be a contributing factor for /r/ distortions or for children with speech sound disorders in general, at least in the absence of dysarthria (Dworkin & Culatta, 1985; Lau & Lee, 2013; Potter et al., 2019). Therefore, there is no theoretical basis to expect nonspeech oral motor exercises to improve children's /r/ production (Lass & Pannbacker, 2008; Lof, 2003). Empirically, published studies to date that have assessed the effects of nonspeech oral motor exercises for children with /r/ errors have found no significant benefit for speech production (Forrest & Iuzzini, 2008; Guisti Braislin & Cascella, 2005). Thus, for children with /r/ distortions who do not show signs of dysarthria, there is neither theoretical nor empirical evidence to suggest that nonspeech oral motor exercises would be beneficial. Given the limited time that children spend in the treatment setting, all available time should be used in providing evidence-based treatment that directly and explicitly targets production of /r/. Indeed, given the current state of research, implementing nonspeech oral motor treatment for children with /r/ distortions may raise ethical questions.

Additionally, producing /r/ requires volitional efferent motor commands to intrinsic lingual muscles to control tongue shape and extrinsic muscles to control positioning. Some treatment approaches require the clinician to provide external tactile cues to the submandibular region, corresponding with the mylohyoid muscle, to cue tongue movements for /r/ (Chumpelik, 1984). Tactile cues along the

mylohyoid, which is not a muscle that controls tongue shape, will not cause a child to passively or actively form a proper tongue shape for /r/. Therefore, such cues will only be effective insofar as the child learns to associate these external touch cues with on-target actions of the intrinsic and extrinsic lingual muscles. Moreover, external tactile cues presented along the posterior aspect of the mylohyoid could encourage children to raise the posterior tongue body, which would be counterproductive to correcting /r/ productions (as detailed above, correct /r/ requires the posterior tongue body to remain low). At present, there is neither empirical nor theoretical evidence supporting the use of tactile cues along the mylohyoid to facilitate /r/ production.

Finally, with respect to how services are delivered to children with residual /r/ distortions, there remains a disconnect between evidence-aligned practices and current practices in many schools. For example, the literature appears to be converging on the benefits of frequent treatment sessions involving many practice trials to remediate a variety of speech production difficulties (Brosseau-Lapré & Greenwell, 2019; Hitchcock et al., 2019; Kaipa & Peterson, 2016; Lundeborg Hammarström et al., 2018; Namasivayam et al., 2015; Preston & Leece, 2017), but treatment frequency may be limited for some children to 1 time per week or less. Additionally, group therapy for residual /r/ distortions is quite common (likely the norm). There is long-standing evidence that group therapy can be effective (e.g., Sommers, 1962; Sommers et al., 1970, 1966). However, research to date on group therapy has tested the effectiveness on homogeneous groupings—that is, a group of children with speech sound disorders who are working on similar speech sound goals. There does not appear to be available evidence that group therapy can be effective for remediating /r/ distortions when delivered in heterogeneous groups (e.g., a mix of children with different speech sound targets and/or different types of communication disorders), yet such groups are widespread. This disconnect between best practice (i.e., frequent sessions, homogeneous groupings) and common practice (i.e., infrequent sessions, heterogeneous groupings) may be, in large part, attributable to the current structure of local educational systems, which results in scheduling constraints, high caseloads, and limited resources; it does not necessarily reflect a belief among school-based speech-language pathologists that these practices are likely to be highly effective. Nevertheless, it is important for clinicians to keep in mind best practices so that, to the extent possible, they can advocate for frequent sessions and homogenous groupings to achieve many practice trials.

Conclusions

Residual /r/ distortions involve atypical articulator movement patterns that require phonetically motivated strategies to elicit perceptually correct rhotic sounds. Clinician cues should emphasize elevating the anterior half of the tongue, retracting the tongue root, lowering the posterior tongue body, raising the sides of the tongue to the back molars/gums, and achieving slight constriction in the corners of the lips. For children who are not stimulable or are only minimally stimulable, principles of acquisition may guide how /r/ is practiced, with later stages of treatment emphasizing principles of speech motor learning to encourage generalization (Maas et al., 2008). Clinicians are also encouraged to be mindful that many popular or commercially promoted approaches may lack an empirical or theoretical basis and, thus, are not recommended practices.

Acknowledgments

Research reported in this publication was supported by National Institute on Deafness and Other Communication Disorders Grant R01DC017476 (principal investigator: T. McAllister). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. The authors thank Suzanne Boyce for sharing copies of magnetic resonance images.

References

Adler-Bock, M., Bernhardt, B., Gick, B., & Bacsfalvi, P. (2007). The use of ultrasound in remediation of North American English /r/ in 2 adolescents. *American Journal of Speech-Language Pathology, 16*(2), 128–139. https://doi.org/10.1044/1058-0360(2007/017)

Alwan, A., Narayanan, S., & Haker, K. (1997). Toward articulatory-acoustic models for liquid approximants based on MRI and EPG data. Part II. The rhotics. *The Journal of the Acoustical Society of America, 101*(2), Article 1078. https://doi.org/10.1121/1.417972

Bacsfalvi, P. (2010). Attaining the lingual components of /r/ with ultrasound for three adolescents with cochlear implants. *Canadian Journal of Speech-Language Pathology and Audiology, 34*(3), 206–217.

Ball, M. J., Müller, N., & Granese, A. (2013). Towards an evidence base for /r/-therapy in English. *Journal of Clinical Speech and Language Studies, 20,* 1–23.

Boyce, S. E. (2015). The articulatory phonetics of /r/ for residual speech errors. *Seminars in Speech and Language, 36*(4), 257–270. https://doi.org/10.1055/s-0035-1562909

Brosseau-Lapré, F., & Greenwell, T. (2019). Innovative service delivery models for serving children with speech sound disorders. *Seminars in Speech and Language, 40*(2), 113–123. https://doi.org/10.1055/s-0039-1677762

Brumbaugh, K. M., & Smit, A. B. (2013). Treating children ages 3–6 who have speech sound disorder: A survey. *Language, Speech, and Hearing Services in Schools, 44*(3), 306–319. https://doi.org/10.1044/0161-1461(2013/12-0029)

Campbell, F., Gick, B., Wilson, I., & Vatikiotis-Bateson, E. (2010). Spatial and temporal properties of gestures in North American English /r/. *Language and Speech, 53*(1), 49–69. https://doi.org/10.1177/0023830909351209

Chumpelik, D. (1984). The PROMPT system of therapy: Theoretical framework and applications for developmental apraxia of speech. *Seminars in Speech and Language, 5*(2), 139–156. https://doi.org/10.1055/s-0028-1085172

Cronin, S. A., Blanchet, P. G., Klonsky, B. G., & Piazza, N. (2014). The effect of a modeled /r/ articulatory disorder on listener perceptions of speech skills and personality traits. *Contemporary Issues in Communication Science and Disorders, 41*(Fall), 169–178. https://doi.org/10.1044/cicsd_41_F_169

Culton, G. L. (1986). Speech disorders among college freshmen: A 13-year survey. *Journal of Speech and Hearing Disorders, 51*(1), 3–7. https://doi.org/10.1044/jshd.5101.03

Curtis, J. F., & Hardy, J. C. (1959). A phonetic study of misarticulation of /r/. *Journal of Speech and Hearing Research, 2*(3), 244–257. https://doi.org/10.1044/jshr.0203.244

Delattre, P., & Freeman, D. C. (1968). A dialect study of American *r*'s by X-ray motion picture. *Linguistics, 6*(44), 29–68. https://doi.org/10.1515/ling.1968.6.44.29

Dublinske, S. (2002). "Adversely affects educational performance" policy 1980–2002; Nothing has changed. *SIG 16 Perspectives on School-Based Issues, 3*(2), 3–7. https://doi.org/10.1044/sbi3.2.3

Dworkin, J. P., & Culatta, R. A. (1985). Oral structural and neuromuscular characteristics in children with normal and disordered articulation. *Journal of Speech and Hearing Disorders, 50*(2), 150–156. https://doi.org/10.1044/jshd.5002.150

Elbert, M., & McReynolds, L. V. (1975). Transfer of /r/ across contexts. *Journal of Speech and Hearing Disorders, 40*(3), 380–387. https://doi.org/10.1044/jshd.4003.380

Espy-Wilson, C. Y., Boyce, S. E., Jackson, M., Narayanan, S., & Alwan, A. (2000). Acoustic modeling of American English /r/. *The Journal of the Acoustical Society of America, 108*(1), 343–356. https://doi.org/10.1121/1.429469

Farquharson, K. (2019). It might not be "just artic": The case for the single sound error. *Perspectives of the ASHA Special Interest Groups, 4*(1), 76–84. https://doi.org/10.1044/2018_PERSSIG1-2018-0019

Felsenfeld, S., Broen, P. A., & McGue, M. (1994). A 28-year follow-up of adults with a history of moderate phonological disorder: Educational and occupational results. *Journal of Speech and Hearing Research, 37*(6), 1341–1353. https://doi.org/10.1044/jshr.3706.1341

Flipsen, P. (2015). Emergence and prevalence of persistent and residual speech errors. *Seminars in Speech and Language, 36*(4), 217–223. https://doi.org/10.1055/s-0035-1562905

Forrest, K., & Iuzzini, J. (2008). A comparison of oral motor and production training for children with speech sound disorders. *Seminars in Speech and Language, 29*(4), 304–311. https://doi.org/10.1055/s-0028-1103394

Gick, B., Allen, B., Roewer-Després, F., & Stavness, I. (2017). Speaking tongues are actively braced. *Journal of Speech, Language, and Hearing Research, 60*(3), 494–506. https://doi.org/10.1044/2016_JSLHR-S-15-0141

Gick, B., Bacsfalvi, P., Bernhardt, B. M., Oh, S., Stolar, S., & Wilson, I. (2007). A motor differentiation model for liquid substitutions in children's speech. *Proceedings of Meetings on Acoustics, 1*(1) Article 060003. https://doi.org/10.1121/1.2951481

Gick, B., & Campbell, F. (2003). Intergestural timing in English /r/. In M. J. Solé, D. Recasens, & J. Romero (Eds.), *Proceedings of the 15th International Congress of Phonetic Sciences* (pp. 1911–1914). Universitat Autònoma de Barcelona.

Guenther, F. H., Espy-Wilson, C. Y., Boyce, S. E., Matthies, M. L., Zandipour, M., & Perkell, J. S. (1999). Articulatory tradeoffs reduce acoustic variability during American English /r/ production. *The Journal of the Acoustical Society of America, 105*(5), 2854–2865. https://doi.org/10.1121/1.426900

Guisti Braislin, M. A., & Cascella, P. W. (2005). A preliminary investigation of the efficacy of oral motor exercises for children with mild articulation disorders. *International Journal of Rehabilitation Research, 28*(3), 263–266. https://doi.org/10.1097/00004356-200509000-00010

Hitchcock, E. R., Harel, D., & McAllister Byun, T. (2015). Social, emotional, and academic impact of residual speech errors in school-aged children: A survey study. *Seminars in Speech and Language, 36*(4), 283–294. https://doi.org/10.1055/s-0035-1562911

Hitchcock, E. R., & McAllister Byun, T. (2015). Enhancing generalisation in biofeedback intervention using the challenge point framework: A case study. *Clinical Linguistics & Phonetics, 29*(1), 59–75. https://doi.org/10.3109/02699206.2014.956232

Hitchcock, E. R., McAllister Byun, T., Swartz, M., & Lazarus, R. (2017). Efficacy of electropalatography for treating misarticulation of /r/. *American Journal of Speech-Language Pathology, 26*(4), 1141–1158. https://doi.org/10.1044/2017_AJSLP-16-0122

Hitchcock, E. R., Swartz, M. T., & Lopez, M. (2019). Speech sound disorder and visual biofeedback intervention: A preliminary investigation of treatment intensity. *Seminars in Speech and Language, 40*(02), 124–137. https://doi.org/10.1055/s-0039-1677763

Hoffman, P. R. (1983). Interallophonic generalization of /r/ training. *Journal of Speech and Hearing Disorders, 48*(2), 215–221. https://doi.org/10.1044/jshd.4802.215

Kaipa, R., & Peterson, A. M. (2016). A systematic review of treatment intensity in speech disorders. *International Journal of Speech-Language Pathology, 18*(6), 507–520. https://doi.org/10.3109/17549507.2015.1126640

Kent, R. D. (1982). Contextual facilitation of correct sound production. *Language, Speech, and Hearing Services in Schools, 13*(2), 66–76. https://doi.org/10.1044/0161-1461.1302.66

Klein, H. B., McAllister Byun, T., Davidson, L., & Grigos, M. I. (2013). A multidimensional investigation of children's /r/ productions: Perceptual, ultrasound, and acoustic measures. *American Journal of Speech-Language Pathology, 22*(3), 540–553. https://doi.org/10.1044/1058-0360(2013/12-0137)

Koegel, L. K., Koegel, R. L., & Ingham, J. C. (1986). Programming rapid generalization of correct articulation through self-monitoring procedures. *Journal of Speech and Hearing Disorders, 51*(1), 24–32. https://doi.org/10.1044/jshd.5101.24

Koegel, R. L., Koegel, L. K., Ingham, J. C., & Van Voy, K. (1988). Within-clinic versus outside-of-clinic self-monitoring of articulation to promote generalization. *Journal of Speech and Hearing Disorders, 53*(4), 392–399. https://doi.org/10.1044/jshd.5304.392

Kwiatkowski, J., & Shriberg, L. D. (1998). The capability-focus treatment framework for child speech disorders. *American Journal of Speech-Language Pathology, 7*(3), 27–38. https://doi.org/10.1044/1058-0360.0703.27

Lass, N. J., & Pannbacker, M. (2008). The application of evidence-based practice to nonspeech oral motor treatments. *Language, Speech, and Hearing Services in Schools, 39*(3), 408–421. https://doi.org/10.1044/0161-1461(2008/038)

Lau, T. H. M., & Lee, K. Y. S. (2013). Oral motor performance in children with suspected speech sound disorders: A comparison with children with typically developing speech. *Speech, Language and Hearing, 16*(3), 139–148. https://doi.org/10.1179/2050572813Y.0000000009

Lewis, B. A., Freebairn, L., Tag, J., Ciesla, A. A., Iyengar, S. K., Stein, C. M., & Taylor, H. G. (2015). Adolescent outcomes of children with early speech sound disorders with and without language impairment. *American Journal of Speech-Language Pathology, 24*(2), 150–163. https://doi.org/10.1044/2014_AJSLP-14-0075

Lof, G. L. (2003). Oral motor exercises and treatment outcomes. *SIG 1 Perspectives on Language Learning and Education, 10*(1), 7–11. https://doi.org/10.1044/lle10.1.7

Lof, G. L., & Watson, M. M. (2008). A nationwide survey of nonspeech oral motor exercise use: Implications for evidence-based practice. *Language, Speech, and Hearing Services in Schools, 39*(3), 392–407. https://doi.org/10.1044/0161-1461(2008/037)

Lundeborg Hammarström, I., Svensson, R.-M., & Myrberg, K. (2018). A shift of treatment approach in speech language pathology services for children with speech sound disorders—A single case study of an intense intervention based on non-linear phonology and motor-learning principles. *Clinical Linguistics & Phonetics, 33*(6), 518–531. https://doi.org/10.1080/02699206.2018.1552990

Maas, E., Robin, D. A., Austermann Hula, S. N., Freedman, S. E., Wulf, G., Ballard, K. J., & Schmidt, R. A. (2008). Principles of motor learning in treatment of motor speech disorders. *American Journal of Speech-Language Pathology, 17*(3), 277–298. https://doi.org/10.1044/1058-0360(2008/025)

Marshalla, P. (2005). *Successful R therapy*. Marshalla Speech & Language.

McAllister Byun, T., & Hitchcock, E. R. (2012). Investigating the use of traditional and spectral biofeedback approaches to intervention for /ɹ/ misarticulation. *American Journal of Speech-Language Pathology, 21*(3), 207–221. https://doi.org/10.1044/1058-0360(2012/11-0083)

McAllister Byun, T., Hitchcock, E. R., & Swartz, M. T. (2014). Retroflex versus bunched in treatment for rhotic misarticulation: Evidence from ultrasound biofeedback intervention. *Journal of Speech, Language, and Hearing Research, 57*(6), 2116–2130. https://doi.org/10.1044/2014_JSLHR-S-14-0034

McAllister, T., Hitchcock, E. R., & Ortiz, J. (n.d.). *Computer-assisted challenge point intervention for residual speech errors*. OSF, Center for Open Science. https://doi.org/10.17605/OSF.IO/95ASZ

McLeod, S., & Singh, S. (2009). *Seeing speech: A quick guide to speech sounds*. Plural.

Mielke, J., Baker, A., & Archangeli, D. (2016). Individual-level contact limits phonological complexity: Evidence from bunched and retroflex /ɹ/. *Language, 92*(1), 101–140. https://doi.org/10.1353/lan.2016.0019

Mines, M. A., Hanson, B. F., & Shoup, J. E. (1978). Frequency of occurrence of phonemes in conversational English. *Language and Speech, 21*(3), 221–241. https://doi.org/10.1177/002383097802100302

Modha, G., Bernhardt, B. M., Church, R., & Bacsfalvi, P. (2008). Case study using ultrasound to treat /ɹ/. *International Journal of Language & Communication Disorders, 43*(3), 323–329.

Namasivayam, A. K., Pukonen, M., Goshulak, D., Hard, J., Rudzicz, F., Rietveld, T., Maassen, B., Kroll, R., & van Lieshout, P. (2015). Treatment intensity and childhood apraxia of speech. *International Journal of Language & Communication Disorders, 50*(4), 529–546. https://doi.org/10.1111/1460-6984.12154

Potter, N. L., Nievergelt, Y., & VanDam, M. (2019). Tongue strength in children with and without speech sound disorders. *American Journal of Speech-Language Pathology, 28*(2), 612–622. https://doi.org/10.1044/2018_AJSLP-18-0023

Preston, J. L., & Leece, M. C. (2017). Intensive treatment for persisting rhotic distortions: A case series. *American Journal of Speech-Language Pathology, 26*(4), 1066–1079. https://doi.org/10.1044/2017_AJSLP-16-0232

Preston, J. L., Leece, M. C., & Maas, E. (2017). Motor-based treatment with and without ultrasound feedback for residual speech-sound errors. *International Journal of Language & Communication Disorders, 52*(1), 80–94. https://doi.org/10.1111/1460-6984.12259

Preston, J. L., Leece, M. C., McNamara, K., & Maas, E. (2017). Variable practice to enhance speech learning in ultrasound biofeedback treatment for childhood apraxia of speech: A single case experimental study. *American Journal of Speech-Language Pathology, 26*(3), 840–852. https://doi.org/10.1044/2017_AJSLP-16-0155

Preston, J. L., Leece, M. C., & Storto, J. (2019). Tutorial: Speech motor chaining treatment for school-age children with speech sound disorders. *Language, Speech, and Hearing Services in Schools, 50*(3), 343–355. https://doi.org/10.1044/2018_LSHSS-18-0081

Preston, J. L., McAllister Byun, T., Boyce, S. E., Hamilton, S., Tiede, M., Phillips, E., Rivera-Campos, A., & Whalen, D. H. (2017). Ultrasound images of the tongue: A tutorial for assessment and remediation of speech sound errors. *Journal of Visualized Experiments, 2017*(119), Article e55123. https://doi.org/10.3791/55123

Preston, J. L., McCabe, P., Rivera-Campos, A., Whittle, J. L., Landry, E., & Maas, E. (2014). Ultrasound visual feedback treatment and practice variability for residual speech sound errors. *Journal of Speech, Language, and Hearing Research, 57*(6), 2102–2115. https://doi.org/10.1044/2014_JSLHR-S-14-0031

Preston, J. L., McCabe, P., Tiede, M., & Whalen, D. H. (2019). Tongue shapes for rhotics in school-age children with and without residual speech errors. *Clinical Linguistics & Phonetics, 33*(4), 334–348. https://doi.org/10.1080/02699206.2018.1517190

Ruscello, D. M., & Shelton, R. L. (1979). Planning and self-assessment in articulatory training. *Journal of Speech and Hearing Disorders, 44*(4), 504–512. https://doi.org/10.1044/jshd.4404.504

Rusiewicz, H. L., & Rivera, J. L. (2017). The effect of hand gesture cues within the treatment of /r/ for a college-aged adult with persisting childhood apraxia of speech. *American Journal of Speech-Language Pathology, 26*(4), 1236–1243. https://doi.org/10.1044/2017_AJSLP-15-0172

Schmidt, A. M. (2007). Evaluating a new clinical palatometry system. *Advances in Speech Language Pathology, 9*(1), 73–81. https://doi.org/10.1080/14417040601123650

Secord, W. A., Boyce, S. E., Donohue, J. S., Fox, R. A., & Shine, R. E. (2007). *Eliciting sounds: Techniques and strategies for clinicians* (2nd ed.). Thomson Delmar Learning.

Shriberg, L. D. (1975). A response evocation program for /ɝ/. *Journal of Speech and Hearing Disorders, 40*(1), 92–105. https://doi.org/10.1044/jshd.4001.92

Shriberg, L. D. (2009). Childhood speech sound disorders: From postbehaviorism to the postgenomic era. In R. Paul & P. Flipsen Jr. (Eds.), *Speech sound disorders in children* (pp. 1–34). Plural.

Silverman, F. H., & Paulus, P. G. (1989). Peer reactions to teenagers who substitute /w/ for /r/. *Language, Speech, and Hearing Services in Schools, 20*(2), 219–221. https://doi.org/10.1044/0161-1461.2002.219

Sommers, R. K. (1962). Factors in the effectiveness of mothers trained to aid in speech correction. *Journal of Speech and Hearing Disorders, 27*(2), 178–186. https://doi.org/10.1044/jshd.2702.178

Sommers, R. K., Leiss, R. H., Fundarella, D., Manning, W., Johnson, R., Oerther, P., Sholly, R., & Siegel, M. (1970). Factors in the effectiveness of articulation therapy with educable retarded children. *Journal of Speech and Hearing Research, 13*(2), 304–316. https://doi.org/10.1044/jshr.1302.304

Sommers, R. K., Schaeffer, M. H., Leiss, R. H., Gerber, A. J., Bray, M. A., Fundrella, D., Olson, J. K., & Tomkins, E. R. (1966). The effectiveness of group and individual therapy. *Journal of Speech and Hearing Research, 9*(2), 219–225. https://doi.org/10.1044/jshr.0902.219

Strode, R., & Chamberlain, C. (1997). *Easy does it for articulation: An oral-motor approach*. LinguiSystems.

Tiede, M. K., Boyce, S. E., Holland, C. K., & Choe, K. A. (2004). A new taxonomy of American English /r/ using MRI and ultrasound. *The Journal of the Acoustical Society of America, 115*(5), 2633–2634. https://doi.org/10.1121/1.4784878

van Lieshout, P., Merrick, G., & Goldstein, L. M. (2008). An articulatory phonology perspective on rhotic articulation problems: A descriptive case study. *Asia Pacific Journal of Speech, Language and Hearing, 11*(4), 283–303. https://doi.org/10.1179/136132808805335572

Whitmire, K. (2007). Guidance letter clarifies key IDEA issues. *The ASHA Leader, 12*(6), 7–28. https://doi.org/10.1044/leader.SCM1.12062007.7

Young, E. H., & Hawk, S. S. (1955). *Moto-kinesthetic speech training*. Stanford University Press.

Zhou, X., Espy-Wilson, C. Y., Boyce, S., Tiede, M., Holland, C., & Choe, A. (2008). A magnetic resonance imaging-based articulatory and acoustic study of "retroflex" and "bunched" American English /r. *The Journal of the Acoustical Society of America, 123*(6), 4466–4481. https://doi.org/10.1121/1.2902168

Appendix (p. 1 of 2)

Introducing /r/ to Clients

Duration: Approximately 15–20 min

Supplemental Material S4 includes the figures referenced here.

✓ Main point(s)	Sample script
__First, learn about /r/ shape.	"We're going to work on ways to move your tongue to make a really good /r/ sound. We're going to look at pictures of people saying really good /r/ sounds."
__Orient to anatomy in sagittal plane.	"When we look at pictures of the /r/ sound, we will usually be looking at the tongue from a side view." (Show Figure A of Supplemental Material S4. Point out the nose, lips, and jaw.)
__Many different correct /r/ shapes.	"Everyone's mouth is different. People have different-sized throats and jaws and tongues. That means that everyone makes the /r/ sound a little bit differently. Look at these pictures." (Show Figure A of Supplemental Material S4.) "These are all pictures of people's tongues while they're saying the /r/ sound. I'm going to trace the tongue in one picture so you know what you're looking at." (Clinician traces tongue.) "Now you try tracing the shape of the tongue in one picture." (Child traces tongue. Feedback provided as necessary.) "Some of these tongue shapes look really different, right? But all of these people are making really good /r/ sounds. That means that there isn't just one good tongue shape for /r/, we just need to find the tongue shape that works for you. We're going to try out a bunch of different tricks. We will help you figure out which of these tricks will help you make your best /r/ sound."
__Explain tip, blade, body, and root.	"The tongue can make lots of different shapes. It can be helpful for us to talk about the different parts of the tongue because they can move differently. Look at this picture." (Show Figure B of Supplemental Material S4.) "The **tip** is the very front in red. Just behind that is the **blade** in orange. The large part in the middle is the **body** in green. The part that is way back in your throat is the **root** in blue. We'll use the words tip, blade, body, and root to describe what's happening with the tongue shape. Here is the same picture with the background removed, so you can really focus on the shape of the tongue." (Show Figure C of Supplemental Material S4.)
__Check for comprehension.	"Let's review. Can you point to the tip, blade, body, and root of the tongue in these pictures?" (Show Figure A from Supplemental Material S4. Give feedback on responses.)
__Explain front bump and back bump.	"One thing that is similar across these tongue shapes is that they aren't a simple shape like a hill or a rainbow. Look at this picture of two different tongue shapes." (Show Figure D from Supplemental Material S4.)
__All good /r/ shapes have two bumps.	"These shapes look very different, but they are both good tongue shapes for /r/. What's important is that both shapes have two different bumps. One bump is in the front where the tip, or blade, or the front of the body is raised. One bump is in the back at the root. If you look at all of the tongue shapes on this page, you can see that they all have two bumps going on at the same time." (Discuss the various images in Figure D and Figure A with the child.)

Appendix (p. 2 of 2)

Introducing /r/ to Clients

✓ Main point(s)	Sample script
Explain properties of canonical tongue shapes to child, starting with sagittal section.	
__Two most common tongue shapes.	"We're going to look at the two most common ways of making an /r/ shape in more detail. Remember that we'll try different things to find the tongue shape that fits best for you. Whatever shape you pick, you're going to make two bumps where the body of the tongue is low and root is back toward the throat, while the front the tongue is raised up."
__Bunched /r/: Two bumps. Move blade up for front bump, push root into throat for back bump.	(Show Figure C from Supplemental Material S4.) "Here's a tongue shape that some people call 'bunched.' Like we've seen, this tongue shape has two bumps. For this tongue shape, the blade of the tongue is raised up near the roof of your mouth in the front. The root of your tongue, here in the back, is pushed back into your throat to make a back bump."
__Retroflexed /r/: Tongue tip points up, still a back bump at the root.	(Show Figure E from Supplemental Material S4.) "Here's a different tongue shape that can make a really good /r/ sound. Some people call this a 'retroflex' tongue shape. For this shape, the tip of the tongue is pointing up at the roof of the mouth, right behind where your teeth are. The back of the tongue is the same as what we saw in the previous tongue shape. The tongue root gets pushed back into your throat to make that space narrower, so there are two bumps."
__Check for comprehension.	"Let's review. Can you explain what needs to happen with the tongue in any tongue shape to make a good /r/ sound?" Answer: There needs to be a bump in the front and a bump in the back. (Discuss images from Figure D and Figure A as needed for comprehension.) (Show Figure F from Supplemental Material S4.) "Now, can you tell me which of these pictures shows a "good" /r/ sound, and which of these pictures does not show a "good" /r/ sound? Answer: The figure on the left with a rainbow tongue shape is not a "good" /r/ sound. The figure on the right with two bumps is a "good" /r/ sound.
__Try producing retroflexed /r/.	"Now I want you to say an /r/ sound and draw it out. While you do, try to move your tongue around so it's like this picture. We'll listen for it to sound like a really good /r/." (Show Figure E from Supplemental Material S4. Reinforce good /r/ or provide articulator placement cues.)
__Try producing bunched /r/.	"Now let's try another tongue shape. I want you to say an /r/ sound and draw it out. While you do, try to move your tongue around so it's like this picture. We'll listen for it to sound like a really good /r/." (Show Figure C from Supplemental Material S4. Reinforce good /r/ or provide articulator placement cues.)
__Note the child's most accurate tongue shape.	(If a facilitative tongue shape is identified, make a note so you can cue the child to use identified tongue shape during practice.)
Explain properties of desired tongue shape focusing on lateral bracing.	
__Explain tongue–palate contact.	"Now we're going to talk about one more thing your tongue might do when you say a really good /r/ sound. If you could see inside someone's mouth during a good /r/ sound, you might actually see that the sides of the tongue are pressed up against the sides of the roof of the mouth, near the back teeth. The middle of the tongue stays down, so it doesn't touch the roof of the mouth." (Show Figure G from Supplemental Material S4.)
__Introduce the butterfly shape.	"Some people call this the butterfly position for your tongue. Picture your tongue like a butterfly with its wings raised up in a V shape. The sides of your tongue are like the wings; they are raised up a little, and they press against the edges of the roof of your mouth or the insides of your back teeth or molars. The body of the butterfly stays down below the wings."
__Check for comprehension.	"Let's review. Can you explain what should happen when the tongue contacts the roof of the mouth?" Answer: Sides of the tongue contact the back molars while the body stays low.
__Try producing /r/ with lateral bracing of tongue.	"Now I want you to say an /r/ sound and draw it out. While you do, try to move your tongue around so it looks more like this picture. We'll listen for it to sound like a really good /r/." (Show Figure G from Supplemental Material S4. Reinforce good /r/ or provide articulator placement cues.)