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Acquiring rhoticity across languages: An ultrasound study of differentiating tongue movements

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Abstract

Clinical investigators working in a number of languages have noted that rhotics develop late and are subject to clinically significant misarticulations. The English rhotic approximant and the Spanish rhotic trill exhibit tongue shape differentiation between a primary constriction along the palate and a secondary constriction in the pharynx. This differentiation is often missing in misarticulations. In this work, we speculate whether the secondary pharyngeal articulation seen in English might also be a cross-linguistic characteristic of rhotics and thus potentially a factor in articulatory delays and misarticulations. We describe an exploratory study analyzing rhotic tongue configurations in ultrasound videos from a small sample of native adult speakers of English, Malayalam, French, Persian and Spanish. Our findings confirm that rhotic sounds most likely to show late mastery and misarticulation also involve tongue root movement toward a pharyngeal constriction, but this conclusion must remain tentative without further research. In the meantime, clinical strategies that include attention to tongue root as well as tongue front configuration (such as facilitative contexts with tongue root movement) may be worth exploring in remediation of rhotic misarticulations across languages.

Keywords

rhoticity; ultrasound; cross-linguistic; phonological acquisition; speech sound disorders

Introduction

It is a truism in linguistics that the same speech sounds, or classes of speech sounds, occur across multiple languages. Cross-linguistic similarities and differences in children's acquisition of these sounds are naturally of linguistic interest, as scientific evidence of what is universal across human languages. It is also, importantly, of clinical interest to speech-language pathologists. For instance, when considering common vs. uncommon patterns of disordered speech in a particular child, it may be helpful to clinicians to consider whether

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these patterns fit into a universal or a language-specific framework. Further, clinical strategies that work in one language may well work in another language.

In this paper, we consider a particular case of potential phonetic similarity in cross-linguistic acquisition patterns that may also have implications for clinical treatment. Our motivation derives from our earlier work on the rhotic approximant /ɹ/ in American English and the trill /r/ across a range of Spanish dialects. Both rhotics are known to involve complex articulations. In terms of the typical developmental trajectory, both are later-developing sounds, both are subject to clinically significant misarticulations, and both are resistant to remediation. In discussing our data with clinicians with different language backgrounds, it was common to hear of similar patterns of acquisition for rhotics, and similar difficulties in assessing and treating rhotic misarticulations. Accordingly, this paper has three major sections. In the first, we bring together scattered descriptions of typical and disordered acquisition of rhotic sounds across a range of languages. As part of the motivation for the study, we briefly describe the linguistic evidence for rhotics as a class of sounds. In the second section, we briefly summarize the evidence for including tongue root retraction toward the back pharyngeal wall, or “pharyngealization”, as a secondary articulatory feature of both American English and Spanish rhotic sounds. We speculate that this feature of tongue root retraction is the major reason these sounds are categorized as articulatorily complex, are late to develop, and are subject to misarticulation. In the third portion of the paper, we illustrate the potential applicability of this hypothesis in a small sample of productions by native speakers of other languages using ultrasound imaging.

Linguistic and Clinical Evidence for Rhotics as a Class

The majority of languages have some type of rhotic sound (Maddieson, 1984). As a group, they are considered to belong to a natural class. However, as Ladefoged (2005a) points out, the evidence for this natural class has, to date, been largely abstract and phonological rather than concrete and phonetic. They occupy the same position in consonant systems and in the sonority hierarchy for syllable structure organization (Lindau & Ladefoged, 1986). They tend to have similar patterns of interaction with other sounds—metathesis with /l/, alternation with /s/, lengthening preceding vowels, vocalizing or reducing to schwa in post-vocalic position (some dialects of English, German, Danish, Colombian Spanish, among others). Allophonically, rhotics often alternate with other rhotics (Ladefoged & Maddieson, 1996).

Phonetically, however, rhotics show a wide range of variation both within and across languages (Ladefoged & Maddieson, 1996). Rhotics may be described in terms of the place of primary constriction (palatal, alveolar, post-alveolar, or uvular, among others). They may also be described in terms of the part of the tongue that makes the primary constriction (as in, apical, laminal, dorsal, coronal). The primary place of articulation for a rhotic may be very broadly defined. In the International Phonetic Alphabet IPA chart, most coronal rhotics are shown as spanning dental, alveolar, and post-alveolar places of articulation (IPA, 2005). The place of articulation may be alveolar, palatal or uvular, while manner of articulation includes trills, taps, fricatives and approximants (Ladefoged, 2005a) as well as retroflex articulation (Van de Velde & van Hout, 2001). There is variation across French dialects in

whether the uvular rhotic is produced as a trill [R] or a fricative [ʀ] (Rose & Wauquier-Gravelines, 2007). In English, as with many other languages, the form of rhotic tends to vary by dialect. In Scottish English varieties, production is variable between trills and approximants (Scobbie et al, 2007; 2015). In North American and Southern British varieties the manner of production is consistently approximant, and the primary place of articulation is alveolar or post-alveolar. There is also dialectal variation in the degree to which rhotics are realized as schwa-like vowels in postvocalic position. This tendency is extreme in “r-less” dialects such as Southern British English, but can occur in a relatively milder and variable form in some rhotic dialects (Campbell, Gick, Wilson, Vatikiotis-Bateson, 2010). Even fully rhotic approximants in English, however, show considerable articulatory variation (Tiede, Boyce, Holland, & Choe, 2004; Boyce, 2015).¹ Examples drawn from midsagittal Magnetic Resonance (MR) imaging scans of the major English articulatory variants, which involve various combinations of raised tip/blade and blade/dorsum along with tongue root retraction, are shown in figure 1.

Evidence for Tongue Root Retraction/“Pharyngealization” in Rhotics

Typical adult production of rhotics across languages

One possibility, discussed briefly by Lindau (1985) and suggested independently by Catford (1986), is that rhotics are connected not by what happens with the front of the tongue, where they show varied types of movements at varied places of articulation, but by what happens with the root of the tongue in the pharynx. Bits and pieces of evidence across languages are intriguing in this regard. Delattre (1971) showed that French and German uvular trills showed movement of the tongue root toward the back pharyngeal wall before the tongue dorsum moved in the direction of the uvula. Ladefoged (2005b) notes that, for languages with a liquid that is allophonically conditioned to sound more lateral (i.e. like [l]) in some environments and more rhotic (like [ɭ]) in some environments, it is the back vowels that condition rhotics and front vowels that condition laterals. For languages with an advanced tongue root distinction, the rhotic variant is more likely to occur in words with a narrowed pharynx. For example, Catford’s observation was made in the context of rhotic conditioning with pharyngealization in several Caucasian languages. Finally, while the rhotic approximants of American English show a wide range of variation with regard to cavities and constrictions in the oral cavity, the variants are remarkably consistent in showing a simultaneous constriction along the palate and a narrowing of the vocal tract in the pharynx (Boyce, 2007; Campbell, Gick, Wilson, & Vatikiotis-Bateson, 2010; Delattre & Freeman, 1968; Lindau, 1985; Shriberg & Kent, 1982; Zhou et al., 2008). Acoustical modelling studies using vocal tract dimensions have shown that this pharyngeal constriction acts together with the palatal constriction to produce the extreme third formant lowering characteristic of the sound (Espy-Wilson, Boyce, Jackson, Narayanan, & Alwan, 2000; Zhou et al., 2008).

¹US phonetic tradition often uses the symbol [ɻ] for syllabic and post-vocalic [ɭ]. In this paper, we follow Ladefoged & Maddieson (1996) by using [ɭ] for all positional variants in rhotic dialects. The same set of tongue configurations can be found in all contexts in rhotic dialects of English (Boyce et al, 2015).

Likewise, in an ultrasound investigation of Spanish trill and tap rhotics using 20 native speakers from a wide range of Spanish-speaking areas, Rivera-Campos & Boyce (2013) found consistent evidence of tongue root retraction for the trill. They found that speakers were less consistent in the degree of tongue root movement for the tap. It should be noted that two of the speakers used a lateral rather than an apical version of the trill, but also showed simultaneous tongue root retraction. These observations suggest that cross-linguistic similarities in phonological patterning among rhotics may in fact be explained by a secondary place of articulation involving tongue root movement to narrow, or constrict, the pharyngeal space. Following Catford (1986) we will refer to this as “pharyngealization” when discussing the linguistic impact of the phenomenon, and as tongue root retraction when describing the articulation proper.

Typical and disordered acquisition of rhotics across languages

While cross-linguistic similarities in rhotic sounds have received a considerable amount of attention from linguists, less attention has been paid to similarities in acquisition or disorder patterns of rhotics across languages. In general, speech sound disorders are defined as failure to master production of a sound, or class of sounds, by the appropriate age. Additionally, sounds acquired at a later age also tend to be the sounds that show the most persistent disorder patterns (Shriberg, 1993). The English rhotic approximant /ɹ/ is a commonly cited example, with many children failing to achieve expected accuracy of production until age 8 (Shriberg, 1993). In addition, it is one of the most commonly misarticulated sounds in children learning English as their first language (Smit et al., 1990; Preston & Edwards, 2007; Shriberg & Kwiatkowski, 1994). Such an observation may apply to other languages where rhotics are also difficult for children to master.

Data on cross-language speech sound acquisition and disorder patterns is relatively scattered among communities of researchers working in particular languages and language environments. Available data, however, suggest that rhotics of all types seem to develop in the relatively late stages of speech sound acquisition, and to be overrepresented in clinically significant disorders. These data, largely drawn from a wide range of language-specific chapters in McLeod (2007), are summarized in table 1. The writers of these chapters are clinical researchers whose analysis of the situation in a particular language is based on both experience and literature in that language as well as in the more widely used research languages. It is worth noting, however, that the data are drawn from research studies that used a variety of methodologies and a variety of approaches to phonetic vs. phonological categorization. Some studies, for instance, reported age of rhotic acquisition in terms of two- or three-year age ranges, while others reported it in more fine-grained ranges of 6 months or a year. Additionally, the definition of acquisition stage varied; some researchers, for instance, defined age of acquisition as the point at which 75% of children had acquired the sound, while others used a 90% criterion. Some researchers used a single context or word to set their criterion, and some required that the sound be perceptually appropriate in all phonetic and prosodic contexts. Thus, the data in table 1 are abstracted from a wider range of allophonic and speaker variability. Nevertheless, the data show remarkable consistency across the wide range of languages and rhotic types studied.

Evidence for a Pharyngealization Role in Disordered Production of Rhotics

Investigators working with Magnetic Resonance (MR) and ultrasound images have previously noted that the misarticulations of /ɹ/ produced by many US English native-speaking children and adolescents lack the combination of an appropriately alveolar or postalveolar constriction by the tongue front (blade/tip) plus an observable tongue root bulge into the pharynx (Hamilton et al., 2012; Klein et al., 2013). These observations are supported by recently obtained MR images. Figure 2a shows an MR image of a child producing a misarticulated attempt at the English syllabic /ɹ/. While this child's tongue root is located close to the back pharyngeal wall, his primary articulatory constriction is in the velar area of the palate and is made with the tongue dorsum. Figure 2b shows an MR image of a different child producing an accurate attempt at the same sound. In the image in figure 2a, the child's tongue root is also positioned toward the back pharyngeal wall but somewhat more closely. In addition, and in clear contrast with figure 2a, his primary articulatory constriction is in the alveolar/postalveolar portion of the palate, and it is clear that the two parts of his tongue are moving in a differentiated fashion. The articulatory configurations shown in Figures 2a and 2b can be contrasted with articulatory configurations of normally-produced vowels. Figures 2c and 2d show MR images of a child with typical articulation producing /i/ and /u/. These images show a vocal tract configuration where the tongue root is advanced toward the lips. The MR images were collected from productions sustained for approximately 12 seconds in a supine position. Both children were approximately 9 years old, and speakers of a rhotic dialect of US English from the Midwest region. Ultrasound images showing a similar contrast between misarticulated and accurate productions from a third child with the same dialect background are shown in figures 4a and 4b.

These considerations led us to wonder about two separate but connected questions. First, we wondered whether the informal clinical reports indicating a similarity in acquisition and disorder patterns for rhotics across languages are borne out by the data. In other words, we wonder whether rhotics across languages are like English in showing a pattern of late acquisition and persistent misarticulation. Second, there is some reason to believe that the difficulty children experience with English rhotics is connected to difficulty in developing the ability to separate movement of the tongue front from movement of the tongue root, and to move both in different directions simultaneously (Klein et al, 2013). If this is true, rhotics such as palatal approximants and trills may be a natural class not only in terms of patterns across languages, but in terms of the articulatory difficulty of acquisition, and propensity for misarticulation (Gick et al., 2007). To answer the first question, it is important to examine the clinical data on acquisition and disorder for rhotics. To answer the second question, it is important to demonstrate that rhotics as a group show double articulation that includes pharyngeal narrowing due to a separate tongue root movement in the pharynx. If rhotics as a group show both late acquisition patterns and secondary pharyngeal narrowing, we may reasonably hypothesize that the two phenomena are related.

Exploring Applicability of the Pharyngealization Hypothesis

In the following section, we tentatively explore the issue of tongue root involvement in rhotics using ultrasound imaging for a small set of adult speakers in five languages: English,

Malayalam, Persian, French, and Spanish. The languages have very different phonological systems and they employ rhotic sounds of different types. We focus on three major types of rhotics—the palatal approximant (bunched or retroflex) such as shown in figure 1, the apical trill, and the uvular trill/fricative. Each of these has been described as late-developing and subject to misarticulation in at least one language. Although many languages use rhotic taps, we have left consideration of these segments for a later time for three reasons: (1) across languages, informal clinician reports suggest that taps are acquired much earlier than other rhotics, (2) Rivera-Campos & Boyce (2013) found relative articulatory inconsistency for rhotic taps in Spanish, and (3) phonologically, alveolar taps pattern with stops as well as rhotics (De Jong, 1998).

In what follows, we survey the behaviour of single speakers of each language during the (non-tap) rhotic of their native language, using ultrasound imaging of single words across a range of phonetic contexts. Some background information about rhotics in each language is included. Our major aim is to provide a “first pass” look at whether the rhotics of these languages resemble the rhotics of English in showing a secondary constriction in the pharynx made by movement of the tongue root toward the back pharyngeal wall. The dataset is not large, and the results are meant to be suggestive rather than definitive. A more comprehensive and quantitative study involving multiple speakers of each language and accounting for allophonic variation within the rhotic category will be required in future.

Method

A single adult native speaker was selected to provide ultrasound imaging data for rhotics in each of the following languages: US Midwestern English, Malayalam, Puerto Rican Spanish, European French (Cannes area), and Gilan-Lahijan Persian (Gilaki dialect). All speakers except the Puerto Rican Spanish speaker were female. All were bilingual in English as well as their native language. The French speaker was trilingual in Italian and English. Speakers had no history of speech, language, or hearing impairments. The English and Spanish speaker observations presented here are representative of data discussed in our larger studies on these languages (Rivera-Campos & Boyce, 2013; Zhou et al., 2008; Boyce et al., 2011).

A separate set of stimuli was designed for each language, aiming to elicit rhotic phonemes in simple one- or two-syllable real words. The stimuli were common, short words that might be chosen for treatment if a child had speech sound difficulties. The words used for the data shown in Table 2 are listed in Appendix A. As noted above, because the tongue front lowering of low back vowels such as /a/ is accompanied by retraction of the tongue root, while the tongue front raising for high front and high back vowels is accompanied by tongue root advancement, we included words with both high and low vowels in anticipatory and perseverative coarticulatory contexts. Illustrations of the contrasting tongue root positioning in these vowels can be seen in Figures 3a–c, which show MR images of an adult speaker of English producing these vowels. In fig 3c, /a/ shows tongue root retraction, while in fig 3a and 3b, /i/ and /u/ show tongue root advancement.

We did not prime speakers to use any particular style or register when reading words aloud, only instructing them to read the words naturally². There were no distractor or practice items. Subjects were not instructed about the purpose of the study. Subjects read the same stimulus list under two conditions: (1) head-stabilized, (2) free-holding the probe. For the purposes of analysis, only the head-stabilized data was used. However, we note that tongue root retraction was present for tokens collected in the free-holding condition as well.

Ultrasound images were recorded via an Aloka SSD-1000 ultrasound scanner with a convex transducer operating at 5MHz (60mm radius, 60° field of view). In general, the clearest images of tongue root movement across the different speakers were obtained with this machine, and with the slowest frame rate. However, because the slower frame rates made identification of the time course of tongue root movement more problematic, the experiment was repeated with the Aloka machine at several different frame rate settings (20 and 57 frames per second), and with a Siemens Acuson X300 with a convex transducer operating at 4 MHz (60mm radius, 90° field of view, 36 frames per second). Observations of tongue shape and movement were consistent across conditions.

Following Stone (2005)'s recommendations for Head and Transducer Support Systems (HATS), the following design considerations were put into place for the apparatus: The subject's head position was stabilized by resting the forehead and the point of the chin on a custom-built stand that left the jaw free to move while restraining the head. The probe was likewise held vertically along the underside of the speaker's jaw by a device affixed to a large frame, perpendicular to the skull. The frame of the apparatus was adjusted to the height of the subject to allow for greater comfort as well as improved imaging. The orientation of the probe was such as to capture a midsagittal image of the tongue surface along the path of the tongue groove. Because the aim was to capture static images of sustained articulations rather than movement over time, and the speakers were carefully monitored for head movement, this system of head stabilization was considered adequate. To ensure that the appropriate areas of the vocal tract were visible, researchers trained subjects to hold the probe so as to show two anatomical landmarks, the shadows cast by the hyoid bone and the mandible notch, on the screen at all times (see figure 4a). Speakers were continuously monitored to ensure that the probe placement did not deviate from midsagittal. The size of the probe together with the field of view ensured that an area of the pharynx behind the hyoid bone shadow could be viewed.

The audio recordings were made using an Audiotecnica AT2021 shotgun microphone. The ultrasound video and audio feeds were simultaneously recorded using a VHS recording device with a frame rate of 30 frames per second. Once recorded to VHS, the data were digitized to .avi file format using Sony SLV-D550P or Panasonic DMR-EZ48V dual VHS-DVD units, a Behringer Xenyx 502 Mixer, Gigaware VHS-to-DVD Video Converter, Realtek High Definition Audio soundcard and Debut Video Capture Professional digitizing software (NCH Software). The audio was digitized at 16 bits and a sampling rate of 32 KHz.

²The Puerto Rican Spanish speaker is bi-dialectal in Puerto Rican Spanish and decided to use what he felt was the prestige variety of Spanish for his recording. The prestige variety has a coronal rhotic (an apicoalveolar trill /r/), while vernacular Puerto Rican Spanish uses a dorsal rhotic (uvular fricative /ʁ/, which our speaker produced when asked). The speaker's decision to use the prestige form may correspond to sociolinguistic pressures on the island (Zentella, 1987).

Researchers used Wavesurfer 1.8.5 (Beskow & Sjolander, 2005) with a video plugin to display a real-time ultrasound video and synchronized audio. This software allows for frame by frame inspection of ultrasound data. Three phonetically trained researchers evaluated each ultrasound recording for tongue root movement into the pharyngeal space. They were instructed to pay particular attention to sustained high vowels, and words with rhotics embedded in high front vowel contexts, because the tongue root is consistently far advanced (away from the back wall of the pharynx) for these vowels. As noted above, Figures 3a–c shows an MR image of the sustained high front vowel /i/, the high back vowel /u/ and the low back vowel /ɑ/, produced by a speaker of English. Ultrasound images for these vowels produced by speakers of all the languages surveyed in this paper were consistent with the English productions in MR images. An illustration of this similarity for /i/ produced by the Spanish speaker is shown in figure 5c.

The ultrasound frame used for rating the productions was chosen by first measuring the acoustic duration of the segment, finding the midpoint of that measurement, and looking for the frame closest to the midpoint. If several frames were available, the frame showing a tongue shape that was most distinctively different from the previous and following phonetic context sounds was chosen. The productions were classified as ‘+pharyngeal constriction’ if some excursion past the hyoid shadow was seen. Twelve tokens of the 100 rhotic productions for all speakers showed unclear evidence of tongue root movement and were removed from the analysis. Of the twelve, seven were from the Malayalam speaker and five from the French speaker.

Results

The results of the ratings for all four languages are shown in table 2. Language-specific considerations and results are described below.

English

As noted above, the /ɹ/ rhotic of English is best described as having an underspecified constriction location somewhere in the alveolar-postalveolar continuum and a secondary constriction located in the pharynx. It is listed as palatal in the current IPA chart, but in the past has been listed as alveolar or postalveolar. The IPA chart does not reference a secondary constriction or pharyngealization. MR images of appropriately-articulated /ɹ/ by adult American English speakers are illustrated in Figure 1. An MR image of an appropriate production by a child is shown in Figure 2b.

These MR images may be compared with ultrasound images shown in figures 4a–b. These are representative of clinically significant misarticulations and appropriate productions by children and young adults with residual speech sound disorders for /ɹ/. They are typical of many collected in the course of clinical treatment, in words with initial, final, and syllabic /ɹ/ in different phonetic contexts. The misarticulated versions have been transcribed variously as [w], [ɔ], [ə], and [ʊ] by clinicians, and may reflect what Adler-Bock et al. (2007) have termed a velar approximant with different degrees of lip rounding. In our study, all appropriately articulated English rhotic approximants showed pharyngeal constriction, regardless of position in the word or phonetic context. Misarticulated approximants either

showed tongue front constriction accompanied by tongue root advancement, or tongue root retraction with velar constriction by the tongue dorsum and no tongue front movement. An MR image of the latter configuration, which sounded something like /ʌ/, is shown in Figure 2a. In figure 4a and 4b, we illustrate a case of a speaker who was originally misarticulating /ɪ/ but who later learned to produce it correctly. Figure 4a shows an attempt at the word ‘ear’, but misarticulated, sounding something like [iə]. The absence of pharyngeal constriction is shown by the relatively vertical angle of the tongue root in front of the hyoid bone shadow. Figure 4b shows the English rhotic approximant in the syllable ‘ree’, accurately produced as [ɹi]. The presence of pharyngeal constriction in 4b is visible as the more horizontal angle of the bright white line in the vicinity of the hyoid bone shadow.

Spanish

Spanish is described as having two rhotic phonemes, /r/ and /ɾ/, which are used contrastively only in the intervocalic position (Lindau, 1985; Proctor, 2011). Although both /r/ and /ɾ/ are considered to be late-developing sounds, children tend to master the Spanish tap before the trill /r/, with the tap mastered by the age of 6 and the trill typically mastered a year later at age 7. The trill in particular is considered challenging to remediate and some children never acquire it successfully (Bosch-Galcerán, 2005). For this reason, we focus on the Spanish trill.

As with English, common descriptions of tongue configuration for the Spanish trill concentrate on specifying the location of the primary articulation (described as alveolar or coronal) and describing the aerodynamic conditions necessary for production of the rapid alternating occlusions characteristic of trilled sounds in general (Fernandez, 2000; Lindau, 1985; Martinez-Celdrán, 1997; Quilis, 1981, 1993; Solé, 2002). Some articulatory descriptions of the trill in Spanish and the related language Catalan can be read as implying tongue root movement (Navarro, 1918; Recasens, 1991), but these mentions are not conclusive. The clinical literature on how to remediate Spanish /r/ misarticulations in children is similarly focused on the action of the tongue tip/blade and the primary place of articulation.

However, in a study of 20 Spanish speakers from a range of dialects, Rivera-Campos & Boyce (2013) observed tongue root retraction toward the back wall of the pharynx in all word positions and in all phonetic contexts. A representative speaker was re-recorded for purposes of this paper; these data are shown in Table 2 below. This pattern of tongue root movement is illustrated in figure 5a and 5b, which show the word-initial Spanish rhotic [r] in ‘riso’ [riso] contrasted with the vowel /i/ from the same word. For this speaker, the ultrasound transducer was not able to simultaneously capture the area of the tongue tip and the area of the tongue root. Consequently, the ultrasound field of view in these images is oriented so as to capture the back of the oral cavity and the tongue root. Retraction of the tongue root toward pharyngeal constriction is visible on either side of the hyoid bone shadow for /r/, while the tongue root is shown in a more advanced, almost vertically oriented, position for /i/. The same speaker’s sustained /i/ is provided in figure 5c, where we see the tongue root showing a nearly vertical orientation, just as for /i/ in /riso/ (figure 5b). (Note that the rapid movement of the tongue blade/tip up and down during the trill /r/ was

not captured in any of the Spanish images, but is visible for the Malayalam as a double white line in the right panel of figures 6a).

Malayalam

As with Spanish, Malayalam is described as having two rhotic phonemes: /r/, a trill, and a tap or flap, /ɾ/. Speakers are faithful to this contrast in intervocalic position (i.e. /kari/ *soot* and /kari/ *curry*), but are less consistent in other word positions (Krishnamurti, 2003). A third phoneme /ɻ/ (also written /ɭ/) has been alternately described as a rhotic and as a lateral (Punnoose, 2011; Scobbie et al., 2013; Punnoose & Ghattab, 2012). It is usually classified as an approximant but may be produced as a fricative under some conditions (Scobbie et al., 2013). Although evidence for the rhoticity of /ɻ/ is unclear, it is said to involve a “dark” resonance suggesting either velarization or pharyngealization. Accordingly, for this paper, we considered both the definitively rhotic trill /r/ and the approximant /ɻ/.

In our study, the Malayalam rhotic trill /r/ consistently showed tongue root movement toward pharyngeal constriction in initial and intervocalic word position in both high front and low back vowel contexts. Figure 6a shows an ultrasound image during the Malayalam rhotic trill in ‘ruppika’ [rupikɑ] and figure 6c shows the image during the rhotic trill in ‘kayer’ [kɑjər], contrasted with the tongue root position for the semivowel [j] in 6d. Tongue root retraction movement for pharyngeal constriction is visible extending through the hyoid bone shadow. Note that the Malayalam trill is very similar to the Spanish trill. (The limitations of frame rate for still images makes it hard to discern the oscillation of the tongue tip/blade during the trill, but it can be seen in the figure for the Malayalam trill [Figure 6a]). The contrast between tongue root retraction for the trill, and tongue root advancement for the /u/, is illustrated in Figure 6b, which shows the tongue shape during [u] in the same word. A similar contrast was visible for phonetic contexts with front vowels and semivowels in figures 6c and 6d for ‘kayer’ [kɑjər]. As with the Spanish speaker, the ultrasound transducer was not able to simultaneously capture the area of the tongue tip and the area of the tongue root. Consequently, the ultrasound field of view in these images is oriented so as to capture the back of the oral cavity and the tongue root.

Our results for Malayalam are similar to those reported by Scobbie and colleagues (Scobbie et al., 2013). In their study, ultrasound and tongue contour-tracking software were used to investigate the articulatory characteristics of rhotics in a single speaker of Malayalam. In their study, the evidence for pharyngeal constriction was strong for the trill. Tongue root movement toward the back pharyngeal wall for /r/ in Tamil (a closely related Dravidian language) has also been shown using MR imaging (Narayanan et al., 1999).

In our data, the /ɻ/ approximant showed pharyngeal constriction in all contexts assessed, although the extent of tongue root movement was not as great as that observed in the trill articulation. As with the trill, this result is consistent with the Scobbie et al. (2013) finding that the /ɻ/ phoneme showed pharyngeal constriction but with less excursion. The authors suggested that substantial pharyngeal constriction may facilitate the complex anterior articulation of the trill by stabilizing the back of the tongue.

Persian

Persian is described as having a single rhotic phoneme, which is sometimes described as a tap and sometimes described as a trill (Rafat, 2010; Izadi et al., 2014). However, there is considerable allophonic variation according to word position for this phoneme (Rafat 2010). The tap is said to occur consistently only in intervocalic position while voiceless alveolar trills are said to occur everywhere else (Carr, 1993; Ladefoged & Maddieson, 1993). Approximant versions of the rhotic may be found in all word positions (Rafat, 2010). As with English and Spanish, rhotics are among the latest developing sounds in Persian-speaking children's phonetic inventories (Damerchi, Jalilehvand, Bakhtiari and Keyhani, 2010) and rhotic misarticulations are common in children (personal communication from speech-language pathologist colleague Hedieh Hashemi Hosseinabad).

Our speaker had an allophonic pattern of producing trills in all word positions except onset position, where the rhotic was more likely to be an approximant. She produced both types of rhotic with strong pharyngeal constriction in all tokens. The difference between pharyngeal constriction for [r] and advanced tongue root for [i] is illustrated in the contrast between Figures 7a ([r]) and 7b ([i]), which show the ultrasound images during each sound for the word [ʃir].

French

Descriptions of the French rhotic concur in describing it as largely uvular, although there is some evidence of dialectal variation employing alveolar allophones (Rose & Wauquier-Gravelines, 2007). Some descriptions state that the uvular trill is more common, particularly in Parisian French (Rose & Wauquier-Gravelines, 2007), while others state that the most common variant is the uvular fricative /ʁ/ (Ladefoged & Maddieson, 1996). Rhotics are collectively described as difficult for children to acquire and master (Rose & Wauquier-Gravelines, 2007). While most descriptions of uvular obstruents concentrate on the raising of the tongue dorsum for the primary constriction, Ladefoged and Maddieson (1996) also cite evidence for secondary tongue root retraction in an x-ray study first reported by Delattre (1971). This evidence is especially interesting, as for these sounds, the tongue root retraction occurs before the beginning of the trill proper (see Figure 8, adapted from Ladefoged & Maddieson, 1996, c.f. Delattre, 1971. Note that the left image is taken from an earlier time point in the trill articulation than the right image).

Our French speaker produced uvular fricatives for all rhotics in all word positions and contexts. Ultrasound imaging of tongue configuration during production of /ʁ/ and /i/ show differences in tongue root positioning for both sounds (See Figures 9a and 9b). These images were taken at the midpoint of each segment in the word "pir" [piʁ]. Our observations of the relative timing of the tongue root movement vis a vis the movement of the tongue dorsum toward the uvula were also consistent with the timing pattern described in Ladefoged & Maddieson (1996). As with English, Spanish, Malayalam and Persian, this movement of the tongue root toward the back wall of the pharynx was particularly clear in the /i/ context but can also be observed in the /u/ context due to fact that both high vowels are produced with a nearly vertical orientation of the tongue root.

Discussion

The results of this observational cross-linguistic study suggest that the non-tap approximant, trill, and fricative rhotics considered here –the English palatal approximant /ɹ/, Malayalam palatal /ɻ/, the Spanish/Malayalam/Persian alveolar trill /r/, and the French uvular fricative /ʁ/– all show a pattern of tongue blade or dorsum movement toward the palate accompanied by tongue root movement toward a pharyngeal constriction. Observation of this pattern was established by contrasting patterns of movement in rhotic vs. non-rhotic contexts using vowels (/i/, /u/, /e/) whose articulation involves an advanced tongue root configuration. As noted above, x-ray data from Delattre & Freeman (1971) indicated that the tongue root movement for French and German uvular trills preceded movement of the tongue dorsum toward the uvular place of articulation. Our observations suggested a similar time course for the primary and secondary constrictions, but the qualitative nature of our observations does not allow us to be precise; the tongue root movement may begin within a short window of time before, during or after the primary constriction is made. Additional data are needed to determine whether this order holds for sounds with a more anterior primary constriction, or for all phonetic contexts.

Overall, our data suggest that the rhotics surveyed in this paper can be classified as *doubly articulated*. In other words, rhotics appear to be produced with both a primary and a secondary place of articulation, with the primary place of articulation occurring somewhere along the continuum from the alveopalate to the velopalate, and the secondary place of articulation involving a movement of the tongue root toward the back wall of the pharynx. The linguistic term “pharyngealization” may be appropriately applied to indicate a secondary pharyngeal place of articulation.

From a clinical point of view, these data on normal patterns of production across different languages (English, Spanish, Malayalam, Persian, French) provide a potential explanation for why rhotics as a group are (1) mastered late, (2) often subject to misarticulation, and (3) difficult to remediate (see Table 1). In effect, these data suggest that rhotics may be difficult to acquire because they involve two different primary and secondary constrictions involving two parts of the tongue.

Clinical wisdom commonly holds that trills are difficult because of the complex anterior articulation using the tongue tip and blade, together with the delicate aerodynamics required for multiple rapid occlusions. Our data, however, suggest that the difficulty of trills may also be associated with differentiation of tongue front and tongue root movement. Additionally, they support the Scobbie et al. (2013) suggestion that the tongue root movement aids tongue body stabilization during the complex anterior articulation of trills. Less information is available for the acquisition of rhotics in Malayalam, and the clinical prevalence of misarticulations, but what information we do have is consistent with the Spanish picture. Clinicians working in languages or dialects that use rhotic approximants such as English have not typically been able to explain why these approximants are particularly difficult to acquire, but the same potential explanation applies. If we assume that producing a differentiated tongue configuration with vocal tract constrictions in both oral and pharyngeal

locations involves greater motor difficulty, it seems quite plausible that rhotics involving pharyngealization should be both harder to acquire and more frequently misarticulated.

From a purely linguistic standpoint, it is interesting to consider whether, as Catford (1986) suggested long ago, pharyngealization may be one of the organizing principles of rhotics as a natural phonetic class. As the IPA usage of Roman letter “r” suggests, trills are considered to be the archetypal rhotics (Punnoose, 2011), and our observations suggest that they are among the rhotics that show the most consistent secondary tongue root movement. The observations from English and Persian on approximants, and from French on uvulars, further suggest that pharyngealization is a strong intersecting feature of the class of rhotics. More data, from more languages and with a more quantitative focus, is necessary to answer this question.

From a clinical standpoint these data on the role of secondary pharyngeal constrictions are significant. Our data strongly imply that those sounds with the most consistent pharyngeal constriction also appear to be the most difficult for children and to be most implicated in speech sound disorders. This information is reflected in few textbooks or teaching materials available to clinicians in any of the languages studied here. It is likely that lack of knowledge regarding tongue root movement patterns/pharyngeal constriction has hampered the development of maximally effective teaching strategies for rhotics across a wide variety of languages.

A limitation of this study is the restricted view afforded by ultrasound. The nature of ultrasound technology does not allow for imaging the palate or pharyngeal walls. Without information about these structures, it is impossible to have precise information about the exact location of constrictions. The ultrasound probe, in midsagittal section, can only image the existence of tongue root movement relative to inexact anatomical reference points such as the hyoid shadow. The role of the pharyngeal walls in creating a constriction cannot be assessed. Finally, scanning the midsagittal section shows the tongue surface along the tongue groove and gives no information on the position of the tongue sides. Because the tongue groove for these rhotic sounds extends from the palatal location into the pharynx, an image of the tongue surface in the tongue groove may underestimate the degree of movement by the tongue sides. There may be an impression of little tongue root excursion when, in fact, the sides of the tongue extend into the airspace and thus reduce the size of the vocal tract constriction.

In addition to the above caveats, it is worth pointing out that while the data suggest an association between the clinical incidence of misarticulations and pharyngealization, it is not clear whether the relationship can be traced to involvement of the tongue root in particular, to the difficulty of learning separate motor control patterns for parts of the tongue at two locations, or to some other factor. More data from more targeted studies will be required to elucidate this question.

Conclusion

In French, Persian, Malayalam, English, and Spanish, qualitative observation shows that pharyngeal constriction is consistently present for rhotic approximants, uvular fricatives, and trills. At this point, it is unclear whether secondary pharyngeal constriction may be a feature of rhotics in general, or it may be a feature that characterizes a subclass of rhotics with notably complex articulation due to differentiated tongue movements. Clinically, the data showing that rhotic sounds are difficult to acquire, together with the data from English misarticulations, suggest that secondary pharyngealization may be characteristic of those rhotic types that are most difficult for children to acquire. Although historically clinicians have focused their remediation efforts on primary constrictions in the oral cavity, consideration of secondary places of articulation, and in particular consideration of the role of the tongue root, may be helpful in designing remediation for rhotic sounds. In other words, clinical strategies that include attention to tongue root as well as tongue front configuration (such as facilitative contexts with tongue root movement) may be worth exploring in remediation of rhotic misarticulations across languages.

This is particularly relevant for clinicians working with imaging technologies that provide information about the pharyngeal cavity, such as ultrasound, and which have been extensively used to remediate speech errors in rhotics (Preston et al, 2013; Bernhardt 2005; Adler Bock et al, 2007). These clinical investigations, however, have occurred in English. Ultrasound is now more accessible to clinicians and researchers alike for studying speech, and it is important to provide cross-linguistic information that can be used to guide investigations in understudied populations, languages, and dialects. Such research across languages may help to resolve long-standing questions about speech sound errors and how to remediate them.

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Appendix A

English

Zipper [zipəɪ]

Ree [ɹi]

Rye [ɹaɪ]

Rake [ɹek]

Row [ɹo]

Ray [ɹe]

Rat [ɹæt]

Drop [dɹɒp]

Green [gɹiːn]

Ear [ɪɹ]

Are [ɑɹ]

Air [eɹ]

Door [dɔɹ]

Actor [æktəɹ]

Brag [bræg]

Free [fri]

Roo [ɹu]

Or [ɔɹ]

Ire [ɑɹ]

Spanish

Raza [rasa]

Rama [rama]

Rema [rema]

Riso [riso]

Roma [roma]
Rugoso [ruɣoso]
Raul [rawl]
Reina [rejna]
Riachuelo [rjatʃwelo]
Ruina [rujna]
Jarra [hara]
Torre [tore]
Cierro [sjero]

Malayalam*

Randeh [raɳdə]
Raathri [ra:tri]
Ruchi [rutʃi]
Rokkam [rɔk:am]
Eruma [eruma]
Kuru [kuru]
Kayer [kajər]
Oraal [ora:ɭ]
Ara [ara]
Paara [para]
Raani [ra:ɳi]
Ruppika [rup:ika]
KuuRa [ku:ra]
NiRa [nira]
Uuzham [u:z̥am]

*Orthographical representations of Malayalam words from Punnoose (2011)

Muzha [muz̥a]

Mazha [maz̥a]

Kuzhi [kuz̥i]

Kiizhe [ki:z̥e]

Puzha [puz̥a]

Kozha [ko:z̥a]

Aazham [a:z̥am]

Mozhi [mɔz̥i]

Pizha [pɪz̥a]

Taazhu [ta:z̥ə]

Kazhi [kaz̥i]

Tuzha [tuz̥a]

Persian**

Reshte [reʃte]

Ruzz [rɒz]

Roke [rok]

Roos [ruz]

Reesh [riʃ]

Rang [ræŋ]

Farsi [fɒrsi]

Aertesh [æteʃ]

Zorrat [zorɒt]

Farrokh [færox]

Gharre [qɒre]

Darre [dɒre]

**Orthographical representations of Persian words provided by native Persian speaker

Jarrah [dʒɔrɒh]

Zarrin [zɔrin]

Ahar [ɒhɔr]

Beh tar [behtær]

Che joor [tʃedʒur]

Chaar [tʃɔr]

Sheer [ʃir]

Ghater [qɔter]

Ahan roba [ɒhɔnrɒbɔ]

Sal rooz [sælruːz]

Ghooree [quri]

Gol rokh [gɒlroʊk]

Esrail [esrɔjɪl]

Tasri [tɒsri]

French

Attere [atɛʁ]

Par [paʁ]

Pire [piʁ]

Docteur [dɔktœʁ]

Encore [ɑ̃kɔʁ]

Origine [ɔʁiʒin]

Peureux [pœʁœ]

Paresser [paʁɛsɛ]

Cheri [ʃɛʁi]

Arrachage [aʁaʃaʒ]

Remercier [ʁɛmɛʁsjɛʁ]

Rien [ʁien]

Rire [ʁiʁ]

Riviere [ʁivjɛʁ]

Revue [ʁəvy]

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Figure 1. Midsagittal Magnetic Resonance Images from 12 native speakers of US English producing sustained syllabic /ɹ/ as in 'pour'. These are adapted from Tiede et al. 2004.

Figure 2a

Figure 2b

Figure 2d

Figure 2.

Figure 2a. Midsagittal Magnetic Resonance Image from an US English-speaking child producing a misarticulated version of sustained syllabic /ɹ/ (sounds like rounded /ə/).

Figure 2b. Midsagittal Magnetic Resonance Image from an US English-speaking child producing an accurate version of sustained syllabic /ɹ/.

Figure 2c. Midsagittal Magnetic Resonance Image from an US English-speaking child producing a sustained /i/ vowel.

Figure 2d. Midsagittal Magnetic Resonance Image from an US English-speaking child producing a sustained /u/ vowel.

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A sagittal T2-weighted MRI scan of the cervical spine. A clear fracture line is visible through the vertebral body of the sixth cervical vertebra (C6). The surrounding soft tissue structures, including the intervertebral discs and spinal cord, are also visible. Technical parameters in the top right corner include: PM, N/A, 1.5T, 80cm, 2.3, FFM, 3.0ms - TR, 12ms, 9.4V, 1.8, 0ms. Orientation markers H (head) and A (anterior) are shown in the bottom left corner.

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Figure 3c

Figure 3.

Figure 3a. Midsagittal Magnetic Resonance Image from a US English-speaking adult producing a sustained /i/ vowel.

Figure 3b. Midsagittal Magnetic Resonance Image from a US English-speaking adult producing a sustained /u/ vowel.

Figure 3c. Midsagittal Magnetic Resonance Image from a US English-speaking adult producing a sustained /a/ vowel.

Figure 4a

Figure 4b

Figure 4.

Figure 4a. Ultrasound Image from a US English-speaking child producing a misarticulated version of /ɪ/ (sounds like rounded [ə] or [ʊ]). Instructions were to say 'ear'.

Figure 4b. Ultrasound Image from an US English-speaking child producing an accurate version of /ɪ/. Instructions were to say 'ree'.

Figure 5a

Figure 5b

Figure 5c

Figure 5.

Figure 5a. Ultrasound Image of Spanish rhotic production of [riso].

Figure 5b. Ultrasound Image of Spanish [i] in [riso].

Figure 5c. Ultrasound Image of Spanish sustained [i] vowel.

Figure 6a

Figure 6b

Figure 6d

Figure 6.

Figure 6a. Ultrasound Image of Malayalam rhotic production of [rup:ika].³

Figure 6b. Ultrasound Image of Malayalam [u] in [rup:ika].

³Note that we transcribe the Malayalam speaker's productions as heard, though in Appendix A, we use the orthography and transcription from Punnoose (2011) as the record of stimuli presented to speakers.

Figure 6c. Ultrasound Image of Malayalam [r] in [kəjər]

Figure 6d. Ultrasound Image of Malayalam [j] in [kəjər]

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Figure 7a

Figure 7b

Figure 7.

Figure 7a. Ultrasound Image of Persian rhotic production of [ʃir].

Figure 7b. Ultrasound Image of Persian [i] in [ʃir].

Figure 8.

X-Ray tracing of sequential frames for the French intervocalic uvular trill. These are adapted from Delattre & Freeman (1971).

Figure 9a

Figure 9b

Figure 9.

Figure 9a. Ultrasound Image of French rhotic [ʀ] in [piʀ].

Figure 9b. Ultrasound Image of French [i] in [piʀ].

Table 1

Summary table of rhotic acquisition across languages, compiled by the authors from data supplied in clinically-focused chapters in McLeod, 2007. Note that chapters were not necessarily consistent in depth of phonetic analysis.

Language	Rhotic described in McLeod (2007)	Described as Late developing
Jordanian Arabic	r	Yes
	ʁ	Yes
Lebanese Arabic	r	Yes
	ʁ	Yes
Dutch	ʀ	Yes
General American English	ɹ	Yes
English	ɹ	Yes
Finnish	r	Yes
Filipino	r	Yes
French	Uvular variation: R, ʁ, r, ʀ	Yes
German	r	Yes
	ʁ	Yes
Greek	ʀ	Yes
Israeli Hebrew	ʁ	Yes
Korean	ʀ	Yes
Maltese	ɹ	Yes
Norwegian	ʀ	Yes
	ʁ	Yes
Portuguese	ʀ	Yes
Putonghua (Modern Standard Chinese)	ɹ	Yes
San Lucas Quiaviní Zapotec	r	Yes
	ʀ	Yes
Sesotho	r	Yes
Spanish	r	Yes
	ʀ	Yes
Thai	r	Yes
Turkish	ʀ	Yes
Welsh	r	Yes
	r ^h	Yes

Table 2

Pharyngeal constriction observations across languages

	Trill [r]		Palatal Approximant [ɹ], [ɻ]		Uvular Fricative [ʁ]	
	% PC	#/Total n	% PC	#/Total n	% PC	#/Total n
Spanish	100%	13/13	N/A		N/A	
Malayalam	100%	14/14	100%	13/13	N/A	
US English	N/A		100%	19/19	N/A	
French (Cannes dialect)	N/A		N/A		15/15	
Persian	100%	8/8	100%	18/18	N/A	