FROM ENGLISH RHOTIC APPROXIMANT TO SPANISH RHOTIC TRILL: A CASE STUDY

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ABSTRACT

The purpose of this case study was to explore the use ultrasound imaging as a biofeedback tool to teach production of the apicoalveolar rhotic trill /r/ to an adult Spanish second language learner. To gather and analyze data, a single case research design was implemented. Ultrasound imaging allowed for monitoring of tongue section positioning during production of speech sounds and allowed for individualized feedback focused on accurate and inaccurate tongue section positioning. Results show changes in tongue configuration during ultrasound sessions as well as post-treatment. Implications for clinical and teaching practices are furthered discussed.

KEY WORDS: biofeedback, Spanish, speech sounds, trill, rhotic, single case research

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INTRODUCTION

Ultrasound imaging is widely used in the medical field for the assessment of various physiological parameters of the human body due to its relative safety compared to technologies that use radiation like X-rays (Merritt 1989). Ultrasound imaging has been recommended in the area of speech production because it allows patients to monitor structures inside the oral cavity (Kelsey, Minifie & Hixon, 1969). Using ultrasound technology, one can monitor the positioning and configuration of the tongue, an articulator that is constantly changing positioning and shape along the vocal track when speech sounds are produced. However, changes in positioning and shape during speech production are not random, given that individuals purposely make these changes by learning how to control movement of the various segments of the tongue.

The tongue can be subdivided into functional segments that can be moved independently (Stone, Epstein, & Iskarous, 2004). These functional segments are tongue root, tongue dorsum, tongue blade, tongue tip, and lateral sides (Stone et al., 2004). To produce speech sounds, independent movements of these segments must be achieved to aid in shaping the vocal tract by creating constrictions that produce the intended acoustic information for the target speech sound. If a shaped vocal tract does not produce the expected acoustic information—due to misarticulations—the sound can be perceived as erroneous and speech intelligibility can be negatively affected.

Misarticulation of speech sounds is common in children as well as in second language learners, both of whom are mastering the sounds of a language. In children, misarticulations are expected to be resolved as the child matures, with late developing sounds exhibiting an adult-like production by age 7 (Bleile, 2006). Speech sound misarticulations beyond that age are typically followed by referrals for speech remediation treatment (Bernthal, Bankson, & Flipsen, 2013). In adults who are learning a second language, misarticulations can occur due to the challenge of learning sounds that are not shared between the main and second languages. For this difficulty, adult learners receive formal instruction on how to produce the target sound, typically through formal coursework.

For English native speakers learning Spanish as a foreign language, the apicoalveolar trill /r/ is commonly the target of errors or substitutions (Añorga & Benander, 2015; Johnson, 2008). Though both languages include two rhotics in their sound inventory, one of the two rhotics is not shared as English uses /ɾ/and /ɹ/ while Spanish uses /ɾ/ and /r/ (Ladefoged & Madieson, 1996). For children who are native speakers of Spanish, the /r/ sound is the last sound to be mastered (Carballo & Mendoza, 2000; Jiménez, 1987) as /r/ requires precise articulation and aerodynamics (Solé, 2002). This same challenge is faced by many native speakers of English that are learning Spanish as a foreign language when productions of /r/ are produced as /ɹ/or /ɾ/ (Johnson, 2008).

English and Spanish Rhotics

English Rhotic Approximant

English uses two rhotic sounds, an approximant /ɹ/, and a tap /ɾ/ (Ladeforged & Maddieson, 1996). Tongue shape for production of the approximant rhotic can vary by speaker and a multiplicity of tongue configurations may be used (Dellatre and Freeman, 1968; Zhou, Espy-Wilson, Boyce, Tiede, Holland, Choe, 2008; Zawadzki and Kuehn, 1980; Alwan, Narayanan, et al, 1997; Guenther, Espy-Wilson, Boyce, Matthies, Zandipour, Perkell, 1999). Data shows that the main constriction for the rhotic approximant can be positioned at several points: alveolar, post-alveolar, and mid-palatal. This variability also influences positioning of the various functional segments of the tongue, creating multiple tongue configurations that produce a perceptually accurate rhotic approximant. Some configurations have a raised tongue tip and blade that points towards the palate, whereas other configurations have a raised tip and blade that does not point towards the palate. The tongue dorsum can also have various configurations, sometimes being arched, dipped or relatively horizontal.

Spanish Apicoalveolar Trill

Spanish also uses the rhotic tap /ɾ/ (Ladefoged & Maddieson, 1996). However, unlike English, Spanish uses an apicoalveolar rhotic /r/ (Ladefoged and Maddierson, 1996; Navarro-Tomas, 1996). Production of /r/ is primarily described as a series of brief and fast apicoalveolar constrictions sustained by aerodynamics (Solé, 2002; Martinez-Celdrán, 1997). These brief and fast apicoalveolar constrictions are made by positioning the frontal segments of the tongue, tongue blade and tongue tip in the alveolar area (Ladefoged & Maddieson, 1996; Navarro-Tomas, 1996). However, other segments of the tongue, like the tongue root, tongue dorsum, and lateral sides require precise positions to achieve /r/. Tongue root has been described as being retracted (Boyce et al., 2016) and air is channeled along the tongue by the bracing of the lateral sides against the teeth (McGowan, 2002). Unlike the English rhotic approximant, /r/ does not have variable tongue configurations that can be used to achieve the target sound.

Teaching production of sounds to second language learners of Spanish

For some second language learners, learning new articulatory movements for a target sound not found in their primary language can be challenging (Waltmunson, 2005). This challenge can be greater if the sound being learned has complex articulatory requirements. Such is the case of /r/, where proper production requires precise tongue configuration and aerodynamics that are sensitive to change (Solé, 2002). In the case of native speakers of American English, learning to produce /r/ will require learning new articulatory movements that are not shared with the English rhotic approximant. This challenge can be intensified by the various tongue shapes native speakers of American English can use for production of /ɹ/ (Zhou, Espy-Wilson, Boyce, Tiede, Holland, Choe, 2008).

Common sources of formal instruction of /r/ include textbooks, diagrams, animations, auditory models, and recorded speech. Though these sources have been used with positive outcomes, some learners can still struggle with acquisition of /r/ (e.g. Lord, 2005; Hurtado & Estrada, 2010; Añorga & Benander, 2015; Kissling 2013). The continued struggle could be borne of the various innate challenges or inaccuracies these sources commonly present. Diagrams and animations regularly offered in textbooks or via computer software are frequently artistic interpretations of the articulatory requirements of a speech sound. These interpretations can portray inaccuracies in constriction placement and tongue section positioning along the vocal tract for the represented speech sound. Another limitation is that these representations mainly focus on what has been described as the main place of articulation of the sound. In case of /r/, attention is primarily given to the apicoalveolar constriction and not much attention is provided to positioning of the rest of the tongue sections. A common pattern is the use of midsaggital views of the oral cavity and articulators to showcase location of the main constriction. Though this view allows the learner to better understand positioning of the main constriction along the vocal tract, the view provides no information about the positioning of lateral sides of the tongue, as such information would require a coronal view of the tongue to be displayed.

A different type of tool used for teaching sound production and for increasing awareness of differences between speech sounds is the use of spectrographic displays (Lord, 2005). Spectrographic displays can be used as a biofeedback tool to provide immediate information about the attempted production, which can then be individualized to bring attention to similarities and discrepancies between the native speaker's and learner's attempt. Herd (2011) reports increased /r/ production accuracy of participants who were native speakers of American English and were learning Spanish as a second language after using spectrographic displays. Participants were presented with a spectrographic image of a native speaker's production of /r/ and were asked to match their attempt with the image presented. Though it is beneficial to have immediate feedback for comparison between the expected and attempted performance, information presented on a spectrographic display comes with challenges for second language learners. First, interpreting spectrographic displays requires training, as the information displayed cannot be intuitively analyzed and understood by the average person. Second, spectrographic displays are abstract representations of tongue configuration and localization of constrictions along the vocal tract, more so than an artistic interpretation of the vocal tract configuration during production of a speech sound. Third, there is no simple correspondence between tongue configuration and the acoustic signal (Neri, A, Cucchiarini, Strik & Boves, 2002).

Biofeedback for Remediating Residual Speech Sound Errors in Children

Children who exhibit speech sound errors beyond the typical age of acquisition are considered to have residual speech sound errors (Shriberg, Austin, Lewis, McSweeny, & Wilson, 1997). These children are referred to speech-language pathologists (SLPs) for remediation of these errors. Some approaches used for teaching accurate production of a speech sound include elicitation procedures based on shaping a sound from another (e.g. shaping /s/ from /t/) and phonetic placement cueing (e.g. use tongue depressor to touch sides of tongue for /s/) with multiple opportunities for repetition and production practice (Secord, Boyce, Donohue, Fox, & Shine, 2007; Van Riper & Erickson, 1996). Other approaches include biofeedback technologies such as spectrographic displays (McAllister Byun & Hitchcock, 2012), electropalatography (Dagenais, 1995; Dent, Gibbon, & Hardcastle, 1995) or ultrasound imaging (Adler-Bock, Bernhardt, Gick, & Bacsfalvi, 2007; Preston, Brick, & Landi, 2013, Preston et al., 2014; Modha, Bernhardt, Church & Bacsfalvi, 2008).

Ultrasound visual biofeedback has been effective for remediating speech sound errors in children with residual speech sounds errors that affected production of velar stops (Cleland, Scobbie, & Wrench, 2015), palatal sounds (Cleland, Scobbie, & Wrench, 2015), alveolar Cleland, Scobbie, & Wrench, 2015), and rhotic approximants (Preston, et al., 2014; Cleland, Scobbie, & Wrench, 2015; Adler-Bock, Bernhardt, Gick & Bacsfalvi, 2007). Imaging of tongue shape when a sound is produced allows for precise and individualized feedback that focuses on the tongue section placement—either accurate or inaccurate—of the individual. This is in contrast to the lack of tongue shape information that can be derived from an individual when more commonly used approaches are employed, such as by shaping a sound from another and phonetic placement. With imaging technologies, the learner and the clinician are made aware of discrete errors that cannot otherwise be identified via perceptual judgement of a sound, or discrete progress in tongue shapes that resembles a more native-like tongue shape even if the production attempted resulted in a sound error.

Research data on the use of ultrasound imaging for remediation of speech sound errors is limited as this technology is not readily available to the average SLP. However, the technology appears to be promising for remediation of speech sound errors. Although there is very limited research on the effectiveness of this technology for teaching pronunciation of foreign language, the ability to monitor tongue section positioning should be strongly considered as a potential tool for teaching pronunciation of to foreign language learners (during accent modification therapy).

The purpose of this research was to use ultrasound visual biofeedback to teach production of the apicoalveolar rhotic trill /r/ to an adult learner of Spanish as a foreign language. We hypothesize that usage of ultrasound visual biofeedback will promote accurate productions of /r/ by monitoring positioning of tongue sections to meet articulatory requirements for /r/. This research intends to answer the following research question: Does ultrasound visual biofeedback facilitates increased production accuracy of /r/ in an adult who is learning Spanish as a foreign language? For this study, we have the following hypotheses: 1) That ultrasound visual biofeedback will promote accurate productions of /r/ in the treated context. 2) That accurate productions of /r/ in the treated context will generalize to untreated contexts. The findings will address the gap in the literature about the potential use of this technology in the area of teaching pronunciation of speech sounds to learners of foreign language.

METHODS

A time-series case study design was used for data collection and to monitor changes over time in the accuracy of /r/ production. Time-series data were also recorded for untreated targets to measure generalization.

Participant

An adult native speaker of American English from Michigan with /r/ production errors participated in this research. The participant had taken courses at the college level of Spanish and spent 10 months in Spain.

Equipment

A Micro System ultrasound scanner was used with a 2-4 MHz transducer probe was used for imaging purposes. Audio and video were simultaneously recorded. A P120 cardioid microphone was used to record audio. For sonographic display, a computer software recording at 30 fps was used.

Data Collection Procedures

Criterion-based assessment for /r/

A criterion-based assessment for /r/ production was developed to elicit production of /r/. The assessment consisted of a list of words containing /r/ in: (1) at initial word position, (2) intervocalic word position and (3) after consonantal sounds /s/, /n/, and /l/ (See Appendix A). Isolated words used from the criterion-based assessment containing /r/ after consonants /s/, /n/, and /l/ were taken from previous work done by Rafat (2008). The participant was asked to read the word list while the ultrasound transducer was positioned and stabilized under the participant's chin using a head stabilizer. The head stabilizer ensured a midsagittal position of the tongue when imaged.

Pre-treatment baselines

To monitor consistency of inaccurate /r/ productions before initiation of treatment, six baseline data points were gathered. Baselines were obtained by using the same criterion-based assessment for /r/ described above (See Appendix A). All baseline data points were taken using the criterion-based assessment for /r/. The participant was unable to produce an accurate /r/ production in any of the presented contexts. Thus, baseline data show no variability in production accuracy of /r/ in any of the contexts.

Treated and untreated /r/ contexts

Productions of /r/ from an initial assessment were perceptually judged by two native speakers of Spanish. Reliability of probe scoring was above 80%. Only contexts with canonical /r/ production accuracy of less than 20% were considered for treated and untreated contexts. From the initial assessment analysis, intervocalic context (VCV) was randomly selected as a treated context with initial (CV) and after consonants /s/, /n/, and /l/ (CC) as untreated. Due to limited number of Spanish words containing /r/ after consonants /s/, /n/, and /l/ (CC) this context was not considered as a potential treated context. VCV was targeted during treatment whereas CV and CC were not targeted but monitored for generalization of skills. Changes over time in /r/ accuracy for all contexts were monitored using probes.

Probes for monitoring changes over time

To track changes in /r/ accuracy, a ten (10) word list was created for initial /r/ and intervocalic /r/ contexts. These words were selected from the baseline word list. The same words from baseline were used for monitoring /r/ after consonants /s/, /n/, and /l/. The treated context was probed after every session while untreated contexts were probed every three sessions.

Structured treatment protocols

Structured treatment protocols were used for teaching production of /r/ and to provide verbal feedback based on performance. Modified versions of structured protocol used by Preston, et al. (2014) were made to account for language variability between Spanish and English as well as to further structure practice. Two different structured protocols were used for teaching and practicing production of /r/, Structured Shaping Protocol (SSP) and Structured Word Practice Protocol (SWPP) (See appendices B and C).

Structured Shaping Protocol

SSP allowed for targeted practice of positioning of the various parts of the tongue (See Figure 1) using facilitative contexts (See Appendix B). These contexts were selected based on: (a) error in tongue section placement exhibited by the participant when attempting to produce /r/ and (b) similarities between the vowel-consonant contexts in tongue section placement with tongue configuration for /r/. For example, shaping /r/ from /a/ as means of maintaining a retracted tongue root positioning during /r/ if error productions from the participant were characterized by a forward tongue root positioning. To begin SSP, five trials for accurate positioning of target tongue section were provided at a level were all feedback focused on performance of positioning the target tongue section (Level 1). Accurate positioning of tongue section scored 1 while inaccurate scored 0. As the participant mastered accurate positioning of target tongue section, participant moved to Level 2 (where feedback on judgement of correctness was introduced) and Level 3 (where amount of feedback is diminished). Moving level criteria was defined as accurately positioning target tongue section in at least four 10111out of five trials. If criteria was not met, the participant was downgraded a level (e.g. from Level 2 to Level 1) and practice continued. SSP was used in every treatment session until participant produced six perceptually correct /r/ sounds. Once six accurate trills were produced, the SSP protocol ended and SWPP was initiated.

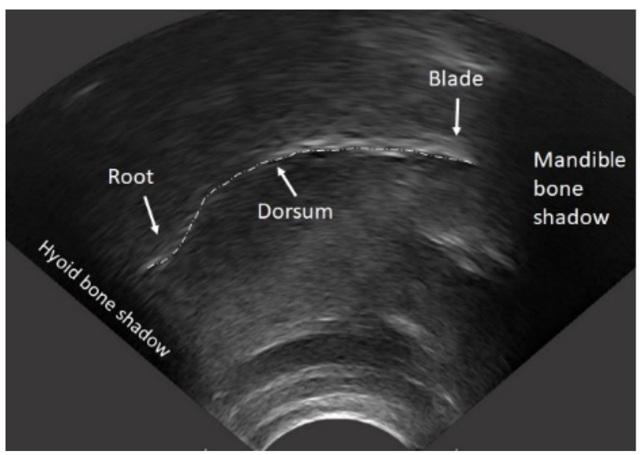

Figure 1. Sonographic image of tongue. Tongue sections visible in mid-sagittal view as well as other landmarks visible on the sonographic display. White line demarcates the contour of tongue surface (enhanced with dotted line). Tongue is facing right.

Structured Word Practice Protocol

SWPP allowed for practice of the treated intervocalic context through various complexity levels: (a) syllables, (b) disyllabic words, (c) phrases, and (d) cloze phrase (See Appendix C). To begin SWPP, five trials for accurate production of /r/ using the treated context VCV were provided. For example, /ara/. Accurate production of /r/ was scored as 1 whereas inaccurate production was scored as 0. As the participant mastered accurate /r/ production, the participant moved from one complexity level to another (e.g. from syllables to disyllabic words to phrases). Moving criteria was defined as accurate /r/ production in at least four out of five trials. If the criteria was not met, the participant was downgraded a complexity level (e.g. from phrases to disyllabic words) and practice continued.

Feedback administration during SSP and SWPP

Oral feedback focused on the positioning of the parts of the tongue—based on sonographic image—was provided to the participant during the treatment sessions. Research on motor tasks have found that skill acquisition can be enhanced by frequency feedback on performance on a task (Knowledge of Performance [KP]) as well as judgements of correctness of the task (Knowledge of Results [KR]) (Schmidt & Lee, 2011). KP feedback was provided with high-frequency during the initial stages (Level 1 in SSP and syllables complexity level during SWPP). As the accuracy increased, KP was transitioned to lower frequency and KR was provided.

At later stages of practice in both SSP and SWPP, less KR was provided and auto-monitoring was introduced. During auto-monitoring instances, the participant was asked to judge the performance based on the sonographic display. It is important to note that instances of auto-monitoring used in our protocols are not part of the principles of motor learning (Maas, et al., 2008). However, they were included as means of promoting independent learning by the participant.

Treatment fidelity and reliability

A total of fifteen (15) one hour treatment sessions were provided. A graduate research assistant with training in the use of the SSP and SWPP protocols reviewed 20% (three sessions) to document adherence to feedback provision during SSP and SWPP. Specified feedback was provided on 94% of trials. Errors involved providing KP when only KR was required and providing KR when no feedback was required.

Probes for treated and untreated contexts

Twenty percent of probes for treated and untreated contexts were scored by three listeners, treating clinician and two secondary listeners who was blind to the purpose of the study. Both secondary listeners perceptually judged probed for instances of accurate /r/ production. Listeners were native Spanish speakers with different dialects of Spanish (Mexico and Puerto Rico), both with a master's degree in Speech-Language Pathology. One listener rated CVC probes (3 probes) while other listener rated one CV probe and one CC probe. Probe agreement between treating clinician and each of the secondary listeners was above 80%. Thus, we used treating clinicians scoring for analysis.

RESULTS

Participant data are presented in Figure 2. The dependent variable for time-series data was accurate /r/ production as judged by unfamiliar listeners. Baseline data show stability of error /r/ production errors prior treatment sessions. VCV context (treated) show no acquisition of /r/ during treatment sessions during probes. However, CV context (untreated) showed accurate /r/ productions during probes. This improvement was first observed in treatment session 5 and continued until the last treatment session. Similar observation was observed for CC context (untreated) but the amount of /r/ were typically less compared to CV.

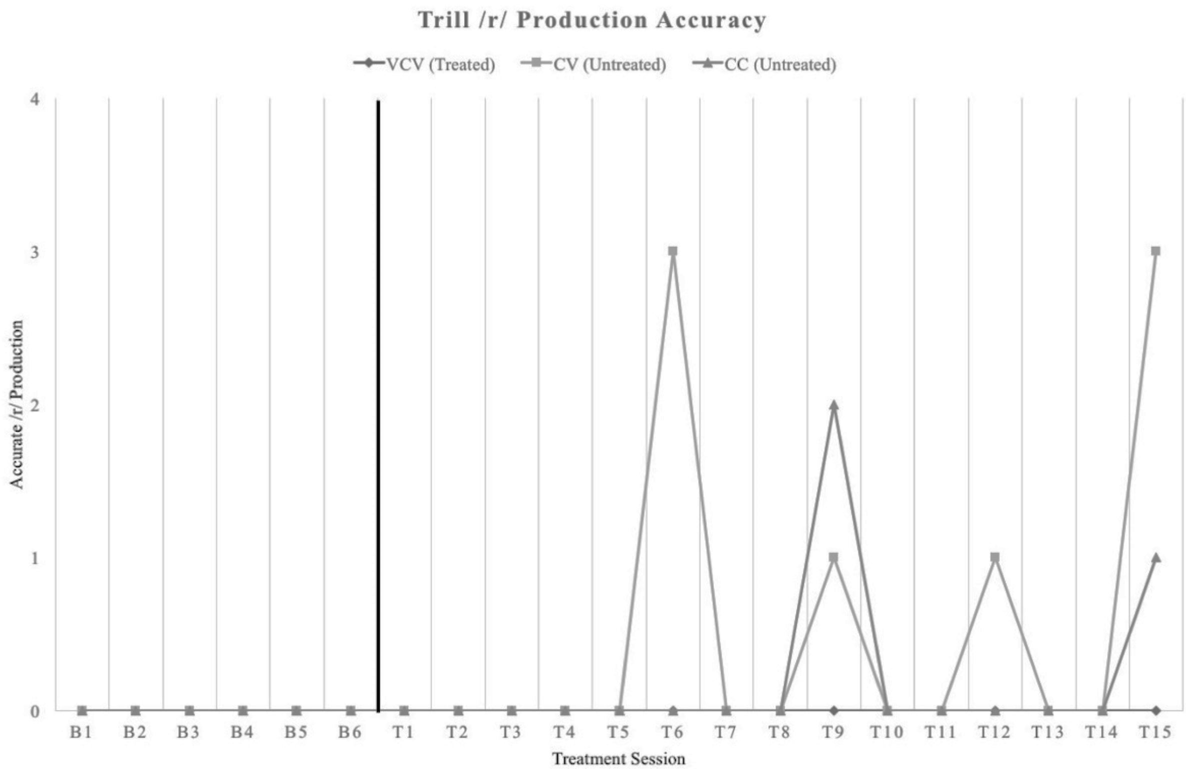

Figure 2. Trill /r/ production accuracy. Relationship between dependent (trill accuracy) and independent variables (ultrasound biofeedback treatment sessions) on probes for treated and untreated contexts.

Trill tongue shape

Error /r/ tongue for our participant is characterized by a retracted tongue root positioning, a depression on the dorsum and an elevated, and bunched tongue blade (See Figure 3). This shape is similar to MRI scans of tongue shapes used by native speakers of American English for production of the rhotic approximant by Tiede, Boyce, Holland and Choe (2004) and Suzanne Boyce (Secord, Boyce, Donohue, Fox & Shine, 2007). Though trilling was perceptually identifiable, the multiple constrictions occurred at the level of the dorsum (See Figure 4), presumably against the uvula as oral structures above the line demarcating midsagittal tongue surface are not imaged by ultrasound. A known speech sound characterized by vibrating the uvula is the uvular trill /R/ (Ladefoge & Maddieson, 1996). However, X-Ray tracings of tongue shape for /R/ from Delattre and Freeman (1968) and Boyce, Hamilton, Rivera-Campos (2016) show a retracted and more rounded tongue dorsum, dissimilar to tongue dorsum positioning observed from our participant.

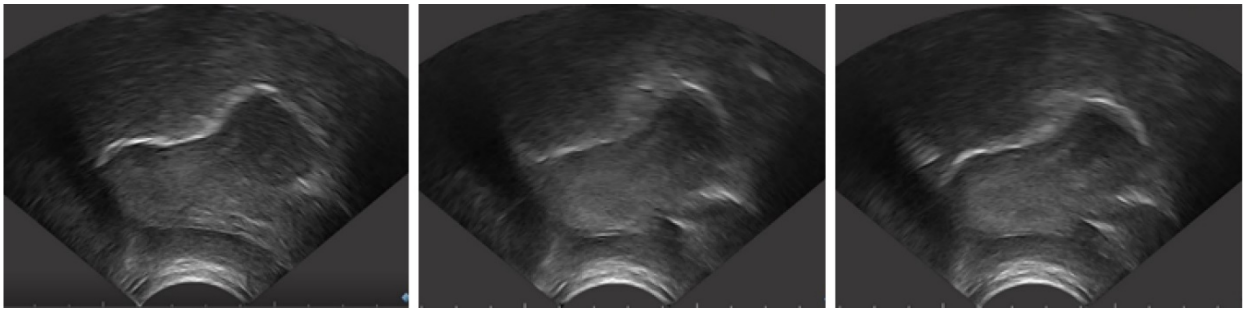

Figure 3. Tongue configuration for rhotics. Picture on the left shows participant's tongue configuration for the English rhotic approximant /ɹ/ in the word "car." Picture on the middle shows participant's error tongue configuration for intervocalic /r/ with front vowels context in the Spanish word /birete/ "graduation cap" during baseline. Picture on the right shows participant's error tongue configuration for intervocalic /r/ with central and back vowel context in the Spanish word /baro/ "clay" during baseline. Notice similar positioning and configuration of tongue root, dorsum, and blade.

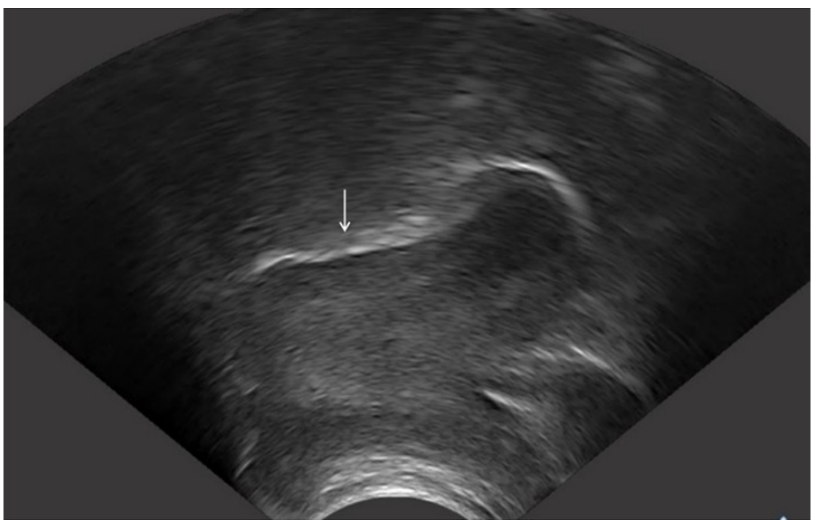

Figure 4. Sustained phonation of error /r/ in isolation. Arrow indicates location of fast and multiple contacts between tongue dorsum and uvula as seen on ultrasound video recording.

Tongue shape during accurate production of /r/ was characterized by a retracted tongue root positioning, a light depression at the dorsum, and raised blade. Overall tongue shape configuration for accurate /r/ productions looked similar to that of a native speaker of Spanish (See Figure 5). Though probes administered after treatment sessions showed a limited correspondence between ultrasound biofeedback treatment and /r/ production during probes, there were observable changes in tongue configuration as it became similar to that of a native speaker (See Figures 5 and 6).

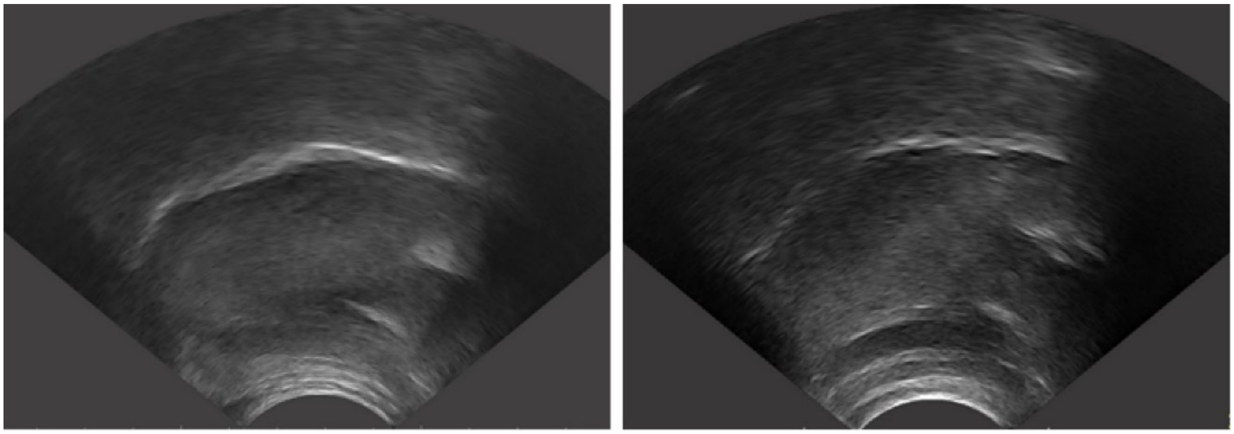

Figure 5. Tongue configuration for accurate /r/. Picture on left shows tongue configuration of accurate production of /r/ during the Spanish word /posreβolusjonaɾjo/ "postrevolutionary." Picture on the right shows tongue configuration of sustained /r/ from a native speaker. Notice similar tongue configuration between both /r/ productions.

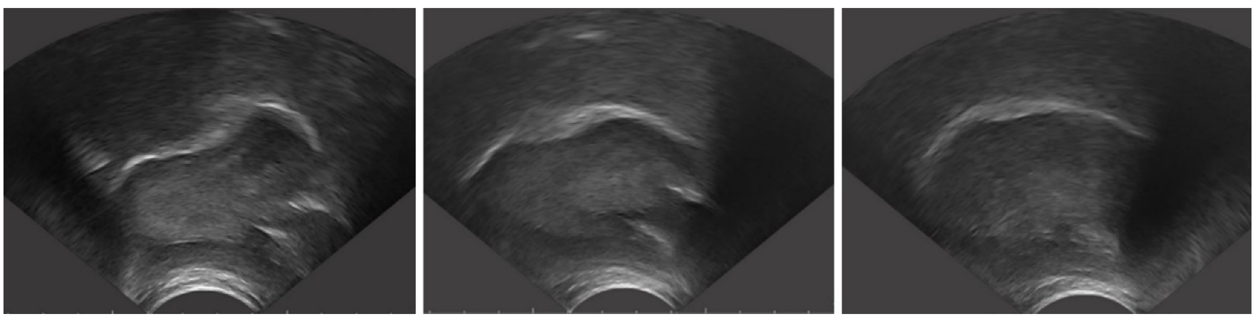

Figure 6. Error and accurate tongue configurations for /r/. Picture on the left shows error tongue configuration for /r/ in the word /baro/ "clay" during baseline. Picture in the middle shows an error tongue configuration for /r/ during CC context. Picture on the right shows tongue configuration during accurate production of /r/ in Spanish word /red/ "net." Notice that depression on the dorsum in error tongue configuration during CC is more pronounced when compared to dorsum configuration during accurate trill for /red/ "net."

DISCUSSION

Data from probes indicate a limited relation between the initiation of ultrasound biofeedback treatment sessions and /r/ production accuracy. Our hypothesis that ultrasound biofeedback will promote accurate production of /r/ in the treated context was not confirmed, as there were no accurate /r/ productions in VCV. Our hypothesis that accurate productions of /r/ in the treated context would generalize to untreated contexts was not confirmed as there was no accurate /r/ productions in the treated context. However, probes for untreated context showed accurate productions of /r/ for both CV and CC.

In the field of speech production and foreign language learning we can find two potential explanations for the observed productions of /r/ during untreated contexts CV and CC. First, data from Johnson (2008) showed that as Spanish proficiency levels increased in research participants from The University of Arizona, the number of correct /r/s at word initial increased. That is, participants with lower Spanish proficiency showed less accuracy in word initial /r/ when compared to participants with higher Spanish proficiency. In his research, the author classified participant Spanish proficiency based on the level of Spanish courses participants' were currently taking. These levels included First Semester Spanish, Fourth Semester

Spanish, Intermediate Spanish and graduate level courses. Our participant has had advanced courses in Spanish at the college level as well as experience living in Spain for ten months. The level of experience of our participant combined with Johnson's observation regarding Spanish proficiency level suggests the possibility that our participant might have benefited from a trained rather than an untrained CV context.

A second potential explanation for acquisition of /r/ in untrained CC context might stem from having of a voiceless pre-rhotic segment. Closer inspection of /r/ accuracy in CC context shows that accurate productions mainly occurred in words like: *desregulaciones, disruptiva, posrevolucionario,* and *posromántico.* Previous work by Solé (2002) describes voiceless /r/ as having lowered intraoral pressures for initiation and maintenance of trilling. Though the scope of this work did not aim at detailed acoustic analysis of /r/ productions, taking under consideration Solé's observation and the element of coarticulation of speech sounds, a voiceless pre-rhotic segment as /s/ could have promoted initiation and maintenance of trilling as the voiceless feature of /s/ may have partly be transferred to /r/.

Although not frequently applied to the field of speech sound production, errorless learning theory could potentially provide a third theoretical explanations of these results. To acquire a new motor movement during a typical motor learning situation, an individual accrues declarative and applies such knowledge to judge results (trial and error). Within this experiment, the participant learned all the instructions about what was needed to produce an accurate /r/ and used that knowledge to make judgements about accurate or inaccurate tongue configuration. This process requires working memory, as the instructions are temporarily stored and used for monitoring motor movement and make adjustments "on line." Although accruing declarative knowledge is common in typical learning situations, when this knowledge is being applied by working memory, it has been found to be disruptive (Beilock & Carr, 2001; Mullen & Hardy, 2000; Wulf & Weigelt, 1997). It is plausible that the application of our participant's declarative knowledge—obtained by KP and KR feedback during treatment sessions—and processed in working memory during productions was detrimental for the success of accurate /r/ production in VCV, as this context was the focus of the treatment sessions. Similarly, it has been found that performance under pressure is detrimental to acquisition of complex motor skills (Lam, Maxwell & Masters, 2009). Feedback can potentially create pressure on the learner as amount of feedback provided during early levels of acquisition of the target motor skill (Levels 1 and 2) required clinical judgement in order to be provided (See Appendix B). This clinical judgement can indirectly be perceived as negative judgement, particularly if feedback was directed to repositioning of tongue section from an error shape.

There is limited research in the use of ultrasound biofeedback for teaching production of an articulatory complex sound such as /r/ to learners of a foreign language. Though this technology has yielded positive results with the remediation of speech sound errors in children, there is limited information about its potential benefits with adults whose challenges on the acquisition and mastery production of a sound is not borne from a speech sound disorder, but from differences in sound inventories between the primary language and foreign language. The results described in this work can be of particular interests to speech language pathologists that work in the area accent modification or with individuals interested in mastering their heritage language. Being able to monitor tongue section positioning can allow the clinician and the learner to monitor progress towards the articulatory requirements of the target sound. This allows both the clinician and the learner to be aware of articulatory improvement or changes that go beyond a perceptual judgement of the target sound.

Limitations and future directions

Limitations of this study provide avenues for future research. This study used one participant to provide preliminary data to answer our research questions. For future research aimed at replicating our methods, data should gathered for more than one participant. Since our results are not generalizable to other second language learners with different levels of Spanish proficiency when compared to our participant, future work should look at the efficacy of ultrasound biofeedback on participants with different levels of Spanish proficiency.

CONCLUSION

Ultrasound biofeedback allows learners to see "on line" the tongue shape being used for production of target sound. For speech sounds that require complex articulatory gestures, ultrasound biofeedback allows for identification of inaccurate tongue section placement and use that information to guide accurate placement. Although probes for treated VCV context did not show improvement for /r/ accuracy, changes in tongue configuration from baseline and probes were observed. These changes in tongue configuration promoted /r/ accuracy in untreated CV and CC contexts.

Ultrasound biofeedback has the potential to be considered as a tool for teaching speech sound production to learners of a foreign language as inaccurate positioning of tongue sections cannot be easily identified without imaging technologies. Thus, learners could potentially develop and maintain motor patterns that promote inaccurate production of speech sounds by developing and maintaining motor patterns through repeated error practice.

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APPENDIX A

Context of /r/ production	Words
Word initial	Riqueza, Rubén, Ruín, Recibo, Raciona, Risa, Ron, Ruleta, Ramón, Roca, Rudeza, Riachuelo, Rosado, Relajo, Ropaje, Río, Red, Rufián, Rey, Raquel
Intervocalic	Acurruco, Carrucho, Verruga, Amarra, Carril, Garra, Agarre, Chorro, Pizarrón, Corriente, Gorro, Borra, Arrimo, Birrete, Tierra, Herramienta, Jarrones, Barre, Perro
After consonants /s/, /n/, and /l/	Honra, Israel, Sonrisa, Monra, Sonreír, Enredo, Desregulaciones, Disruptiva, Posrevolucionario, Posromántico, Malrotar, Alrededor, Ulrico, Dalriada

APPENDIX B

Sample of Structured Shaping Protocol with scoring. Dotted arrow lines illustrate changes in feedback levels as participant master positioning of target tongue section. Each instance provided the participant with one of four types of feedback; Knowledge of Performance (KP), Knowledge of Results (KR), no feedback (cells with no letters), and Auto-monitoring (A).

Context	Level 1 Feedback					T	Level 2 Feedback					T	Level 3 Feedback					T
/ara/	0 KP	0 KP	1 KP	0 KP	1 KP	2	KR	KP	KR	KR	KP				KR		A	
	0 KP	1 KP	1 KP	1 KP	1 KP	4	1 KP	1 KR	1 KP	1 KR	1 KR	5	0 KR	0	1 A	1	1	3
	KP	KP	KP	KP	KP		1 KR	KP	KP	KR	KR		A				KR	
	KP	KP	KP	KP	KP		KR	KR	KR	KP	KP				A	KR		

APPENDIX C

Sample of Structured Word Practice Protocol. Progression criteria through complexity levels (e.g. moving from syllable to disyllabic, disyllabic to phrases, etc.) was similar to Structured Shaping Protocol.

Ctx	Syllable Cv / vCv : **arra**					T	Disyllabic: **jarra**					T	Phr: **Mi jarra**					T	CPhr: **Mi jarra de agua**					T
/ara/	KP	KP	KP	KP	KP		KP	KR	KR	KR	KP		KP	KR		KR					KR		A	
	KP	KP	KP	KP	KP		KR	KR	KP	KR	KP		KR		KP	KR			KR		A			
/ara/	KP	KP	KP	KP	KP		KR	KP	KR	KP	KR			KP	KR	KR			A				KR	
	KP	KP	KP	KP	KP		KR	KR	KP	KP	KR			KR	KR		KP				A	KR		