PERSPECTIVES OF STUDENTS IN THE USE OF AN APP-BASED SONOGRAPHIC IMAGING OF TRILL PRODUCTION

by

Emily Dickson

Bachelor of Science, 2018
Texas Christian University
Fort Worth, Texas

Submitted to the Graduate Faculty of
Harris College of Nursing and Health Sciences
Texas Christian University
in partial fulfillment of the requirements
for the degree of

Master of Science

May 2021

PERSPECTIVES OF STUDENTS IN THE USE OF

AN APP-BASED SONOGRAPHIC IMAGING

OF TRILL PRODUCTION

A Thesis for the Degree
Master of Science

by

Emily Dickson

Thesis Approved by:

Dr. Ahmed Rivera-Campos, CCC-SLP, Major Professor, Davies School of COSD

Maria Ciriza-Lope (5/3/31)

Dr. María Ciriza Lope, Committee Member

Irmgard Payne, CCC-SLP, Committee Member

Jean Rivera-Perez, Ph.D., CCC-SLP, Committee Member

Dr. Deborah Rhea, Associate Dean
Harris College of Nursing & Health Sciences

May 2021

ABSTRACT

PERSPECTIVES OF STUDENTS IN THE USE OF
AN APP-BASED SONOGRAPHIC IMAGING
OF TRILL PRODUCTION

by Emily Dickson, M.S., 2021
Department of Communication Sciences & Disorders
Texas Christian University

Thesis Advisor: Dr. Ahmed Rivera-Campos, CCC-SLP, Assistant Professor of COSD

The purpose of this study was to investigate the perspectives of collegiate students in regards to an app-based ultrasound biofeedback training program for production of the trill /r/ modeled within the PALS framework. An app-based training on using ultrasound biofeedback technology to help improve pronunciation of the Spanish trill /r/ was developed for remote presentation over a Zoom-based pronunciation class for collegiate learners of Spanish. Participating students shared their opinions about the material that they learned through semi-structured discussion questions. The perspectives of these students showed overall themes of visualization of the tongue, the ability to understand and explain the concepts, integration of sonographic tongue information in teaching, and the difference of in-person learning and app-based learning. In all, this study provided preliminary data on the perspectives of learners of Spanish in regards to using ultrasound biofeedback technology for pronunciation practice of the trill.

ACKNOWLEDGEMENTS

I wish to thank my graduate thesis committee for their support throughout this thesis creation process. I thank my primary research supervisor, Dr. Rivera-Campos, for his guidance throughout this ever-changing world of research in speech-language pathology. I also thank my committee members, Dr. Ciriza Lope, Mrs. Payne, and Dr. Rivera-Perez for their support in not only the development of this research, but also for helping to further inter-departmental work between the areas of speech pathology and Spanish. It is my sincere hope that this thesis will be a part of more cultural-linguistic diversity in speech-language pathology research in the future. I would also like to thank my family, my boyfriend, and my classmates who have accompanied me on this educational journey. I love you all. Finally, thank you to my fourteen year-old Border Collie, named Tony Bennett, who would nudge my door open when I was busy writing this paper; you always reminded me to give you scratches and treats when necessary.

TABLE OF CONTENTS

INTRODUCTION

For many language learners, improving pronunciation is an important skill in the learning process. Low-level pronunciation skills can lead to language learning anxiety and weaker self-efficacy (Baran-Lucarz; 2014). Speech is essentially a motor task, and all of the articulation components must work accurately in order to produce speech sounds in any language (Hu et al; 2013). In the case of Spanish language-learning, research has shown that trilling (carro for 'car') can be especially difficult for Anglophone learners of Spanish to pronounce. One method for visualizing the tongue is using imaging technologies such as ultrasound imaging. Ultrasound imaging (UI) may be useful as a tool for pronunciation practice of the trill /r/. In a medical setting, UI provides a live visual of different physiological components of the body in a relatively safer procedure than x-rays; in a speech pathology setting, ultrasound monitors the articulatory movements of the tongue (Rivera-Campos; 2019). There is very little research on the connection between the use of UI and pronunciation practice of the trill /r/ in learners of Spanish, but some studies have begun to emerge. In a second-language learning environment such as the classroom, the use of technology may further share this information with students. Spanish has become increasingly prominent in second-language education in the United States (Pascual & Prada; 2018). As Spanish-language education increases, innovative solutions may be needed for the pronunciation component.

LITERATURE REVIEW

The Spanish Trill /r/

Spanish is one of the few languages that contains more than one rhotic phoneme – the voiced alveolar tap /ɾ/ and the trilled /r/ (Boyce et al; 2016). American English does not have the trill /r/ as part of its phonemic inventory and therefore it is a specific tongue shape that is

challenging for new learners (Face; 2006). The Spanish trilled /r/ depends on two major components – the alveolar place of articulation and the aerodynamic conditions to maintain a rapid repeated occlusion (Boyce et al; 2016). The sound also depends on a continuous, non-turbulent flow of air through the vocal tract (Howson et al, 2014). In addition, the tissue of the tongue must adjust for the changes in tension and inertia to maintain a vibratory state (Howson et al; 2014). In the English /ɹ/, the tongue tip can either be retroflexed upward or bunched downward (Adler Bock et al; 2007). Even the place of articulation can vary among English speakers. It can be retroflexed in the alveolar area or the post-alveolar area (Face; 2006). It also typically has a tongue dorsum that is arched, dipped, or flat (Rivera-Campos; 2019). Unlike the English rhotic approximant /ɹ/, there is no variation in tongue configurations for the production of /r/ (Rivera-Campos; 2019). As an articulatory complex sound, the trill involves short apicoalveolar contacts which require a retracted tongue root, the lateral sides of the tongue raised, and an elevated tongue blade (Adler Bock et al; 2017). Studies have also pointed out that even after years of direct instruction some learners never achieve /r/ production (Johnson; 2008). When teaching the trill /r/, information on the learner's tongue shape is valuable for guiding the learner to identify what changes in tongue section positioning are needed since the sound has complex articulatory requirements. Having information on a learners' tongue shape is unlikely without technologies such as ultrasound imaging.

Ultrasound Imaging and Speech Production

Due to its portability and non-invasive procedures, UI has become a popular tool for observing tongue articulation (Lawson et al; 2008). UI has also been a reliable tool in teaching articulation techniques to children with hearing impairments because there is visual feedback involved; images of the tongue appear on monitor when high-frequency sound waves leave the

handheld transducer below the chin, hit the air just above the tongue's surface, and reflect back to the transducer (Adler Bock et al; 2007). The parts of the tongue that can be observed by the ultrasound images are the root, dorsum, blade, tip, and lateral sides (Rivera-Campos; 2019). Two different views can be observed – the sagittal view, where the root to near the tip is visible, and the coronal view, where the left and right lateral sides of the tongue are visible. (Adler Bock et al; 2017). The speech sounds that have been the most commonly targeted in research in this are vowels, rhotic sounds, velar and uvular consonants, and dynamic tongue movements from one sound to another (Bird et al; 2018).

One 2008 study in Scotland investigated the use of ultrasound imaging as a tool for assessing articulation outside of the clinic setting. Fourteen school-age males read from a list of words in their native language (L1) and spoke freely with other classmates; ten of them did so while wearing a head-stabilizing headset with the transducer below the chin. In the end, there was no significant change in student performance compared to a control group that completed the speaking tasks without wearing the technology, but the researchers believed that the familiar school environment and the familiarity with peers may have strongly contributed to this lack of change (Lawson et al; 2008).

One of the most common uses of ultrasound for observing speech articulation is remediation of L1 rhotic sound errors in a speech therapy context. In a 2007 case study, two adolescent males received fourteen speech therapy sessions lasting one hour each; in these sessions, ultrasound feedback was used to remediate English /ɹ/ errors. The result for both participants was a significantly increased accuracy of /ɹ/ at the word level, and one of the participants commented in the post-treatment interview that he liked how he could both see and hear the sound using the ultrasound (Adler Bock et al; 2007). The English rhotic approximant /ɹ/

is one of the most complex phonemes of the English language due to its articulatory and acoustic traits. (Adler Bock et al; 2007) Because of this, it is a late-developing sound that can both have consistent misarticulations and difficulty in correction (Boyce et al; 2016). In terms of shaping methods, correct rhotic positions can be described to a client through verbal means as well as visual means with illustrations and mirrors, but this is not always successful in speech therapy. There are other visual ways to display tongue movement such as diagrams and spectrographic displays, but they can be inaccurate at times as well as difficult to interpret by a client outside the field of speech-language pathology (Rivera-Campos; 2019).

A team of researchers in Czechoslovakia conducted a study in 2014 in which they investigated the ultrasound imaging differences in trilled /r/ production in native Czech speakers. When 10 adults in Vancouver had their trilled rhotic productions analyzed by ultrasound, tongue height was visually perceived to be higher in the Czech trilled /ř/ than the regularly trilled /r/, but the change was not significant (Howson et al; 2014). Thus, UI was used as a visual method to help differentiate the tongue configurations of two similar sounds.

In 2016, an exploratory study was conducted using ultrasound imaging to analyze the rhotic tongue configurations of adult native speakers of English, Malayalam, French, Persian, and Spanish. The rhotics of these languages appeared to have two places of articulation: a primary place around the alveopalate and the velopalate, and a secondary place that involved a retracted tongue root towards the pharynx. Trills, including in Spanish, are particularly difficult to master due anterior configuration of the tongue blade and tip as well as the aerodynamics involved to make rapid contact. However, one limitation of this study was that ultrasound cannot observe the palate or pharyngeal walls in this context (Boyce et al; 2016).

Second-Language Learning and Pronunciation

In addition to monolingual young children, another population that can experience difficulties in articulation is second-language (L2) learners (Rivera-Campos; 2019). Teaching L2 sounds can be especially difficult when the sounds are not easily visible to the learner (Bird et al; 2018). Many factors may influence success in L2 pronunciation, including age, proficiency level, type of educational institution, language environment, and setting of instruction (Lee et al; 2015). For instance, a cross-sectional study in 2006 observed the use of the Spanish trilled /r/ in different levels of Spanish proficiency. The participants in the study were forty-one native speakers of English studying college-level Spanish: twenty were in a fourth semester and twenty-one were in a more advanced elective college Spanish course. They were asked to read a story in Spanish aloud for audio recording. Even though those in the more advanced Spanish course produced /r/ with significantly more accuracy than those in the less advanced Spanish group, they only produced the target sound 26.6% of the time. This was marked by substituting an alveolar tap /ɾ/ for the trill (Face; 2006).

Ultrasound technology has been used in previous studies to instruct L2 learners on proper /r/ pronunciation. A time-series case study was conducted in 2019 to assess the use of ultrasound technology to teach the Spanish trilled /r/ to a college student who was a native speaker of English. In this study, a head stabilizer was used to make sure the position of the transducer was consistent. The treated context of a VCV pattern did not significantly improve, but the untreated contexts of CV and CC patterns did significantly change. Results were confirmed by the acoustic perception of a native speaker of Spanish. The student had an advanced level of Spanish proficiency, so this could have been a factor in /r/ improvement (Rivera-Campos; 2019). The inclusion of this technology in second language pronunciation is a growing field and it appears to have potential for teaching complex sounds that are not shared between a learner's L1 and the L2

(Antolík et al.; 2019, Ouni; 2014). The visualization of L2 sounds via ultrasound, whether it be the learner's own graph or viewing a video ultrasound model of someone else's correct production, is much easier for an L2 learner to comprehend than other graph representations such as spectrograms (Bliss et al; 2018). The use of visual feedback has also utilized acoustic information represented in spectrograms, which may be more effective than traditional instruction alone; this is especially the case when visualization is involved (Olson; 2014). The use of imaging technologies in production of speech sounds have provided more detailed information on articulatory requirements (Boyce et al; 2016), coarticulatory effects (Johnson; 2018), and acoustic information of speech sounds (Zhou et al; 2007); all of these provide additional information on speech sound production.

L2 pronunciation instruction is often given the least amount of attention in a class period (Sturm; 2019). L2 learning, in regards to improving pronunciation, requires not only the auditory example of the target sound but also visual information on how to articulate it (Bliss et al; 2018). The incorporation of pronunciation instruction in second-language learning classrooms may have a positive effect on L2 learning as a whole. In Spanish courses, pronunciation courses are not widely incorporated into the curriculum; however, explicit instruction has shown improvements in students' pronunciation when the emphasis was on recognizing the differences in speech sounds and their productions (Lord; 2005). In one 2019 study, four L2 French students at the basic-collegiate level were followed on their pronunciation skills over four semesters of instruction in the absence of explicit pronunciation instruction. There was some improvement in the first semester, but progress slowed and showed inconsistencies thereafter. Even if for a few minutes per class period, incorporation of explicit instruction has shown to produce improved pronunciation outcomes in students than no instruction at all (Strum; 2019). It is not likely that

simply hearing new speech sounds will lead to mastery; the brain may use the sound system of the first language (L1) in order to decipher L2 sounds, and this may need additional help from external sources such as formal instruction (Conti; 2016). L2 learners may use their own strategies to attempt to produce a new sound in the L2, but it may come out more as an approximation rather than the true sound (Flege; 1980).

Adults may vary widely in their potential for L2 pronunciation improvement. Only between 5% and 15% of adults learning a second language achieve "native-like" pronunciation abilities (Hu et al; 2013). There appears to be an interaction between the sound systems of individuals learning multiple languages, especially in bilingual children, but the exact interaction is unclear (Fabiano-Smith et al; 2010). The Critical Period Hypothesis suggests that children have the highest potential for second-language proficiency compared to adults due to loss of brain plasticity over time (Birdsong; 1999). However, different proficiencies in L2 can all benefit in some form from explicit pronunciation instruction (Lee et al; 2015). On the other hand, competence in the L2 can play a major role in pronunciation improvement (Neufeld; 1980). Success can be improved by incorporating immediate feedback with direct comparisons to a native speaker example (Bliss et al; 2018). Phonological working memory, that is, remembering verbal information over brief periods of time, may contribute to higher success rates in L2 pronunciation (Hu et al; 2013). In addition, adults may find it easier to listen for subtle speech sound differences in L2, but find it harder to produce the motor movements required to say the sounds (Neufeld; 1980).

Technology and Adult Learning

Today, technology may be a medium for L2 education for pronunciation. This is especially true given the recently common digital-learning environment due to the COVID-19

pandemic. The most effective feature of such a learning approach is feedback on pronunciation attempts; ongoing advances in technology can make electronic applications more precise in feedback (Levy; 2009). The incorporation of technology-based learning, such as with application-based training, has had positive effects on L2 pronunciation instruction only when there is feedback involved rather than one-way instruction (Lee et al; 2015). The use of technology for L2 learning may supplement education with material not provided by the teacher, and students may have more control over their own learning process while using a digital application, especially if it is interactive (Ahmadi; 2018). This method of education may be useful for sharing information about trill production, but very few studies have investigated this.

Learners of Spanish who have difficulties with the Spanish trill are trying to acquire a new skill in pronunciation. New skills can be acquired by adult learners with specific learning approaches. The four-phase Participatory Adult Learning Strategy (PALS) has shown to be successful in this endeavor of learning new skills in general. The first phase is the introduction and illustration of a topic in which the instructor demonstrates real-life use of the knowledge. The second phase includes application in which the learners themselves practice the use of their knowledge and evaluate their performance. The third phase is when the learners reflect on their level of gained knowledge. The fourth phase is when the learner decides on the next steps of learning depending on their current level of topic mastery. Multiple, repeated learning opportunities allow for the best chance of success in this approach (Dunst et al; 2009). The PALS approach also includes building up knowledge in small amounts over time; the goal is higher-level knowledge of a skill for the learner's own application (Jarvis; 1995). This approach emphasizes not only understanding of the topic, but proper application and self-awareness as

well. Embedding PALS within app-based learning may provide an effective learning experience within a digital context, especially when in-person learning isn't possible.

RESEARCH QUESTION

The inclusion of UI technology in second language pronunciation is a growing field and it appears to have potential for teaching complex sounds that are not shared between a learner's L1 and the L2 (Antolík et al.; 2019, Ouni; 2014). It is possible to modify ultrasound-based instruction to present the graphs in a large classroom setting (Bird et al; 2018). To investigate the students' view of incorporating this technology into second-language pronunciation learning, this work is driven by the following research question: What are the perspectives of collegiate learners of Spanish in regards to an app-based sonographic imaging pronunciation training within the PALS framework for production of the trill /r/?

METHODOLOGY

Participants

The participants in this study were collegiate-level students taking a Spanish pronunciation, Span 32903, during the spring semester of 2021 from the Hispanic and Linguistic Studies department at TCU. Of the twelve students enrolled in the course, seven students consented to participate. This class took place fully online via the Zoom platform. An app-based training using sonographic tongue imaging media for teaching pronunciation of trill /r/ was used as part of the typical lecture/activities that students would receive in any given semester when taking the course. However, to minimize the possibilities of undue influence or coercion from the instructor or the course, all students were informed that sharing their perspectives on the use of the app-based learning on pronunciation of trill /r/ was completely voluntary, and it was not tied

to any assessment or grade related to their current course. Student participation (or lack of participation) on the discussion had no effect on their course grade.

The instructor of the Spanish course announced the voluntary participation of the research in class prior to the research taking place (participation on this research is only during one of the days the course is scheduled). Students were informed of this two weeks and one week prior to the scheduled research date. The instructor was provided with the consent form to distribute to the students with instructions to complete and email them to the primary investigator if they chose to participate.

Instrumentation/Tools

A computerized training prototype app focused on teaching pronunciation of trill /r/ was developed by the investigators using the PALS framework. This app is currently in early development stages, and at the time of this paper's publication, is not yet ready for distribution beyond this study. The prototype app introduced three modules: "Introduction to Ultrasound," "Tongue Root Positioning," and "Tongue Dorsum Positioning." The app followed the PALS framework in that each module introduced information in a lecture format (phase 1), the participants were asked to apply their knowledge within multiple-choice application questions (phase 2), the participants were asked to reflect upon their current level of understanding (phase 3), and at the end of the modules, the participants were asked to either restart the module or continue onto the next one (phase 4). In more detail, each module commenced with the introduction of new information and demonstration on the use of new knowledge. Demonstration on the application of the new knowledge was achieved through the use of sonographic tongue imaging pictures and video recordings of speech sound production by native speakers of Spanish as well as adult Anglophone native speakers learning Spanish. For example, productions of /a/,

/i/, and trill /r/ by native speakers of Spanish as well as learners of Spanish. Next, each module provided multiple choice comprehension questions in order for the students to evaluate their own understanding of the individual modules. During this practice, feedback was provided based on the selected response. For example, redirecting to a "try again" page for incorrect answers and a "correct" page and explanation for correct answers. After the application practice, the module provided a summary page in which the student reflected upon the new information in the module. Lastly, a page in which the student had the ability to restart the module, review the questions again, or move on to the next module.

Overall, the app-based sonographic imaging on pronunciation of trill /r/ presented unidentified sonographic tongue video clips of the native speakers of Spanish and Spanish second language learners producing the trill in various word contexts. The sonographic video clips presented only tongue configuration and movements. The app taught fundamentals on the interpretation of sonographic tongue imaging to aid in understanding of the articulatory requirements for the pronunciation of /r/. Additionally, the app provided information on facilitative contexts that promote acquisition of the trill /r/ for learners of Spanish. For instance, the /a/ sound could facilitate a retracted tongue root necessary for trill production

Procedures

The Spanish course took place fully online on Zoom; this allowed for social-distancing protocols to be followed during the COVID-19 pandemic. The web-based application was completed on the Microsoft PowerPoint software, and hyperlink restrictions allowed for navigation of the application only with selected buttons, not with the "next slide" option. In addition to the typical teaching strategies used by the instructor of the class in any given semester when teaching the Spanish pronunciation course, an app-based sonographic imaging on

pronunciation of trill /r/ was used for teaching production of trill. The app, which was presented in English, was introduced during the course's schedule for the introduction and explanation on the pronunciation of Spanish consonantal sounds not shared between Spanish and English.

The app was presented by the PI in one 50-minute Zoom class lecture. Because this topic was part of the course's planned lectures, students were required to attend the app-based training presentation regardless of their participation in data collection in the following class session. Students' perceptions on the app was collected following the 50-minute Zoom class lecture at the following day of class meeting. The participating students were divided into 3 smaller groups to gather information on their perceptions of the app training. Students who opted to not participate in the data gathering process were not present for the Zoom class in which data collection occurred. Only the small group discussion of Group 1, Group 2, and Group 3 were audio recorded for purposes of data collection and analysis. Each small group was moderated by a member of the research team. Each moderator guided the small-group discussion using pre-constructed, semi-structured questions (See appendix A). Each moderator welcomed the small group to the discussion and reminded them that their responses were completely voluntary, and that they were free to withdraw participation at any time. After this, they presented the semi-structured questions and provided follow up questions in the event additional clarification was needed pertaining to what was being shared by the participant. Moderators then concluded the session by asking if any other comments needed to be made. The average length of all small group discussions was 13 minutes.

Each small group discussion was audio recorded. An undergraduate research assistant who was blinded to the purpose of this study transcribed all recorded group discussions verbatim into a Word document. All participants were assigned a number that was used during all

verbatim transcriptions. Once transcriptions were completed, audio files were deleted. Transcriptions were open coded by the PI. Codes that showed a relationship between them were grouped together into broader themes. These themes were analyzed and interpreted for further understanding of the data.

RESULTS

Based on the participants' responses in the discussion groups, the investigators found four main themes with subthemes that occurred within each one. A summary of these coded themes can be found in Table 1 in the Tables page.

1) Visualization of the Tongue.

Being able to see tongue configuration when speech sounds are produced allows for a deeper understanding of the articulatory requirements for that speech sound. This visualization also allows for comparing and contrasting tongue section positioning of different speech sounds. This in turn can be useful for determining facilitative contexts that can aid second-language learners of Spanish in how to reposition tongue sections in order to achieve the intended production of a phoneme such as the trill /r/. Additionally, being able to compare and contrasts tongue configuration can allow the learner to identify articulatory routines that can be carried over from one language to another as they acquire pronunciation of the target sound.

Articulatory requirements.

Participants reported an interest in the ability to view parts of the tongue in motion during the sonographic videos of tongue movement. They also noted the usefulness of understanding production of trill /r/ in this context. As trill /r/ requires precise articulatory requirements at the level of the tongue root, dorsum, sides, and blade, being able to see the movement and positioning of these tongue sections can allow learners to make the necessary modifications.

Participant 3: "It's obviously super useful […] that you can visualize the different locations of the tongue while you're making a particular sound and I […] I really can't think of anything that would be like as cheap or as easy, like ease of use (uh) than ultrasound."

Participant 5: "I thought it was interesting to see the different like movements of the tongue especially since you can't really see your own tongue when you do it […] I liked how you get like a different angle of the type of movements […] one tongue can make. So I thought that was really interesting."

Participant 6: "It's very innovative […] it just seemed like it would be difficult to learn, […] Like it's like what exactly is my tongue doing or my mouth doing here? But […] once that person does end up learn figuring out how like it works and how their tongue is moving, I think it would be very useful."

Participant 4: "Being able to see, see it in action was great […] being able to see a video of how it's being pronounced was helpful."

Participant 5: "I just liked how interactive it was and you got to kind of experience what your tongue would be doing when you're saying your trill "r". I know personally for me, I like seeing the things in person rather than just reading about it, so that was my favorite part of this application."

Participant 6: "I think that was super helpful and then just seeing how the tongue should move when the trill is produced."

Facilitative context for tongue section repositioning.

Reconfiguring tongue shape is important for speech sound production. As each sound requires its own articulatory gestures for tongue configuration, being able to have information on

consonantal and vowel sounds that can facilitate reconfiguration on an errored tongue shape is important. This can be particularly helpful when the tongue section that needs reconfiguration is located further down the oral cavity (e.g. tongue root).

> **Participant 1:** "I can't actually do the trill well enough to like pass as like a native speaker and so it was really interesting to see that like you can do things with your tongue and like corresponding sounds to help with that."

Identification of errors in tongue configuration.

Apart from simply seeing the tongue parts in motion, participants were able to view how a change in a tongue part position may make an errored attempt of the trill /r/. For instance, the participants were able to identify during the self-assessment questions that a forward tongue root created an errored trill /r/ when a retracted root was necessary. This app-based instruction only covered the errored positioning for the tongue root and tongue dorsum. Some comments regarding this theme are found below:

> **Participant 3:** "Firstly, it's […] identifying that like one – there's different parts of the tongue. Two – there can be different problems with different parts of the tongue that can lead to you not being able to pronounce it, rather it's the blade, rather it's the dorsum, rather it's […] the root. You can kind of help, even diagnose it yourself to figure out what, what the exact issue is. I think that's, that's very, very helpful."

> **Participant 2:** "I wonder what it would've looked like if someone, like for someone who couldn't roll their 'r', what it would look like on the ultrasound and like kind of see how like they like […] I guess it would be cool to like see some progression."

2) Now that I understand it, I can explain it.

Understanding the articulatory gestures required to production of a target sound can allow second-language learners to critically think about their articulatory routines and how these can either facilitate or disrupt production of a speech sound. In turn, an individual can use this deeper understanding on the gestures for a speech sound and generalize it to other speech sound in the same language that share a similar articulatory complexity, evaluate tongue configurations, and self-identify errors. Examples of participant responses in this area include:

> **Participant 2:** "I think the visualization played a big part […] I already knew how to trill my 'r' but I never like, understood […] what went behind that. Like I just was able to do it I guess […] now I can kind of explain to someone about like that process."
>
> **Participant 6:** "I think for me it's kind of cool because you get like a more visual type of learning experience whereas in a just a lecture is just all sound based so I think it could be super helpful."
>
> **Participant 3:** "Firstly, its, its identifying that like one – there's different parts of the tongue. Two – there can be different problems with different parts of the tongue that can lead to you not being able to pronounce it, rather it's the blade, rather it's the dorsum, rather it's […] the root. You can kind of help, even diagnose it yourself to figure out what, what the exact issue is. I think that's, that's very, very helpful."

Expansion of second-language learning.

The participants also commented on the use of ultrasound technology and the app-based training to help other second-language learners in their pronunciation practice. The fact that because the training focused on a single Spanish speech sound – the trill – the concepts taught in the training can be helpful in improving production of that one sound. They noted that thinking

about how to position your tongue can assist second-language learners in pronouncing the Spanish trill.

> **Participant 1:** "I think the specialized focus […] is like specific to Spanish sounds […] it puts it in a niche that like super helpful, especially for second language speakers, who like trying to get to a point where they sound more fluent in that native but like can't quite get there without like an extra helping hand."
>
> **Participant 2:** "It kind of helps us understand like how to approach like the trilled 'r' differently […] because some people might not understand that it's not just about being able to roll your 'r' but it's, it's more so about like the way that you shape your mouth and your tongue and I mean it kind of just breaks it down a little bit so it, the differentiation is what helps me."
>
> **Participant 7:** "I think that's also […] very helpful for someone who's actually whose using it to, to improve their pronunciation […] trying to pronounce something."

Specific training on the trill.

The participants also commented on the use of ultrasound technology and the app-based training to help other second-language learners in their pronunciation practice. The fact that because the training focused on a single Spanish speech sound – the trill – the concepts taught in the training can be helpful in improving production of that one sound. Because the trill is a complex articulatory gesture, having dedicated education on this specific phoneme can be beneficial for pronunciation instruction, especially since this is a late-occurring phoneme. They noted that thinking about how to position your tongue can assist second-language learners in pronouncing the Spanish trill.

Participant 1: "I think the specialized focus […] is like specific to Spanish sounds […] it puts it in a niche that like super helpful, especially for second language speakers, who like trying to get to a point where they sound more fluent in that native but like can't quite get there without like an extra helping hand."

Participant 2: "It kind of helps us understand like how to approach like the trilled 'r' differently […] because some people might not understand that it's not just about being able to roll your 'r' but it's, it's more so about like the way that you shape your mouth and your tongue and I mean it kind of just breaks it down a little bit so it, the differentiation is what helps me."

Participant 7: "I think that's also […] very helpful for someone who's actually whose using it to, to improve their pronunciation […] trying to pronounce something."

3) Integration of Sonographic Tongue Information in Teaching

With the ability of ultrasound imaging for providing information on tongue configuration for speech sound production, integration of this technique into teaching strategies or commercially available teaching apps, or other established language learning platforms may benefit learners of a language. The articulatory knowledge acquired from using sonographic tongue information can be at the reach of a bigger amount of learners of language. When modeling the new information on the articulatory requirements for speech sounds, it is important to provide learners with many examples of tongue shapes that allowed for good pronunciation of the speech sound and well as ones that were not conducive.

Commercial language apps.

With the mobility and accessibility of smart devices, individuals have access to a variety of informational sources at any time they could require them. An example of these would be

language learning apps developed for mobile phones. An advantage of using such language learning app in mobile devices is that the learner can learn at their own pace as well as learn at the comfort of their home or at any other place. The addition of sonographic articulatory information can be used to make learning more interactive and promote the use of language learning apps by individual seeking to supplement their language learning.

> **Participant 3:** "Personally I don't have a problem with trilling my "R" but I know lots and lots of people do. I mean, if it was something you know that was like integrated into Duolingo I definitely think people would like use it for sure."
>
> **Participant 4:** "I think that if it was integrated into some type of language practice […] that would be really useful because […] I wouldn't think to reach out about just that specific sound […] and so if it was a part of a larger language practice Spanish learning system, I think that would be really useful."

Accessibility and navigation.

Having the option to access the sonographic information for learning about production of a sound when they needed it appeared to be valued by participants. The flexibility of access to this information with examples by native and non-native speakers can allow individuals with limited resources to relocate or travel to sites of places beyond their immediate access. Ease of navigation through a language learning application is important for promoting learning.

> **Participant 6:** "I think that's yeah, like accessibility […]I liked that at the end of each like module there was the option to go back if […] we needed too."
>
> **Participant 7:** "I think it's useful because it's more accessible, you know. So not having to like go to like an office or travel like go somewhere you can just pull out the app and kind of start practicing by yourself."

Interfaces and teaching structures that are perceived as "not user-friendly" or cumbersome can hinder the learner's interests in continuing their learning and use of the teaching application. A language teaching app within the framework of PALS can be used to create user interfaces that allow learners to return to previously discussed topics in the event they require to review new knowledge or skills before they move on new knowledge or skills needed for production of difficulty to produce speech sound.

> **Participant 6:** "I think that's yeah, like accessibility […] I liked that at the end of each like module there was the option to go back if […] we needed to."

Error tongue configuration.

Providing multiple examples of error tongue configuration when producing a target sound is important for promoting learning of new articulatory movements needed for production of a speech sound. Additionally, some of those error examples might reflect the error that the learner currently performs when attempting production of the new sound. By providing additional examples of error tongue configurations, learners can potentially use these for guidance on how their articulatory gestures are impeding or promoting production of the target sound.

> **Participant 2:** "I wonder what it would've looked like if someone, like for someone who couldn't roll their 'r', what it would look like on the ultrasound and like kind of see how like they like […] I guess it would be cool to like see some progression."

Teaching time.

Interpretation of a sonographic tongue image of video requires the learner to become familiar with identifying oral structures in a variety of visual planes (e.g. sagittal and coronal planes). Sonographic imaging of tongue sections using either of these planes of view requires

training and sufficient exposure and experience identifying and assessing tongue section movements along the oral cavity during speech production. With adequate exposure and practice, interpretation of fast movements of each tongue section becomes easier. If not enough time is dedicated to this, learners can experience interpretation of fast moving tongue section more challenging when compared to individuals with more experience using this approach. If learners face challenges in easily interpreting tongue section placement from video recording of tongue movement during speech sound production, it can be harder to understand what tongue configuration they need to achieve or imitate.

> **Participant 1:** "I think if we would have taken a little bit more time to like focus on, in general what you can do, like with your mouth with ultrasound that might have been more helpful because all of us had trouble with like, is this slanted or dipped or whatever."
>
> **Participant 3:** "Sometimes [the sound production examples] weren't the best example of the tongue doing this thing or the tongue doing that thing that it's supposed to do."
>
> **Participant 5:** "If you didn't pause at like the right moment [on a sound production example] you would never have gotten it […] it was sort of difficult to sometimes pick up what position the tongue was because it would just be like that like happen in a millisecond."

Desire to improve speech sounds other than trill.

Many students expressed their own desire to use ultrasound in the future. Some expressed the desire to try ultrasound for elective speech reasons other than the production of the trill. These responses included:

Participant 1: "I would absolutely love to be able to like come in and have the ultrasound and like see what my mouth is doing. (Um) I know of course right now it's not possible because of COVID […] I really wish we could, cause I feel like it would be helpful for me personally but I also can see like someone as a beginning speaker it's so hard to sometimes visualize what you're supposed to be doing. Especially with sounds you aren't familiar like the trilled 'r'."

Participant 3: "I like to speak clearly about things, like both in Spanish and in English so maybe I'm sure there, there's sounds that I make every day in, in words that aren't the way you're supposed to make those sounds. So, I mean it could, it could potentially help me who doesn't have any necessarily issues but made me speak a little bit more clearly. So, I like that."

Participant 5: "I think I would use it because I would like to pronounce words more clearly as well and especially like for me personally I'm a journalism major so I communicate with people I got to make sure that I talk clearly whether it's in English or talking in Spanish class so I think it would be beneficial to have an app [training] like this to help you with those problems."

4) In-person learning versus app-based learning.

Learning preferences for acquisition of new knowledge and skills can vary by individual. Some individuals might prefer learning experiences that are guided by teacher or mentor at a classroom setting while others might prefer the flexibility of learning at their own pace and time. A feature that one participant expressed to have value in for helping with acquisition of speech sound pronunciation was the ability to practice with a native speaker as instruction on how to articulate a sound does not provide the ultimate goal of pronunciation of a speech sound, to

convey a message to another person in a realistic or natural interaction. This was conveyed by two participants during the small group discussion.

> **Participant 1:** "With like languages it always helps to have like somebody to talk to […] and if you had a function on the app that was like […] have a like twenty minute conversation with a native speaker […] I think that would be like super helpful but if it was just […] structures, 'here's how to pronounce them those kinds of things,' I think that can only take you so far."
>
> **Participant 2:** "I've learned Spanish the best, like I've retained the most information […] being in person [compared to online practice]."
>
> **Participant 4:** Additionally, we also go over when to use a trilled 'r' but we don't really talk about how to make that sound so that would also be helpful and different than a traditional classroom."

The participants commented on the new information on the movements of the tongue as they relate to producing the Spanish trill as well as how they wouldn't get this information in traditional learning experiences. The participants also noted the visual manner in which to learn about pronunciation rather than purely by listening. Many students gave positive statements on their Spanish Pronunciation course as a whole, but only some commented on the app-based training itself:

> **Participant 5:** "I personally really enjoy learning about like the trilled 'r' and like kind of like where to positon the tongue when you're saying the words because I think it's vital for speaking Spanish like kind of where you're positioning your tongue and like to make sure you're pronouncing it correctly instead of like botching it every time you're trying to pronounce a word."

DISCUSSION

Empirical data on native speakers of Spanish, as well as learners of Spanish as an additional language, has shown that trill /r/ is one of the latest speech sounds to acquire and master (Johnson; 2008). Although American English and Spanish share the alveolar rhotic tap /ɾ/ as part of their sound inventory, the trill /r/ and rhotic approximant /ɹ/ are not shared. Although the speech sounds /ɾ/, /ɹ/, and /r/ belong to the same group of sounds, rhotic consonants, the tongue configuration and articulatory gestures are not the same. The trill /r/, which is a speech sound acquired later in life that has a unique tongue configuration, can create a distinct challenge for L2 learners of Spanish.

Articulatory tendencies for production of speech sounds that belong to the same group (e.g. rhotics) have been described to be transferred from one language to another. This articulatory tendency carry-over can have effects that either promote or do not promote production of sounds in another language. That is, the transferred articulatory tendency can either change the acoustics and distort the target sound, or not do so (Howson et al; 2014).

Native speakers of American English can produce /ɹ/ using a variety of tongue configurations. All these different configurations possess the acoustic trait of having the third formant approximate the second formant, which is what native speakers of American English use to perceptually identify production of /ɹ/ (Zhou et al; 2007). In contrast, trill /r/ is not described as having multiple tongue configurations that produce the salient acoustic feature used by native speakers of Spanish for its perceptual identification. With American English speakers having many tongue configuration options for production of /ɹ/ and the limited option of tongue configuration for production of trill /r/, acquisition of /r/ by native speakers of American English who are learning Spanish can become very challenging. For example, if the articulatory tendency

being transferred from /ɹ/ to /r/ is a concave tongue dorsum, then production of /r/ may distorted because the trill is not described as having this articulatory gesture of a concave tongue dorsum.

Positioning of certain tongue sections within the oral cavity are not easily recognizable by the speakers. This is because some articulatory gestures (e.g. a retracted or forward tongue root positioning, a concave tongue dorsum, lowered lateral sides, etc.) do not provide proprioceptive knowledge to the speaker. That is, the speaker does not feel that tongue section making contact with another structure. For example, contact between the tongue tip and blade against the alveolar region when producing sounds like /n/ or /t/. If a native speaker of American English transfers a concave tongue dorsum from /ɹ/ to /r/, the sound will be distorted. The learner is not aware of the transferring of an articulatory gesture that impedes production of the target sound.

Implementation of ultrasound imaging for teaching production of a speech sound provides visual information on the positioning and configuration of the various tongue section when producing speech. This visual information can be used for a variety of purposes that can aid the learner in the acquisition of speech sounds that are considered late to be acquired and mastered. Being able to have visual information on tongue configuration, which was a theme found in the data, provides a great deal of information to the learner that can be used in a variety of ways such as understanding of articulatory requirements, facilitative contexts, transfer of articulatory tendencies, and progress monitoring. Participants communicated the usefulness of having that type of information during the app-based training. Based on the amount of information that can be extracted from visualizing tongue movement and tongue section positioning, a more robust understanding on how to achieve pronunciation of a sound is provided. Visualization of tongue movement and gestures can provide information to the learner

on articulatory gestures that are not easily detected as the gesture provides limited or no proprioception information. Providing learners with more descriptive articulatory requirements, the learner can be more aware of the necessary tongue configuration. In the case of trill /r/ production, articulatory gestures that do not provide tactile cues are tongue root positioning and dorsum location and configuration. Visualization of tongue movement and configuration provides learners with visual information on coarticulatory effects that can be used or avoid for purposes of speech sound acquisition. For example, using vowels with a retracted tongue root when practicing /r/ pronunciation or limiting the use of vowels with a forward tongue root positioning—since the trill requires a retracted tongue root. Without visualization of tongue movement, learners could potentially practice trill production in contexts that might pose additional challenges in trill acquisition. Tongue visualization also provides information on errored tongue configuration, tongue section repositioning, and any articulatory tendency that is being transferred that might be distorting pronunciation of the target sound. For example, a bunched tongue dorsum from the English rhotic approximant. If a learner can identify what requires repositioning, practice that focuses on the identified error can be applied. Tongue visualization appeared to be a very important feature of the training app our participants found to be helpful. As such, implementation of such information on pronunciation courses should be considered. In addition, the participants noted that the specificity of the training on the Spanish trill /r/ itself was beneficial to their learning, and it can be helpful for other learners as well. A focus on the hard-to-pronounce sound, such as the trill, should be a consideration in pronunciation training as well.

With the amount of information that is gathered from tongue visualization, learners can acquire a deeper and more thorough understanding on how the target sound is produced and what

changes they need to address in order to achieve it. The responses from the participating students showed an overall fascination in using ultrasound technology. This was true among the participants who could produce the trill and the participants who could not produce the trill. Consequently, learners may move from surface level stages of understanding (e.g. remembering) to deeper and more complex mastery of the knowledge (e.g. evaluate) (Anderson et al; 2001). Striving for deeper levels or knowledge and skills that go beyond the lower levels of established learning frameworks can facilitate acquisition and mastery of a late-developing speech sound such as the trill /r/.

Interest in the integration of sonographic tongue information in teaching was a theme observed in our data. With the current technological advances in communication, internet, tablets, smartphones, etc., access to information sources become easier. When integrating sonographic tongue information on pronunciation teaching, quick accessibility and ease of navigation should be taken under consideration. This can be of interest to commercial app developers. The participants expressed value in the ability to easily navigate through the app training as they pleased. For example, having the ability to go back to previously discussed material. It is important to note that being able to return to previously presented material is part of the PALS teaching approach. PALS empowers the learner to make a self-assessment so that the learner makes an informed decision on whether they feel prepared to continue their learning or if they need to revisit discussed material. If allowing learners to make an informed decision before continuing their learning progress is something of value for learners, it is important to incorporate such methodology to aid in pronunciation teaching. Another aspect to consider when implementing sonographic information to pronunciation instruction is the amount of examples and variation of errored pronunciations. The teaching app focused mainly on showing the

articulatory requirements of trill /r/ with production examples from native speakers of Spanish as well as speakers of Spanish learners. However, the participants expressed their interests in having additional examples or error tongue shapes. They noted a need for multiple visual examples of error tongue shapes in order to supplement the learners' awareness on the identification of tongue sections, their movement, and their positioning along the oral cavity. Additionally, this provides opportunities to compare and contrast coarticulatory effects that might hinder pronunciation of the intended speech sound. Finally, implementation of sonographic tongue information must take under consideration the amount of time required for learners to become comfortable with the learning and interpretation of the sonographic image or video examples. Although the app provided application practice, it might be beneficial for leaners to spend additional time in the application of new knowledge. When looking at the movement of the various tongue sections in live ultrasound imaging, it is observable that such sections move quite fast, and to the untrained eye, it can take additional time to make an accurate identification and assessment of tongue configuration. Although such challenges can be ameliorated by the use of still sonographic tongue images, providing video recordings of tongue section movement are important for viewing the displacement of tongue sections relative to other oral structures. Thus, the use of both videos and still images can facilitate a more accurate assessment of tongue configuration.

App-based learning might not be beneficial for every learner, but learning through an app interface has its advantages. The ability of the student to learn whenever is convenient in a variety of settings (i.e. at home, on the go, etc.) can be beneficial. However, this might not be considered meaningful enough to pursue learning for a subset of learners. Some students value the in-person interactions between teacher and peers during their language and pronunciation

training. The value of such experience might stem from its parallel to communicative interactions that can be encountered when speaking with a native speaker of Spanish or a study abroad experience. Fortunately, implementation of sonographic tongue information can be done with in-person courses as well app-based learning. This versatility allows for students who prefer a more traditional classroom instruction to benefit from the visual information provided by imaging technologies such as ultrasound. The participants noted this to be an overall unique learning experience that they may not have experienced in a traditional learning environment.

Especially during these socially-distanced times during the COVID-19 pandemic, this can be an innovative way to share this education with others when in-person instruction is restricted. Some participants mentioned that they are studying areas which require good spoken communication, such as journalism. They expressed an interest in using ultrasound to teach the improved production of speech sounds for such professional situations. The participants also commented on how this can be a useful expansion of foundational concepts for pronunciation practice in Spanish. Overall, ultrasound sonographic imaging as a tool for pronunciation practice, within the context of app-based training, may be a useful method for improving the practice of hard-to-produce speech sounds, especially the Spanish trill.

LIMITATIONS OF THE STUDY

Some limitations of the study were due to the global COVID-19 pandemic. Direct use of the ultrasound technology would give participants a view of their own tongue during attempts at the Spanish trill. Even if participants were not able to use the technology, in-person instruction may have provided more direct instruction of the material in the app-based training. In addition, due to time constraints, only three modules were used in the app-based training. A more complete training would have included additional modules on the tongue blade and tongue sides.

CONCLUSIONS

This study includes preliminary qualitative data on how UI technology can be used to augment pronunciation practice in the Spanish language within the context of app-based training online during these socially-distanced times. The PALS model appeared to be beneficial to the participants' learning experience during the app-based training through their ability to accurately recall concepts during the discussion. The perspectives of these students showed overall themes of visualization of the tongue, the ability to understand and explain the concepts, integration of sonographic tongue information in teaching, and the difference of in-person learning and app-based learning. Future studies could look at other languages and their speech sounds that are difficult to pronounce for second-language learners. As technology advances, there may be more sophisticated ways of teaching pronunciation online with specific feedback for learners. With the help of advancements in technology such as UI and online learning platforms, learners of Spanish may be able to improve their confidence in speaking through clear pronunciation of unique sounds without misunderstandings in communication.

REFERENCES

Ahmadi, M.R. (2018). The Use of Technology in English Language Learning: A Literature Review. *International Journal of Research in English Education*, *3*(2).

Alder-Bock, M., Bernhardt, B. M., 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), 128-39.

Anderson, L.W., Krathwohl, D.R. (2001). *A taxonomy for learning, teaching, and assessing, Abridged Edition*. Boston, MA: Allyn & Bacon.

Antolík, T. et al. (2019). The Effectiveness of Real-Time Ultrasound Visual Feedback on Tongue Movements in L2 Pronunciation Training: Japanese Learners' Progress on the French Vowel Contrast /y/-/u/. *Journal of Second Language Pronunciation,* 5: 72-97.

Baran-Lucarz, M. (2014). The link between pronunciation anxiety and willingness to communicate in the foreign-language classroom: The Polish EFL context. *Canadian Modern Language Review*, *70*(4), 445–473. doi: 10.3138/cmlr.2666

Birdsong, D. (1999). *Second Language Acquisition and the Critical Period Hypothesis*. Erlbuam.

Bird, S., Gick, B. Ultrasound biofeedback in pronunciation teaching and learning (2018). International Symposium on Applied Phonetics.

Bliss, H., Abel, J. & Gick, B. (2018). Computer-assisted visual articulation feedback in L2 pronunciation instruction: a review. *Journal of Second Language Pronunciation* 4, 129-153.

Boyce, S. E., Hamilton, S. M., & Rivera-Campos, A. (2016). Acquiring rhoticity across languages: An ultrasound study of differentiating tongue movements. *Clinical Linguistics & Phonetics, 30*(3-5), 174-201.

Conti, G. (2016, May 31). Nine research facts about L2 phonology teaching and learning that every teacher should know. *The Language Gym.* https://gianfrancoconti.com/2016/01/23/nine-research-facts-about-l2-phonology-that-every-teacher-should-know/.

Dunst, C. J. and Trivette, C. M. (2009). Let's be PALS: an evidence-based approach to professional development. *Infants & Young Children, 22*, 164-176. Retrieved from https://journals.lww.com/iycjournal/Fulltext/2009/07000/Let_s_Be_PALS_An_Evidence_Based_Approach_to.2.aspx

Fabiano-Smith, L., Barlow, J.A. (2010). Interaction in Bilingual Phonological Acquisition: Evidence from Phonetic Inventories. *Int J Biling Educ Biling*.

Face, Timothy L. (2006). Intervocalic Rhotic Pronunciation by Adult Learners of Spanish as a Second Language. In *Selected Proceedings of the 7th Conference on the Acquisition of Spanish and Portuguese as First and Second Languages*, ed. Carol A. Klee and Timothy L. Face, 47-58. Somerville, MA: Cascadilla Proceedings Project.

Flege, J.E. (1980). Phonetic Approximation in Second Language Acquisition. *Language Learning*. 30(1), 117-134.

Hu, X., Ackermann, H., Martin, J.A., Erb, M., Winkler, S., & Reiterer, S.M (2013). Language aptitude for pronunciation in advanced second language (L2) learners: Behavioral predictors and neural substrates. *Brain and Language*, *127*(3), 366-376.

Howson, P., Komova, E., & Gick, B. (2014). Czech trills revisited: An ultrasound EGG and acoustic study. *Journal of the International Phonetic Association, 44*(2), 115-132. Johnson,

K. E. 2008. “Second Language Acquisition of the Spanish Multiple Vibrant Consonant.” PhD diss., University of Arizona.

Jarvis, P. (1995). *Adult and continuing education: Theory and practice* (2nd ed.). London: Routledge.

Johnson, K. E. (2008). “Second Language Acquisition of the Spanish Multiple Vibrant Consonant.” PhD diss., University of Arizona.

Lawson, E., Stuart-Smith, J., & Scobbie, J. (2008). Articulatory insights into language variation and change: Preliminary findings from an ultrasound study of derhoticization in Scottish.

Lee, J., Jang, J., Plonsky, L. The effectiveness of second language pronunciation instruction: a meta-analysis (2015). *Applied Linguistics*. *36*(3). 345-366.

Levy, M. (2009). Technology in Use for Second Language Learning. *The Modern Language Journal*, *93*(1). 769-782.

Lord, G. (2005). (How) Can We Teach Foreign Language Pronunciation? On the Effects of a Spanish Phonetics Course. *Hispania, 88*(3), 557-567. doi:10.2307/20063159

Neufeld, G.G. (1980). On the Adult’s Ability to Acquire Phonology. *Teachers of English to Speakers of Other Languages Quarterly*. *14*(3). 285-298.

Olson, D.J. (2014). Benefits of Visual Feedback on Segmental Production in the L2 Classroom. *Language Learning & Technology*. *18*(3). 173-192.

Ouni, S. (2014). “Tongue Control and its Implication in Pronunciation Training.” *Computer Assisted Language Learning* 27: 439-453.

Pascual y Cabo, D., Prada J. (2018). “Redefining Spanish teaching and learning in the United States.” *Foreign Language Annals*. 51(3): 533-547.

Rivera-Campos, A. (2019). From English Rhotic Approximant to Spanish Rhotic Trill: A Case Study. *Journal of the National Black Association for Speech-Language and Hearing, 14*(1), 46-59.

Sturm, J.L. Current approaches to pronunciation instruction: A longitudinal case study in French (2019). *Foreign Language Annals.* 52(1).

Zhou, X., Espy-Wilson, C.Y., Tiede, M., Boyce, S. (2007). An articulatory and acoustic study of “retroflex” and “bunched” American English rhotic sound based on MRI. *Interspeech*, (54-57).

TABLES

Table 1

Main themes from participants' responses with codes for sub-themes

Theme	Codes
1) Visualization of tongue	Articulatory requirements
	Facilitative contexts for tongue section repositioning
	Identification of errors in tongue configuration
2) Now that I can understand it, I can explain it	Expansion of second-language learning
	Specific training on the trill
3) Integration of sonographic tongue information in teaching	Commercial language apps
	Accessibility and Navigation
	Error tongue configuration
	Teaching time
	Desire to improve speech sounds other than trill
4) In-person learning versus app-based learning	This theme required no codes for sub-themes

APPENDIX

Appendix A: Semi-Structured Discussion Questions

1. What are your thoughts on what you just learned today about the trill?
    a. What do you think about the use of ultrasound imaging for pronunciation learning?
    b. What do you think about the app-based training as it relates to your learning Spanish?
2. How would you compare this experience with learning about trill /r/ when compared to usual classroom lectures?
    a. What do you think helped best with your understanding on how to pronounce trill /r/?
    b. What do you consider helpful in the use of the app for pronunciation of /r/?
    c. What do you think was the least helpful aspect of the app for the pronunciation of /r/?
3. How would you feel about using this technology in the future?
4. Do you have any other comments to share?