CHAPTER 11

Ultrasound imaging applications in second language acquisition

Bryan Gick,[1] Barbara May Bernhardt,[2]
Penelope Bacsfalvi,[3] and Ian Wilson[4]
[1]University of British Columbia, Haskins Laboratories /
[2,3]University of British Columbia / [4]University of Aizu

Introduction

Ultrasound imaging has been used for decades as a tool for direct measurement of the tongue for speech research (e.g., Kelsey, Woodhouse & Minifie 1969; Skolnick, Zagzebski & Watkin 1975; Zagzebski 1975). However, with recent improvements in the image quality and affordability of ultrasound systems, possible applications of ultrasound to second language (L2) acquisition are only now beginning to be explored. This chapter discusses current directions in applying ultrasound to both research and pedagogical issues in L2 acquisition and is organized as follows. First, a brief description of ultrasound imaging, along with examples of its application for speech research, are given. The next section provides an overview on the use of technology in pronunciation training and instruction and identifies major research contributions in this area. Methods for conducting speech research using ultrasound imaging are then explained in detail, and several examples of recent and current studies are described. The chapter concludes with a discussion of some of the limitations of ultrasound research and a consideration of promising avenues for future research.

Background

An ultrasound machine emits ultra-high frequency sound through a transducer or "probe" containing piezoelectric crystals. When this transducer is held against the skin of the neck, the sound travels through the tongue and is reflected back to the transducer, resulting in echo patterns from which 2-dimensional images of the tongue surface are reproduced, as shown in Figure 1. These images can be viewed continuously on the machine itself for visual feedback, or recorded to video for later analysis. Because ultrasound is not able to image through bone or air, it can only allow visualization of the tongue and not, for example, the palate, jaw or rear pharyngeal wall. However, it is able to image the entire length of the moving tongue (sagittally, or along any 2-dimensional axis), and to do so at high temporal resolution (30 frames/sec or more), and with little or no discomfort or danger to the subject.

Perhaps the most obvious application of ultrasound in the pedagogical realm is to provide visual biofeedback in the teaching of challenging speech sounds. Other methods of articulatory visual feedback training have been shown to be effective in previous studies of L2 teaching (Catford & Pisoni 1970). However, tools providing direct visual biofeedback of articulation have traditionally been too expensive, slow, hard to use, or invasive for pedagogical purposes. With the cost of ultrasound systems coming within reach of many laboratories and practitioner groups, and an increase in portability and image quality, ultrasound has become a feasible tool for L2 applications. Recent speech therapy studies with hearing-impaired speakers (Bernhardt, Gick, Bacsfalvi & Ashdown 2003) and with speakers who have delayed acquisition of /r/ (Adler-Bock, Bernhardt, Gick & Bacsfalvi

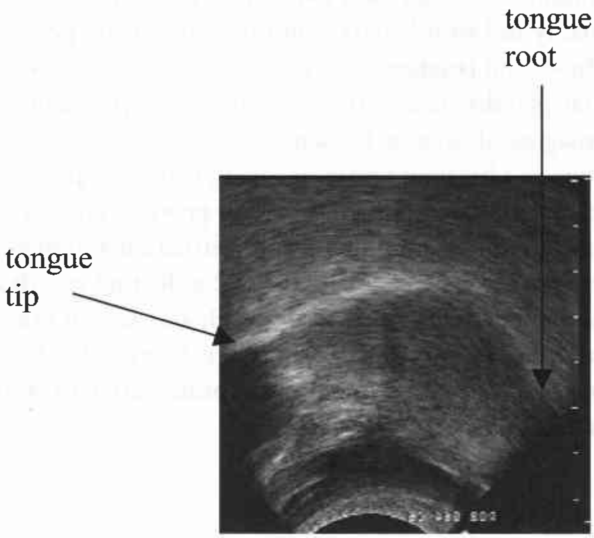

Figure 1. Example of a midsagittal ultrasound image of the tongue, showing the location of the tongue tip and root, the "shadow" of the jaw or sublingual cavity (below the tip), the "shadow" of the hyoid bone (below the root), and the arc at the bottom of the image indicating the location where the head of the transducer contacts the skin of the subject's neck.

2007) have shown that visual feedback therapy using ultrasound can facilitate the acquisition of articulatory targets across a wide range of speech sounds. Similar techniques described below are currently being applied to L2 learners.

In the research realm, beyond evaluation of the pedagogical efficacy of ultrasound as a learning tool, ultrasound provides the ability to measure articulator positions directly, allowing a finer-grained view of speech production and control. One area where this is of obvious interest for L2 acquisition is in describing the physical details of difficult or unusual sounds in specific languages to help facilitate in their learning (e.g., English /r/ as discussed above). Another area of particular relevance to L2 acquisition is that of language-specific "articulatory settings" (Honikman 1964). While these settings have long been discussed in the pedagogical literature (see Collins & Mees 1995), they have proven elusive to measurement. Recent imaging studies have, however, uncovered these settings through measuring language-specific postures held during non-speech segments between utterances (Gick, Wilson, Koch & Cook 2004; Wilson 2006). Ultrasound imaging will allow further study of this phenomenon across speakers of different languages, and will help to feed pedagogical programs advocating the direct teaching of articulatory setting (Mompeán González 2003).

Review of previous literature

The methods and status of pronunciation teaching have fluctuated greatly in the last 50 years (see Morley 1991, and Celce-Murcia, Brinton & Goodwin 1996, for excellent reviews, as well as Chun, Hardison & Pennington, this volume). In the 1940s to the early 1960s, when the audiolingual method of language teaching was the primary one in North America, the pronunciation component was a high priority, with a bottom-up focus (i.e., a focus on sound segments as the building blocks). From the late 1960s to the mid 1980s, when communicative competence and task-based methodologies were heavily promoted, pronunciation teaching was overshadowed by a focus on other areas. From the mid 1980s through the 1990s, pronunciation teaching was revitalized, especially with the realization of the salience of teaching suprasegmentals (i.e., stress, rhythm, and intonation), a top-down approach, and a call for the teaching of articulatory setting (including voice quality or voice-setting). A major development in the 1990s was the increasing popularity of computer-aided pronunciation (CAP) pedagogy (see Chapter 12, this volume, by Chun, Hardison & Pennington for a detailed discussion of CAP).

Electronic methods of teaching pronunciation have been used at least as far back as the early 1950s, shortly after the first commercially available sound spectrograph, the "Sona-Graph", was produced in 1951. Locke (1954: 420) reports that Pierre Delattre was already using spectrograms to teach pronunciation of French vowels, and Locke himself used spectrograms to teach timing, diphthongs, and aspiration. At that time, however, a real-time spectrograph had not yet been designed and so these methods simply provided a record of a student's speech, not online feedback. More CAP methods exist now enabling the pronunciation student to receive visual information, either dynamic or static, about his/her pronunciation. This visual information can take the form of after-the-fact analyses of one's pronunciation, e.g. formants, intonation contours, VOT, etc., or it can be instant biofeedback, either articulatory or acoustic. Anderson-Hsieh (1996) refers to the latter as *electronic visual feedback* (EVF). Most means of EVF provide acoustic information, as opposed to direct articulatory information. It is left to the student and/or teacher to interpret the mapping from the acoustic information provided to the articulatory adjustments that are demanded. In some cases this is not difficult, e.g. it is usually a simple matter to adjust the duration of a segment or the pitch of one's voice, but in other cases the mapping is not very transparent due to the non-linear relationship between vocal tract configurations and acoustic output, e.g. learning what to do to lower the third formant for production of /r/ in English (Guenther, Espy-Wilson, Boyce, Matthies, Zandipour & Perkell 1999; Lambacher 1999).

Articulatory information and feedback have often been used effectively in L2 teaching and learning. Commonly applied methods include the use of direct articulatory instruction and textbook figures of the vocal tract (e.g., Catford & Pisoni 1970; Kelly 2000), the use of a mirror for immediate articulatory feedback (e.g. Clawson 1907: 51; Dale & Poms 1994), encouraging students to concentrate on tactile and proprioceptive feedback (e.g. Acton 1984; Catford 1987; Celce-Murcia, Brinton & Goodwin 1996), and even using a ruler to monitor lip aperture (Odisho 2003: 89). Catford and Pisoni (1970) found that when teaching subjects new sounds, giving the subjects articulatory instruction and having them silently practice was more effective than simply having them listen and mimic. This advantage also carried over to the realm of speech perception as subjects given articulatory training also showed more proficiency at identifying the new sounds they were learning to produce. The results from Yule and Macdonald's (1994) study of 23 Chinese speakers emphasize the great degree of variability in learners' results after different types of pronunciation teaching (for a detailed discussion of L2 pronunciation teaching, see Chapter 13 by Derwing, this volume). One of the few methods of EVF that provides direct and immediate feedback of articulatory information is electropalatography (EPG), a method that has the subject speak with a prosthetic palate in place in his/her mouth. The palate has sensors that monitor the place of contact of the tongue with the palate and this information is displayed on a computer in real-time. This has been used successfully with hearing-impaired subjects and in other clinical applications (see Bernhardt, Gick, Bacsfalvi & Ashdown 2003). However, primarily because of the high cost and time investment required to have custom pseudopalates made for each subject or student, EPG has not been widely used to teach pronunciation to normally hearing L2 learners.

Ultrasound imaging addresses many of the shortcomings of previous EVF methods for L2 applications, being relatively affordable, non-invasive, safe, portable, quick, and versatile, while offering high-dimensional continuous data to be viewed and/or collected. This method has the potential to contribute to the teaching of pronunciation through both a top-down method (i.e., by shedding more light on underlying articulatory setting) and a bottom-up method (i.e., by enabling learners to view real-time images of their tongues as they produce individual sounds).

One example of a typical application of ultrasound imaging to pronunciation teaching involves English /r/. The /r/ sound can be particularly difficult to teach because it involves multiple constrictions (pharyngeal, palatal and labial; Delattre & Freeman 1968) and, as Lambacher (1999) points out, because the labial constriction hides the tongue from view. In a recent intervention study using ultrasound to provide visual articulatory feedback to adolescent English speakers with delayed mastery of /r/, Adler-Bock, Bernhardt, Gick & Bacsfalvi (2007) found that ultrasound allowed this complex sound to be broken down into its individual component movements, enabling learners to experience success at various componential levels on their way to mastering production of the /r/ without having to master the entire sound. In the end, this technique helped learners to make dramatic progress with a challenging speech target in a very short time. Techniques and issues for research and pedagogical applications will be discussed in detail in the following section.

Research methods for ultrasound imaging in L2 acquisition

Increased access to ultrasound imaging will enable advances in certain aspects of sound acquisition and production in L2 research and pedagogy. Aspects of production that were previously inferred from partial or indirect data can now be viewed directly. Because it is non-invasive and portable, and provides an easily interpretable signal, ultrasound technology lends itself well to use in the clinic or classroom (for a description of some field applications of ultrasound, see Gick 2002). While there are many possible applications for ultrasound imaging in L2 research and pedagogy, the present section focuses on describing the details of experiment design for L2 intervention studies, and briefly describes the methods used in a pilot study of Japanese learners of English.

Single participant design

Researchers interested in outcomes measures will find the single participant design merges nicely with the goals of ultrasound intervention studies. Single participant design allows for more focus on individual data, individual variation, and more detail, all of which are often applicable to L2 learning situations. In a group design, individual variation may be lost, and participants often need to be perfectly matched for a large number of criteria (e.g., age, education, language background and experience with the second language). Single participant research uses an approach that repeatedly measures the dependent variables from individual participants (Morgan & Morgan 2001). The dependent variables in such a design would consist of the targets to be learned (e.g., vowels, consonants, or suprasegmentals). The aspects of speech production to be analyzed would include: (a) articulator position and accuracy of segments, and (b) speech intelligibility and accuracy of production. Articulatory accuracy can be measured using graphical analysis software, such as NIH Image (http://rsb.info.nih.gov/nih-image/Default.html), ImageJ (http://rsb.info.nih.gov/ij/) or more specialized ultrasound-specific software such as Ultrax (developed at UBC by S. Rahemtulla and B. Gick; see http://www.linguistics.ubc.ca/isrl; see Figure 2), while intelligibility can be measured by listener judgments (e.g., Bernhardt, Bacsfalvi, Gick, Radanov & Williams 2005; see also Chapter 7 by Munro, this volume). A changing-criterion design with replication across targets using a multiple probe strategy is a powerful design for this type of study (Richards, Taylor, Ramasamy & Richards 1999). A changing criterion design allows the clinician to change the criterion gradually in a step-wise fashion, demonstrating learning at each step of the intervention. In this way, there is no question that the success is due to the intervention.

The design of a typical single-participant intervention study has three phases: (a) a baseline, (b) the intervention, and (c) a follow-up. The functional relationship between the independent variable and the dependent variables will be documented through step-wise improvement in speech production that matches the phases and sub-phases of the research design. Criteria during the intervention phase will be changed when the participant meets the criteria for three consecutive sessions. Intelligibility will be measured at each session. This will occur two-thirds of the way through the session after the client has "warmed-up" and before fatigue begins. Criteria will be met when the participant produces seven out of ten target productions during a sub-phase. Reliability is addressed through repetition of the experiment over many participants. In general, one needs to assure that the data are consistent across participants (Huck 2000). Aside from repetition, inter-observer agreement ensures that the process has been fair, ethical and rigorous (Richards, Taylor, Ramasamy, & Richards 1999).

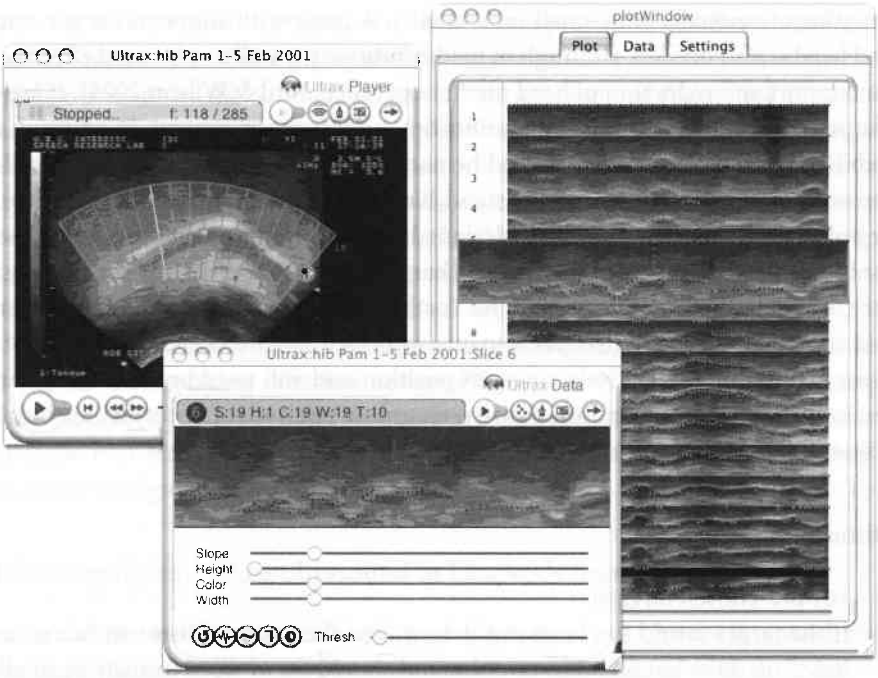

Figure 2. Example of Ultrax ultrasound analysis software. The left image shows a mid-saggital image of the tongue overlaid with an array of measurement lines; the center image shows the control window for edge detection settings; the right image tracks the movement of the tongue along each measurement line over time throughout an utterance.

Equipment

The primary piece of equipment needed is the ultrasound machine. For laboratory applications, any large hospital machine will do, though more recent models tend to have superior image quality. For portable applications see, for example, http://www.sonosite.com for an example of a very small portable unit. Other personal computer-based units can be adapted to field use using a laptop computer. All ultrasound machines require a transducer, and it is important to choose one that is appropriate for imaging the tongue. Our group has obtained the best results using endo-vaginal or pediatric intercostal transducers. These transducers have very small heads with sharp convex angles (120–180 degrees). This allows for a small contact area near the bend in the neck, avoiding several problems such as interference with jaw movement, excessive transducer displacement because of lingual floor muscles, and obscuring of the tongue tip from “shadows” cast by the jaw or the sublingual cavity. The one drawback of the endo-vaginal transducer is that the handle tends to be quite long, which can become awkward in space-limited situations (especially with small individuals). A chair with supports for the arms and head is also needed, although in field conditions, a wall can be used effectively for support and reduction of head movement (Gick, Bird & Wilson 2005). If articulatory data will be subject to quantification and/or measurement, in addition to stabilizing the head, a device should be used to hold the transducer (e.g., a tabletop or floor-mounted microphone stand, a mechanical arm such as that of a dental or ophthalmic chair, or a specially designed helmet). If images are only being used for biofeedback, the transducer may be hand-held by the subject or the investigator (see Gick, Bird & Wilson 2005 for further details regarding field applications and controls). Be aware that participants will often fatigue after 20 to 30 minutes from maintaining a relatively constant position and will need breaks during long sessions for rest and hydration. Finally, recording equipment is needed, including acoustic recording equipment and possibly video equipment.

Stimuli

1. For pre-chosen targets:
   If the target sound has been pre-determined then stimuli lists can be created based on those sounds. The target sound should occur word initially, medially, and finally in different phonetic contexts. Each context should be repeated at least ten times, distributing like tokens across the recording session to avoid list effects, and minimize any movement effects of both transducer and head.
2. For unknown goals:
   If the participant is unknown to the researcher, a broader set of data should be collected. Once again tokens should be distributed across the recording session. A list of words may then be created that gives a wide range of L2 consonants and vowels in a variety of contexts. In addition, the investigator should be aware of phonetic contexts that may influence the shape or position of the target sound.

Evaluation

A rating scale is effective in quantifying how much a participant's speech intelligibility has improved over the period of the experiment. Target sounds may be measured as individual sounds or in words in word-initial, medial and final positions (including in clusters). Productions may be judged by the investigators or by everyday native-speaking listeners using, e.g., a four-point Likert-type scale: 1 (exactly on target), 2 (in category), 3 (somewhat), 4 (not at all). While points 1 and 4 are clear, points 2 and 3 need further explanation. Point 2 (in category) indicates that a speech sound, for example /r/, would have most of the components of /r/

but may lack a crucial component or have a component of another sound, e.g., a raised tongue body. Point 3 (somewhat) would indicate that there is some rhotic quality present in the sound, but that all components of the /r/ are inaccurate, e.g., the tongue is too retracted in the pharynx, there is excessive lip rounding, and there is no retroflexed or bunched anterior gesture. Therapists, L2 teachers and investigators can use ultrasound outside of the experiment or training session to train themselves in the perception of such mismatches with the target. If the experimenters are the ones evaluating the productions, steps should be taken to ensure that sufficient inter-observer agreement is attained.

Criteria should be determined prior to evaluation, each of which represents a step in the changing criterion design. In the case of English /r/, for example, four criteria (C1, C2, C3, and C4) may be set and measured by the researchers: C1 (tongue *root retraction*), C2 (tongue *grooving*), C3 (*palatal constriction*), and C4 (*S-shape configuration* for tongue).

Pilot experiment: Using ultrasound in L2 speech sound training

In order to test the potential utility of ultrasound in L2 speech sound training, a preliminary single-session investigation was conducted with three Japanese linguistics student participants who had recently arrived in North America, facilitated by the four authors of this paper (three native speakers of Canadian English, and one native speaker of American English). Each subject participated in a single one-hour-long session with the investigator team for assessment, training, and post-assessment of their production of the English approximants /l/ and /r/ (for a detailed discussion of other training methods for this contrast, see Chapter 10 by Bradlow, this volume).

Pre- and post-training ultrasound recordings of /r/ and /l/ were made using an Aloka ProSound SSD-5000 ultrasound machine with a UST-9118 endo-vaginal 180-degree convex array transducer held in position using a fixed mechanical arm. Target sounds were elicited in word-initial, word-medial, and word-final positions in six vowel contexts (a variety of front, back, low and high vowels). Word-initial and word-final stimuli consisted of CV or CVC syllables; word-medial stimuli consisted of CVCV words. The randomized word list was repeated ten times pre- and post-training, with each word uttered in the carrier phrase "See X be". During the initial assessment, two of the authors phonetically transcribed on-line to identify contexts in which the participants' pronunciations of the two English approximants needed the most improvement.

The initial assessment showed that all three participants could already produce an English-sounding /l/ or /r/ in at least some phonetic context, with variability among the speakers in degree of proficiency with these targets. One speaker's /r/ was at 100% accuracy; however, this speaker showed neutralization of back low and mid vowels in the context of post-vocalic /l/. Thus, these contexts for /l/ became the training targets. Another speaker's /l/ was 100% accurate, but this speaker showed inconsistent production of /r/ across all word positions, with medial position showing the greatest difference from English. Medial context was the primary focus of training for this second speaker, although /r/ was targeted in all word positions. The third speaker produced /r/ only in post-vocalic position after /a/ and /ɔ/, and /l/ only pre-vocalically. For the third speaker, the /ar/ and /ɔr/ productions were used as anchors to address other postvocalic and word-initial /r/ productions. The /l/ was not targeted during ultrasound training, but the participant was given verbal instructions for self-correction at the end of the session using verbal cues only.

For the training part of the session (about 30 minutes), the participants were first shown their best and most troublesome productions from the ultrasound video-recordings. They were asked to compare their productions (both in drawings and verbally) with images produced by the authors in terms of (a) general shape of the tongue, and (b) specific shapes and movements of various parts of the tongue – tip, blade, body, dorsum, and root. In other work in the Interdisciplinary Speech Research Laboratory with adolescents with speech impairments, it has been found effective to have the participant engage intellectually in the treatment process, reflecting on the details of the articulation, and sub-dividing the tongue into relevant areas for shape and movement (Adler-Bock, Bernhardt, Gick & Bacsfalvi 2007; Bernhardt, Gick, Bacsfalvi & Ashdown 2003; Bacsfalvi, Adler-Bock, Bernhardt & Gick 2004). Because these L2 participants were linguistics students, they already had some knowledge of phonetics that they could apply to the training session, making the extremely short training period feasible. Further, all of the participants had had years of English training, including pronunciation training. However, none of the participants had previously examined images of their productions of /l/ and /r/. Syllable- and word-lists were created on the spot for practice in the session and post-training.

The particular components identified for English productions of /l/ and /r/ on ultrasound were as follows: The /l/ has two major lingual constrictions – a tip constriction at the alveolar ridge, and a dorsum retraction toward the uvula or into the upper pharynx. The 'stretching' of the tongue allows for the lateral release that is characteristic of the /l/. Pre-vocalic /l/ before non-back vowels shows simultaneous production of the two constrictions; post-vocalic /l/ and /l/ before back vowels shows sequential timing of the constrictions, with the post-vocalic constriction preceding the pre-vocalic constriction. For the /r/, there are two major variant shapes: bunched and retroflex. Both have two primary lingual constrictions: an anterior constriction in the palatal region, and a root retraction into the pharyngeal cavity. For the retroflexed /r/, the anterior constriction shows a curling back and raising of the tongue tip, with the body gently sloping downwards towards the pharynx. In the bunched /r/, the anterior constriction shows the tip down and the blade/body raised toward the palate, with a fairly steep downwards slope towards the tongue root. In both cases, the sides of the tongue body contact the back teeth and palate, bracing the anterior sections of the tongue.

At the end of the 30-minute session, all three participants were able to produce their target approximant successfully in the problem contexts. In the pre-training assessment, participants varied in which and how many articulatory components of /l/ or /r/ were missing or incorrectly produced. Post-assessment showed generalization of the changes made to the word-list for the assessment, although least for the third speaker, who had the most changes to make. The success of ultrasound in facilitating change for these participants who had persistent difficulties with specific L2 pronunciation targets exemplifies how visual feedback technologies can have exciting potential for L2 training in speech production, and helps to illustrate the goals and methods of an intervention study using ultrasound imaging. More in-depth training studies are ongoing using speakers from a variety of backgrounds and ages.

Discussion

While the potential benefits of articulatory feedback for speech training have long been acknowledged, it is only recently that the technology has reached a point where implementation in typical L2 research and pedagogy has become feasible. Previous findings using ultrasound imaging in pronunciation training, as well as the pilot experiment outlined in the present paper, show strong promise for ultrasound imaging in the future of these areas.

Other areas of L2 research where ultrasound imaging has clear implications – such as in the description of poorly described speech sounds and a deeper understanding of articulatory settings - have been described elsewhere (see above), and may be considered equally promising for the future of L2 pronunciation research.

Limitations and future directions

Because ultrasound applications in speech research are still relatively new, there remain a number of core issues in ultrasound research that have not been thoroughly worked through, mainly concerning quantification. First, because ultrasound provides a large amount of information (full spatial 2-dimensional images of the tongue at standard video rate), there has been little standardization, with different researchers using different methods of measuring the tongue, some focusing on "depth" or distance from the transducer, others reconstructing absolute spatial positions, and still others approximating and quantifying the shape of the tongue surface. Second, any quantification technique except those that depend only on shape (e.g., Stone, Morish, Sonies, & Shawker 1987; Iskarous 2004) requires location of the tongue surface in space. Because ultrasound does not image bone or other fixed anatomical structures, head and transducer stabilization or tracking is a vital part of determining best practices for ultrasound tongue measurements. Third, although temporal resolution is high compared to some other available imaging techniques (e.g., MRI), 30 frames per second is still too slow to capture some types of movement adequately. All of these issues are the subjects of ongoing investigation. However, it is important to note that none of these are limiting factors in using ultrasound for its most powerful L2 application: the imaging of tongue positions for visual feedback in learning to produce novel speech sounds.

Conclusions

While applications for ultrasound are still new in speech research, this is even more the case in L2 research. Even so, the potential value of this tool for pronunciation teaching is already being realized, and the implications of such a powerful tool for the advancement of knowledge and theory in L2 acquisition are extensive. One of the more important fundamental contributions of ultrasound in pedagogy to date has been in allowing teachers and learners to break down complex articulatory tasks into their practical components. However, whether in visualization, description, or experimental investigation, ultrasound provides an easy-to-use, non-invasive technique available to L2 researchers.

Suggested readings

Computer-aided pronunciation (CAP) in pedagogy:

Anderson-Hsieh, J. 1996. A guide to computer assisted aids for pronunciation improvement. *Speak Out!* 19: 28–31.

Hincks, R. 2003. Speech technologies for pronunciation feedback and evaluation. *ReCALL* 15(1): 3–20.

Pennington, M. C. 1999. Computer-aided pronunciation pedagogy: Promise, limitations, directions. *Computer Assisted Language Learning* 12(5): 427–440.

Ultrasound applications in speech:

Bernhardt, B., Gick, B., Bacsfalvi, P., & Adler-Bock, M. 2005. Ultrasound in speech therapy with adolescents and adults. *Clinical Linguistics and Phonetics*. 19(6/7): 605–617.

Stone, M. 1997. Laboratory techniques for investigating speech articulation. In W. J. Hardcastle & J. Laver (eds.), *Handbook of Phonetic Sciences*, Oxford: Blackwell, 11–32.

References

Acton, W. 1984. Changing fossilized pronunciation. *TESOL Quarterly* 18(1): 69–83.

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

Anderson-Hsieh, J. 1996. Teaching suprasegmentals to Japanese ESL learners through electronic visual feedback. *Japan Association for Language Teaching (JALT) Journal* 18(2): 315–325.

Bacsfalvi, P., Adler-Bock, M., Bernhardt, B., & Gick, B. 2004. Technology breakthroughs for /r/ and /l/ treatment. Poster presented at the CASLPA Annual Conference. Ottawa. May 2004.

Bernhardt, B., Gick, B., Bacsfalvi, P., & Ashdown, J. 2003. Speech habilitation of hard of hearing adolescents using electropalatography and ultrasound as evaluated by trained listeners. *Clinical Linguistics & Phonetics*. 17(3): 199–217.

Bernhardt, B., Bacsfalvi, P., Gick, B., Radanov, B. & Williams, R. 2005. Exploring electropalatography and ultrasound in speech habilitation. *Journal of Speech Language Pathology and Audiology* 29(4): 169–182.

Bradlow, A. R. 2008. Training non-native language sound patterns: Lessons from training Japanese adults on the English /ɹ/–/l/ contrast. In J. G. Hansen Edwards & M. L. Zampini (eds.), *Phonology and second language acquisition*, Philadelphia: John Benjamins.

Catford, J. C. 1987. Phonetics and the teaching of pronunciation: A systemic description of English phonology. In J. Morley, (ed.), *Current perspectives on pronunciation: Practices anchored in theory*, Washington, D.C.: TESOL, 87–100.

Catford, J. C., & Pisoni, D. B. 1970. Auditory vs. articulatory training in exotic sounds. *Modern Language Journal* 54(7): 477–481.

Celce-Murcia, M., Brinton, D. M., & Goodwin, J. M. 1996. *Teaching pronunciation: A reference for teachers of English to speakers of other languages*. Cambridge: Cambridge University Press.

Chun, D. M., Hardison, D. M., & Pennington, M. C. 2008. Technologies for prosody in context: Past and future of L2 research and practice. In J. G. Hansen Edwards & M. L. Zampini (eds.), *Phonology and second language acquisition*, Philadelphia: John Benjamins.

Clawson, E. 1907. Value of phonetics from the standpoint of the student. *The School Review* 15(1): 48–54.

Collins, B., & Mees, I. M. 1995. Approaches to articulatory setting in foreign-language teaching. In J. W. Lewis, (ed.), *Studies in general and English phonetics: Essays in honour of Professor J. D. O'Connor*, London: Routledge, 415–424.

Dale, P. W., & Poms, L. 1994. *English pronunciation for international students*. Englewood Cliffs, NJ: Prentice Hall.

Delattre, P. C., & Freeman, D. C. 1968. A dialect study of American *r*'s by x-ray motion picture. *Linguistics* 44: 29–68.

Derwing, T. M. 2008. Curriculum issues in teaching pronunciation to second language learners. In J. G. Hansen Edwards & M. L. Zampini (eds.), *Phonology and Second Language Acquisition*, Philadelphia: John Benjamins.

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

Gick, B. 2002. The use of ultrasound for linguistic phonetic fieldwork. *Journal of the International Phonetic Association*. 32(2): 113–122.

Gick, B., Bird, S., & Wilson, I. 2005. Techniques for field application of lingual ultrasound imaging. *Clinical Linguistics and Phonetics*. 19(6/7): 503–514.

Gick, B., Wilson, I., Koch, K., & Cook, C. 2004. Language-specific articulatory settings: Evidence from inter-utterance rest position. *Phonetica* 61(4): 220–233.

Honikman, B. 1964. Articulatory settings. In Abercrombie, Fry, MacCarthy, Scott and Trim (eds.), *In honour of Daniel Jones*, London: Longman, 73–84.

Huck, S. 2000. *Reading statistics and research*. New York: Longman.

Iskarous, K. 2004. Edge detection and shape measurement of the edge of the tongue. Ms., Haskins Laboratories, New Haven, CT.

Kelly, G. 2000. *How to teach pronunciation*. Harlow, U.K.: Longman.

Kelsey, C. A., Woodhouse, R. J., & Minifie, F. D. 1969. Ultrasonic observations of coarticulation in the pharynx. *Journal of the Acoustical Society of America* 46(4): 1016–1018.

Lambacher, S. 1999. A CALL tool for improving second language acquisition of English consonants by Japanese learners. *Computer Assisted Language Learning* 12(2): 137–156.

Locke, W. N. 1954. III. Speech analysis and synthesis: Development and prospects. Part (pp. 416–423) of Girard, D.P., Borglum, G., Locke, W.N., & Dostert, L.E., Teaching aids: Problems and possibilities. *The French Review* 27(6): 406–427. Originally presented at the 68th Annual Meeting of the MLA, Chicago, Dec. 29, 1953.

Mompeán González, J. A. 2003. Pedagogical tools for teaching articulatory setting. In M. J. Solé, D. Recansens, & J. Romero (eds.), *Proceedings of the 15th International Congress of Phonetic Sciences Barcelona 2003* (ICPhS), Adelaide, South Australia: Causal, 1603–1606.

Morgan, D. L., & Morgan, R. K. 2001. Single-participant research design: Bringing science to managed care. *American Psychologist* 56: 119–127.

Morley, J. 1991. The pronunciation component in teaching English to speakers of other languages. *TESOL Quarterly*, 25(3): 481–520.

Munro, M. J. 2008. Foreign accent and speech intelligibility. In J. G. Hansen Edwards & M. L. Zampini (eds.), *Phonology and second language acquisition*, Philadelphia: John Benjamins.

Odisho, E. Y. 2003. *Techniques of teaching pronunciation in ESL, bilingual & foreign language classes*. Munich: LINCOM Europa.

Richards, S. B., Taylor, R. L., Ramasamy, R., & Richards, R. 1999. *Single subject research: Applications in educational and clinical settings*. San Diego, CA: Singular Publishing Group.

Skolnick, M. L., Zagzebski, J. A., & Watkin, K. L. 1975. Two dimensional ultrasonic demonstration of lateral pharyngeal wall movement in real time – a preliminary report. *Cleft Palate Journal* 12: 299–303.

Stone, M., Morish, K., Sonies, B. C., & Shawker, T. H. 1987. Tongue curvature: A model of shape during vowel production. *Folia Phoniatrica* 39: 302–315.

Wilson, I. L. 2006. *Articulatory settings of French and English monolingual and bilingual speakers*. PhD dissertation, University of British Columbia.

Yule, G., & Macdonald, D. 1994. The effects of pronunciation teaching. In J. Morley, (ed.), *Pronunciation pedagogy and theory: New views, new directions*, Alexandria, VA: TESOL, 111–118.

Zagzebski, J. A. 1975. Ultrasonic measurement of lateral pharyngeal wall motion at two levels in the vocal tract. *Journal of Speech and Hearing Research* 18: 308–318.