

Static Palatography for Language Fieldwork

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This article describes how to do *static palatography*, a way to collect articulatory records about speech sounds that can be used either in the field or in the laboratory. Palatography creates records of the contact pattern of the tongue on the roof of the mouth during an utterance, and when the actual dimensions of the palate are known, can be a rich source of data about articulatory strategies. This paper (1) instructs the reader about the tools and methods needed to collect *palatograms* (records of contact on the roof of the mouth) and *linguograms* (records of contact on the tongue); (2) shows how to collect three-dimensional information about the size and shape of a speaker's hard palate; (3) illustrates how to incorporate these three types of records into life-size, anatomically accurate midsagittal diagrams of speakers' articulations; and (4) demonstrates how palatograms can be measured (and how linguograms can be categorized) in order to statistically compare articulatory strategies across speech sounds and/or across speakers.

1. INTRODUCTION.¹ Fieldworkers who document languages often have difficulty in determining exactly how a speech sound is articulated by native speakers. This article provides a detailed description of static palatography, a method of collecting articulatory records about speech sounds that can be used either in the field or in the laboratory. Static palatography (also known as direct palatography) uses an edible, paint-like marking material to record the contact pattern of the tongue with the roof of the mouth during an utterance. It is especially applicable to the field situation because, apart from a video camera, most of the necessary supplies can be found in larger towns. Additional advantages of the method are its portability, its low cost in comparison with electronic systems of gathering articulatory phonetic data, and the information it yields regarding both the tongue and the palate.

Other relatively portable methods of collecting data on speech articulations include some types of *dynamic palatography* (Hardcastle et al. 1989) and *portable ultrasound* (Gick 2002). Dynamic palatography, also known as electropalatography (EPG), uses a plastic retainer-like device implanted with electrodes and worn on the palate, to sample information about contact patterns on the palate over time. A drawback, however, is that EPG cannot provide information about tongue configurations during an utterance. On the other hand, portable ultrasound provides information on tongue shape and position during an ut-

¹ Acknowledgments: I am grateful to Peter Ladefoged for training me in palatographic techniques, and to Ian Maddieson, Sinisa Spajic, and Kimberly Thomas Vilakati for discussion and development of novel data processing methods. I also thank William O'Grady, Amy Schafer, and an anonymous reviewer for helpful comments.

terance, but since it tracks soft tissue rather than bone, it cannot show the tongue's position with respect to various areas on the roof of the mouth. In the laboratory, static palatography can be used together with EPG and/or ultrasound to acquire information about both active and passive articulators. Static palatography can also be used as a reliable stand-alone method, if EPG and ultrasound systems are beyond the fieldworker's budget, or if the worker is already in the field. Disadvantages of static palatography are that the speech collected tends to be overly careful, and that the resulting pictures represent a cumulative record of tongue-palate contact over the whole utterance.

In sections 2.1 through 2.5, I describe the tools and methods needed to collect palatograms (records of contact on the roof of the mouth) and linguograms (records of contact on the tongue). In sections 2.6 through 2.9, I describe how to collect three-dimensional information about the size and shape of a speaker's hard palate. Section 3 shows how to incorporate these three types of records into life-size, anatomically accurate midsagittal diagrams of speakers' articulations. Section 4 illustrates how palatograms can be measured and how linguograms can be categorized in order to statistically compare articulatory strategies across speech sounds and/or across speakers.

2. COLLECTING ARTICULATORY RECORDS. The palatographic techniques described here build on methods summarized in Ladefoged 1997, 2003. Static palatography essentially involves painting a speaker's tongue or palate with a nontoxic marking material, after which the speaker utters a word containing the speech sound in question. During the articulation, marking material is transferred to the opposite articulator. This contact pattern is videotaped and the speaker then rinses his or her mouth with water.

Static palatography (hereafter palatography) is one of the most labor- and time-intensive types of linguistic fieldwork, both for language consultants and for the fieldworker. As such, a smooth working relationship and a good measure of trust have to be developed among participants, to ensure that language consultants feel comfortable participating in this kind of documentation. Do not expect to *begin* your fieldwork in a community by collecting palatographic records from relative strangers. In my experience, palatography is the last kind of data the fieldworker collects, after steady, ongoing association with members of a community, and after interest in the language project has gathered momentum.

In each case, the fieldworker must demonstrate to potential participants how palatograms, linguograms, and impressions of the hard palate are made, so that they can observe and ask questions about the procedure, or about related concerns such as cleanliness and sterilization, before deciding to participate. The fieldworker demonstrates each procedure on herself or on a language consultant already participating in palatography.

Palatography sessions involve a fair amount of equipment, a good deal of set-up time, and lots of "dishwashing." A session with a given speaker usually lasts from one to two hours, depending on when the speaker wishes to end the session. Set-up and clean-up time before and after the session can last an hour each. You should expect that some consultants will choose not to continue this painstaking work after the first session. Although this sounds forbidding, it is my experience that other consultants become quite interested in how they articulate their language sounds, remain patient and willing to participate in this aspect of the study, and even encourage interest among other members of the community.

2.1 PALATOGRAPHY WORD LISTS. As mentioned above, static palatography is a cumulative record of tongue–palate contact during an utterance. Thus, it is important to plan utterances carefully. For example, unless you are intentionally investigating the behavior of consonants in high-vowel environments, choose words that contain only non–high vowels and labials (aside from the tongue–palate segment of interest) in order to avoid confounding effects of multiple tongue–palate contacts. Words should also be in common use in the language. Review the word list with each speaker to make sure s/he is familiar with each word, as well as with the glosses you will be using as prompts in the contact language. Table 1 shows an example word list for the coronal stops of Western Arrernte, an Arandic language of Central Australia. Note that each word includes only one coronal contact, except for /matəɹə/ ‘cloud’, which contains two: the target stop [t], and the postalveolar approximant, [ɹ]. In such a case, if no other words can be found, save this word until last, when the speaker is accustomed to other aspects of palatography, and then instruct the speaker to think of the word while saying it, but to omit the final syllable.

Features	<i>[-apical]</i> <i>[+anterior]</i>	<i>[+apical]</i> <i>[+anterior]</i>	<i>[+apical]</i> <i>[-anterior]</i>	<i>[-apical]</i> <i>[-anterior]</i>
<i>Stops</i> <i>Between</i> <i>Vowels</i>	'pəɹə <i>pouch (n)</i>	'matə(ɹə) <i>cloud (n)</i>	'pəɹə <i>rock (n)</i>	'pəɹəmə <i>is coming(vi)</i>
<i>Stops</i> <i>Word-initially</i>	'təmə <i>grind (vt)</i>	'Təpə <i>back (n)</i>		'təpə <i>grub (n)</i>

TABLE 1: Static Palatography word list for W. Arrernte coronal stops

2.2 EQUIPMENT AND SUPPLIES. Static palatography requires an extensive checklist of materials. You will need the following:

- digital video camera (extra battery pack recommended)
- 30-watt external light source attachment for video camera
- tripod
- clean dishcloths
- four or five intraoral mirrors (different sizes)
- large hand mirror for speaker’s use
- cup for speaker’s use
- large cooking pot
- small bowls
- tissues or small towels for speaker’s use
- chair with backrest for speaker’s use
- small table, chair, stool, or raised surface within speaker’s reach
- two large towels to protect speaker’s clothing
- wall for speaker to lean against
- 2–4 gallons (7–15 liters) of potable cold water
- 2–4 gallons (7–15 liters) of hot water for cleaning and sterilization

- dishwashing detergent
- dilute bleach or other sterilizing solution
- small paint brushes (various sizes)
- “digestive charcoal capsules” (also known as “activated charcoal capsules”), available over the counter in pharmacies or chemists’ shops for treatment of indigestion
- olive oil or other cooking oil
- assorted small flexible plastic containers with lids
- chromatic dental alginate (available by mail from dental supply outlets)
- plastic scoop or spatula
- pad of graph paper
- one “letter” or “A4” sized piece of cardboard, 1.25 mm in thickness (usually comes attached to a pad of graph paper)
- scissors or craft knife to cut cardboard
- masking tape
- ruler
- smooth, flat, cutting board (about 190 mm x 125 mm)
- razor blade, approximately 80 mm in length (e.g., replacement blade for box cutter)
- plaster of paris
- petroleum jelly
- measuring calipers
- small ziplock plastic storage bags
- lemon or other citrus juice (optional)

Long rectangular intraoral mirrors can be ordered from dental supply companies for approximately US\$50 each, or can be made to order by a glass company for approximately US\$10 each. Mirrors should be made of glass about 4 mm (0.15 in.) thick and 200 mm (8 in.) in length; i.e., long enough for a speaker to be able to insert the mirror into her mouth to reflect the palate, without her fingers obscuring the reflection. Mirrors must have smoothed, rounded edges so that they are safe for users to handle and insert in their mouth. Four or five mirrors of different widths should be made, to fit different sized mouths: useful widths are 50, 55, 60, and 65 mm (2–2.5 in.).

2.3 SETTING UP. An unused schoolroom or a quiet room in a house where you can set up and work uninterrupted is an ideal place for palatography sessions, especially if you have access to potable water nearby, and a way to boil water to wash and sterilize equipment. However, palatography sessions can be conducted outside, if necessary. One main concern should be for the self-consciousness of the speaker; outside sessions can draw a crowd and distract or inhibit the speaker.

Before the speaker arrives, wash and rinse a small paintbrush, the palatography mirrors, the hand mirror, the cooking pot, a cup, and several small bowls. Use very hot water with soapy dishwashing detergent. Sterilize the equipment by using a very small amount of bleach in water (follow directions on the bleach container), rinse, and allow to dry. Using

hot, soapy water is important not just for sterilization, but for keeping the oil-based marking mixture smooth. (When cold water is used, globules of water remain on the brush and cause the marking mixture to be lumpy and hard to apply.) Wide, soft brushes about 10 mm in width are preferable to slimmer brushes or disposable cotton tips, because it takes only a few strokes to cover the entire tongue or palate with paint, an advantage for ticklish speakers. Use masking tape to label the brush with the speaker's name for later reuse; each speaker will have a different labeled brush.

Prepare the "edible paint" mixture of olive oil and powdered digestive charcoal. Pull apart 20 or so charcoal capsules, emptying the powder into a small bowl or plastic container. If necessary, grind the powder with the bottom corner of a cup to make sure the mixture will be smooth and uniform in consistency. Slowly add olive oil, stirring with the paintbrush, until a thick black paint results.

Position the chair in which the speaker will be sitting against a wall. Set up the tripod, video camera and light source facing the chair, about five feet away. (You may wish to mark the position with masking tape so that you can easily recreate this set-up.) Position the small table or stool next to the chair, cover it with a clean towel or dishcloth, and place on it the hand mirror, tissues, a clean cup, a container of water and the large cooking pot, to be used as a spittoon.

When the speaker arrives, ask her to sit comfortably in the chair facing the video camera, with her head resting against the wall. Adjust the angle of the video camera on the tripod, and adjust the zoom on the video camera to center squarely on the speaker's mouth. Fix the camera in this position. Next, ask the speaker to choose a palatography mirror that fits comfortably in her mouth but is wide enough to fully reflect the upper teeth on both the left and right sides. Have the speaker practice inserting the mirror, anchoring the two back corners of the mirror behind her upper back teeth, resting her head against the wall, and opening her mouth wide to reflect the palate.

2.4 PALATOGRAMS. Help the speaker to place the large towels over her lap and shoulders, to protect her clothing from stray charcoal. Place the cooking pot on her lap. When she is ready, ask her to protrude and relax her tongue. Paint the upper surface and sides, and the

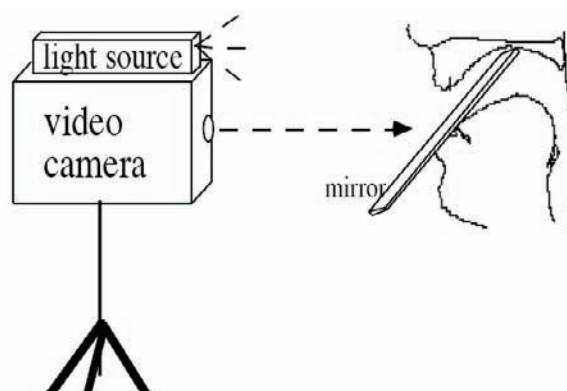


FIGURE 1: Schematic of set-up for static palatography

underside of the tip and blade. (After getting used to this procedure, some speakers become adept at painting their own tongues with the help of the hand mirror.) Paint the tongue evenly, but sparsely (i.e., without causing drips), as far back on the tongue as is comfortable for the speaker. Then ask the speaker to return her tongue to a resting position inside the mouth, and keep her mouth relaxed and open so that no tongue-palate contact is made. Drooling may or may not occur; either is normal. Ask the speaker to close her eyes (the external light source on the video camera is usually very bright), turn the video recorder and light source on, and prompt the speaker to say the target word by giving its gloss. While the video camera is still recording, direct the speaker to place the palatography mirror in her mouth to reflect the articulation, positioning the corners of the mirror behind the back molars, so that the entire pattern of contact can be seen through the video camera (see figure 2). For each recording, check through the viewfinder that you can see a good image of the palate. Participants tend to become fairly adept at placing the mirror in the same way for each palatogram. Nevertheless, the mirror's position will inevitably change slightly from token to token, causing angular distortion of the image filmed. Methods for correcting this distortion are discussed in section 3.2. After recording the palatogram for several seconds, turn off the video camera and light, allow the speaker to view the articulation in the hand mirror as a matter of interest, and ask her to rinse her mouth with water. Allow her to relax for a few moments before painting her tongue for the next palatogram. (If the speaker wishes, you can add a small amount of citrus juice to the water, to cut the oil. However, some speakers dislike the sharp taste of unsweetened citrus and prefer plain water. Do not sweeten the rinse mixture, as this can cause oversalivation.)

Be aware that speaker's tongues differ in their absorbency to the charcoal mixture. For a few speakers, black color may begin to collect on the tongue despite repeated rinsings. In these cases, begin subsequent sessions by obtaining linguograms (section 2.5) before palatograms, since repeatedly painting the tongue for palatograms can cause loss of sufficient contrast on the tongue in linguograms.

Although the speaker is meant to rinse out the oil-charcoal paint mixture after each palatogram or linguogram is recorded, assure her that the mixture is entirely edible, and can be swallowed without danger.

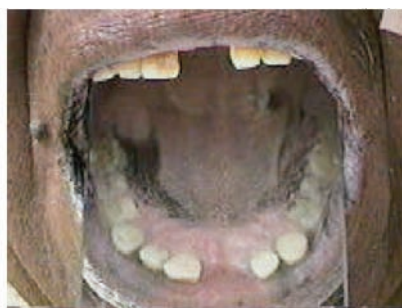


FIGURE 2: Palatographic image from video. Upper teeth are shown at the top and reflected in the mirror at the bottom. Token: /pətə/ 'rock'.

2.5 LINGUOGRAMS. Ask the speaker to rest her head on the wall behind her, and to incline her head back slightly. Paint the roof of her mouth and the inside surfaces of the upper teeth, being careful not to allow paint to drip onto the tongue or lower teeth. Because it is less accessible, the roof of the mouth is more difficult to paint than the tongue. In addition, the speaker's palate may be ticklish. However, paint as far back on the palate as the speaker can comfortably tolerate. Ask her to relax with her mouth open, bring her head upright, and close her eyes. Turn the camera and light source on. Direct the speaker to say the single word in question, and to put her tongue out and down so that the pattern can be filmed. Then instruct the speaker to move her tongue up, down, and to either side, to show any sublingual contact, or contact on the sides of the tongue. Again, allow the speaker to view the articulation and then rinse her mouth.

No intraoral mirror is required for linguograms. Figures 3 and 4 show two still images taken from a video clip of a speaker uttering the W. Arrernte word /pətə/ 'rock', and then showing contact areas on the tongue. In figure 3, the speaker has stretched her tongue out and down to show a large portion of the upper surface, including the dorsum; a few moments later in figure 4 she has brought it in and up so that the underside is visible. Note how different in size and shape the tongue can appear to be.



FIGURE 3: Linguogram showing tongue blade and body contact. Token: /pətə/ 'rock'



FIGURE 4: Linguogram showing tongue tip and sublingual contact. Token: /pətə/ 'rock'

2.6 PALATE IMPRESSIONS. In addition to palatographic and linguographic patterns for the target articulation, it is important to obtain accurate three-dimensional information about the particular size and shape of the speaker's palatal vault, in order to accurately reconstruct the articulation and depict it in a midsagittal diagram. For this reason, two alginate impressions of the speaker's palate are taken.

Your goal in making a palate impression is to create a three-dimensional picture of the mouth cavity between the occlusal (biting) plane and the roof of the mouth (including

the inner surfaces of the teeth), as shown schematically in figure 5. Note that a palate impression is different from a dental impression made by a dentist, whose goal is to create a negative of the *outer surfaces* of the teeth.

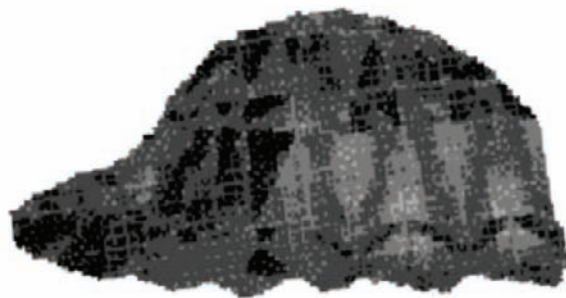


FIGURE 5: Schematic of a palate impression (image credit: Cheng Cheng Saw.)

Use a chromatic dental alginate such as Kromopan or Jel-trate. Since ambient air temperature and the particular impression material used can affect the process, this is a trial-and-error method that takes some experience. Practice taking palate impressions of your own mouth until you are comfortable using the alginate.

Chromatic dental alginate has different color phases. Kromopan, for example, is purple during the mixing phase, pink while it is setting, and green once it has finished setting. Place several tablespoons of powdered alginate in a flexible plastic container and add water while mixing quickly. (Use slightly less water than the package's instructions call for, since you will be placing a mound of alginate on top of a palatography mirror rather than into a dental impression tray.) Mix thoroughly, making sure there are no air bubbles in the alginate, until the purple mixture begins to thicken into a paste and turn pink. Gather the setting alginate in a plastic scoop or spatula, transfer it to the end of the speaker's palatography mirror, and hand the mirror to the speaker. Instruct the speaker to lean well forward over a large cooking pot or sink, place the alginate in her mouth, breathe through her nose, and slowly bite down on the alginate until the mirror is firmly pinned in the occlusal plane between her upper and lower teeth. Extra alginate will drip forward out of her mouth. Leaning forward is important, to make sure that any alginate drips forward rather than potentially being swallowed or inhaled. Tell the speaker to continue breathing through her nose, and to drool as need be, while the alginate sets. Once the alginate turns green, ask the speaker to remove the impression by gently rocking the mirror up and down and from side to side, and then provide water and towels, to help her rinse her mouth and dry off.

Check the impression to make sure it has no air bubbles or other holes or gaps. Carefully remove it from the mirror by scraping *against the mirror* with a metal spatula or knife,

as in figure 6.² Store the impression in water, in a labeled plastic container with a lid, to prevent shrinkage. Make two alginate impressions for each speaker.



FIGURE 6: Slide the alginate impression from the mirror. (Photo credit: Ian Maddieson.)

2.7 LIFESIZE MIDSAGITTAL SECTION AND CONTOUR MAP OF THE PALATAL VAULT.

Use one of the alginate impressions to make topographic tracings of the shape and dimensions of the speaker's palatal vault for future reference. First, since they do not figure in speech articulations, trim off any impressions of the outer surfaces of the teeth, as shown in figure 7. Gently dry the impression. Place the flat portion on a piece of graph paper, and trace around its edges (figure 8.) Label the tracing with the speaker's identifying information. Next, slice the impression in half in the *midsagittal* plane, between the two central incisors (figure 9). You may have to estimate the midline, if one or more incisors is missing. On an unlined sheet of paper, trace each resulting half in the midsagittal plane, to yield a profile image of the shape and size of the palate (figures 10 and 11.)



FIGURE 7: Remove impressions of the outer surfaces of the teeth.
(Photo credit: Ian Maddieson.)

²Note that the palatography mirror shown in figures 6, 7, and 9 is slightly different from the rectangular mirrors described above.

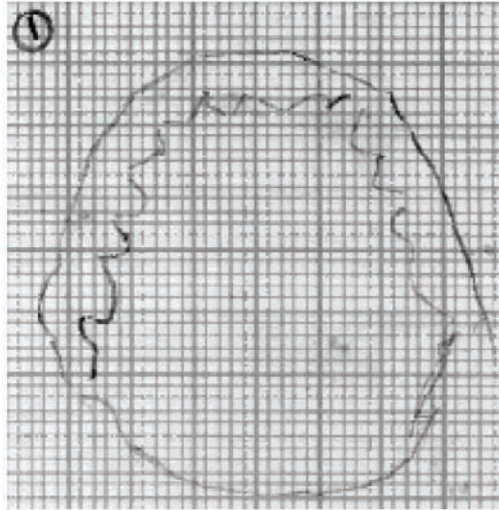


FIGURE 8: Trace the alginate impression in the occlusal plane.
(The serrated curve shows where inner surfaces of the teeth join the palate.)



FIGURE 9: Slice the impression in half, in the midsagittal plane.
(Photo credit: Ian Maddieson.)



FIGURES 10 and 11: Trace the midsagittal profile of the palate.
(Photo credits: Ian Maddieson.)

Next, place both halves back together and bisect the impression in the *coronal* plane (usually between the second premolar and first molar on each side; see the Appendix for a diagram of an adult upper dental arch). Use these midsagittal and coronal cuts to define *x* and *y* axes and an origin on the graph paper, as shown in figure 12.

Now slice the alginate impression parallel to the *occlusal* plane, removing the bottom 5 mm of the impression. A slicing tool for this purpose is described in section 2.8. You may have to slice each quadrant separately. Realign the four quadrants together at the origin and retrace the impression. This yields the contour line labeled “5” (mm) in figure 13. Repeat this process, slicing successive 5-mm increments from the bottom of each quadrant of the impression, placing the quadrants together at the origin, and retracing each contour. From figure 13 we can see that the highest area of the speaker’s palatal vault is more than 20 mm above the occlusal plane.

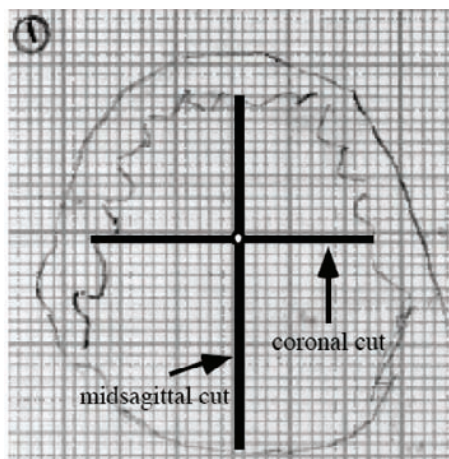


FIGURE 12: Alginate impression cut into four quadrants, in midsagittal and coronal planes.

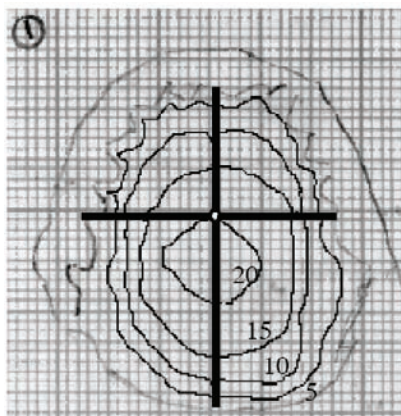


FIGURE 13: Contour map of Speaker 1’s palate.

2.8 SLICING TOOL. The easiest way to reliably slice 5 mm from the bottom of the alginate impression is to build the simple tool described below and shown in figure 14.³ Cut eight strips of 1.25 mm-thick cardboard. Tape four strips together to form a “wall” 5 mm in height. Place two cardboard walls parallel to each other, 70 mm or so apart on a flat, smooth cutting board. On top of, and perpendicular to, the cardboard walls tape an 80-mm-long razor blade, to create a wide slicing area. Push each quadrant of the palate impression through this tool. After each of the four quadrants has been sliced, place them together at the origin on the tracing paper and trace the resulting contour. Repeat this process until all of the impression material is drawn in this way.

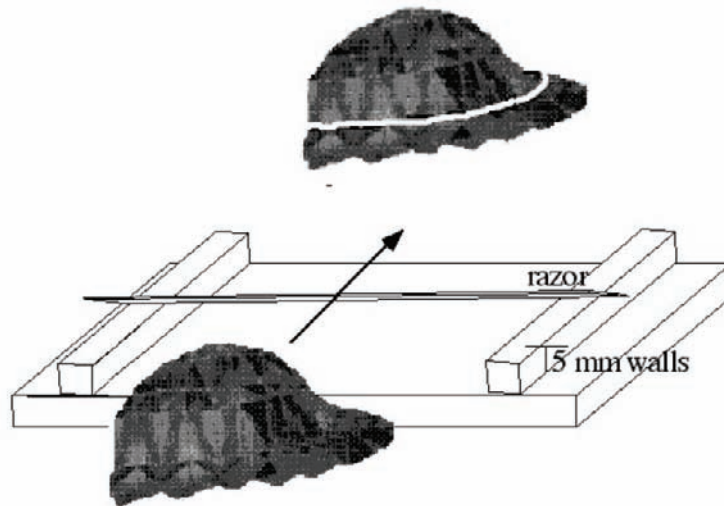


FIGURE 14: Sketch of a slicing tool for use in creating a contour map of the palate. The white line around the upper dental impression shows where the razor has sliced it. Note that though a drawing of the entire palate impression is shown here to conceptualize the process, the impression will already have been sliced into four quadrants.

2.9 PLASTER CASTS. It is also useful to preserve a record of landmarks in the mouth such as the location of teeth and ridges on the palate, because when we study palatograms, these landmarks help to locate where an articulation has taken place. Use the second alginate impression to create a cast of the palate in hard plaster. In this case, there is no need to trim the impression. Grease a flexible plastic tub with petroleum jelly. Mix the plaster per instructions on the package and pour it into the tub, taking care that no air bubbles remain in the plaster (this could create air pockets and render the resulting cast imprecise). Next, grease the alginate impression with petroleum jelly and place it upside down in the plaster (i.e., occlusal surface up). After thirty minutes, ease the hardened cast out of the tub and gently pry or cut the alginate impression out of the plaster mold.

³ This tool is a slight modification of one developed by my colleague Sinisa Spajic at UCLA.

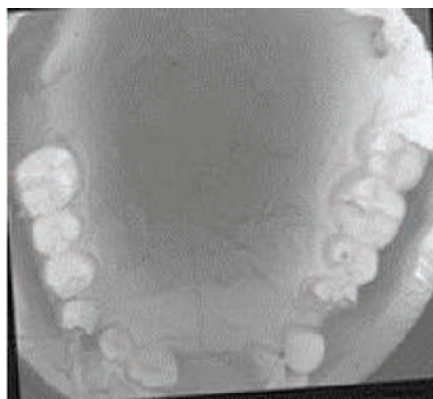


FIGURE 15: Hard plaster cast made from alginate dental impression.

3. RECONSTRUCTING ARTICULATIONS. The remainder of this article has to do with processing still images from video, correcting palatographic images to life-size, reconstructing speakers' articulations in midsagittal diagrams, and making measurements for use with inferential statistics. That is to say, your language consultant has completed her part. However, as with other fieldwork, the ideal case is to process the items discussed in this section while still in the field, so that if you find that some information has to be collected again, you will still have access to your speakers.

3.1 IMAGE PROCESSING FOR PALATOGRAMS AND LINGUOGRAMS. First, transfer each relevant video clip into a separate computer file. If your video is digital, this will simply require using a video program such as iMovie or Adobe Premiere to copy the clip. If your video is analog, it must first be digitized, again using a program such as Premiere to "capture" the clip at a sample rate of thirty frames per second. Next, for each palatogram, examine the copied clip frame by frame, and choose a still image that most clearly shows the pattern made on the roof of the mouth. For each linguogram choose two still images: one that clearly shows the upper surface of the tongue, and one that shows the underside.

3.2 CORRECTING PALATOGRAMS TO LIFE SIZE. As mentioned in section 2.4, slight differences in the way the mirror is held in the mouth will cause the image being reflected to appear lengthened or shortened, in both vertical and horizontal directions. Thus, for each palatogram, angular distortion must be independently corrected on the vertical and horizontal axes by referring to life-size dimensions on plaster casts and alginate tracings. (In the following discussion, "vertical" and "horizontal" refer to "front-to-back" and "side-to-side" anatomical dimensions, respectively.) You can demonstrate this distortion for yourself by inserting a palatography mirror in your mouth to reflect the palate, looking into a hand mirror, and changing the angle depicted as "x" in figure 16 by moving the jaw up and down; this lengthens or shortens the vertical dimension.

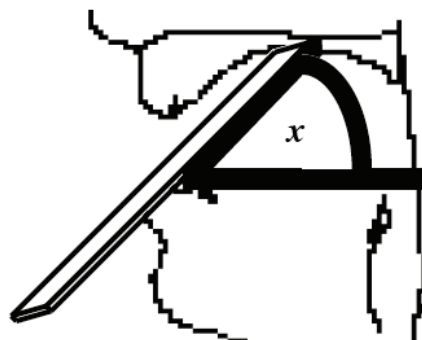


FIGURE 16: Angle of mirror with respect to occlusal plane (x) will cause reflected image to be lengthened or shortened.

Use calipers to measure the width of the plaster cast, just forward of the first molars on each side, between the inner surfaces of the teeth. Verify this measurement on the contour tracing. Next, open the palatographic still frame in a graphics program such as NIH Image (public domain software for image analysis) or Adobe Photoshop, and take the same horizontal measurement on the still frame (line “h” in figure 17.) Use the ratio of the line’s apparent size on the palatogram to its actual size as a correction factor in scaling the horizontal dimension of the image. Be sure that the aspect ratio is not set to “locked” in the graphics program, or the horizontal and vertical dimensions will change together.

With a ruler and a sharp pencil, draw line “h” on the plaster cast. Then use the calipers to measure the length of the plaster cast in the sagittal midline, between line “h” and the front edge of the central incisors. Verify the measurement on the contour map. Take the same front-to-back measurement on the palatographic still frame (line “v” in figure 18) and use the ratio of apparent-to-actual size of line “v” as a correction factor in scaling the image in the vertical dimension.

Note that although you need only measure “h” and “v” once on the plaster cast, “h” and “v” must be measured individually for each palatographic still frame, and the appropriate correction factors applied.



FIGURE 17: Horizontal calibration measure (h) bounded by inside surfaces of teeth.



FIGURE 18: Vertical calibration measure (v) bounded by front edge of central incisors and line 'h'.

Observe that the speaker shown in figures 17 and 18 does not have a complete dentition. In such cases, use reliable landmarks to estimate reference lines as closely as possible. In this case the 'front edge of the central incisors' was defined by extrapolating a line from the remaining incisor.

3.3 MIDSAGITTAL DIAGRAMS: PUTTING IT ALL TOGETHER. Once you have in hand (1) linguographic still frames, (2) palatographic still frames that have been corrected to life size, and (3) the speaker's midsagittal tracing, you are ready to construct an anatomically accurate midsagittal diagram that depicts the speaker's articulation. Figure 19 shows a W. Arrernte speaker's [+apical] [+anterior] stop /t/. Figure 20 shows the same speaker's [-apical] [-anterior] stop /t̥/. In each picture, the portion of the midsagittal diagram outlined in black comes from the alginate tracing and is thus known with certainty. Also, the location

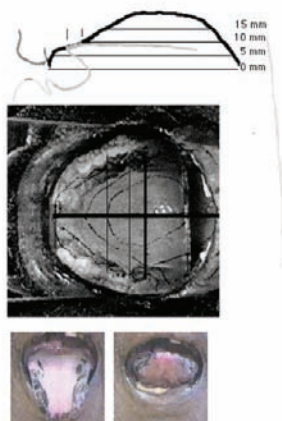


FIGURE 19: Reconstructed midsagittal section, palatogram and linguograms for a W. Arrernte speaker's phonologically [+apical] [+anterior] stop.

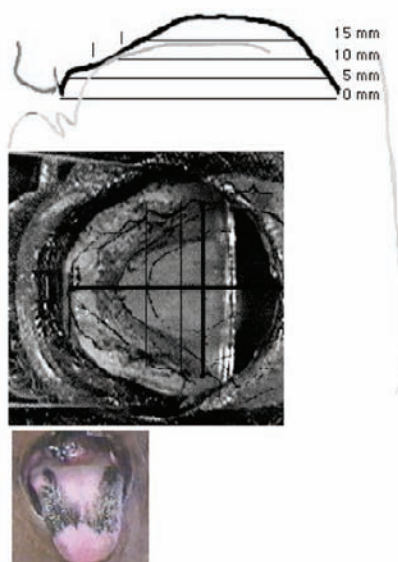


FIGURE 20: Reconstructed midsagittal section, palatogram and linguogram for a W. Arrernte speaker's phonologically [-apical] [-anterior] stop. (Image of underside of tongue was not recorded.)

and length of midsagittal contact on the palate (bounded by the two vertical lines above the tracing) are known with certainty. Other traces (in gray) are inferred.

Below each midsagittal diagram are the pictures from which it has been reconstructed. The palatogram, with proportions corrected to life size and with the speaker's topographic contour map superimposed, has been rotated 90 degrees so that the lips point left, as in the midsagittal tracing. The linguograms have not been corrected for size, since the tongue can stretch, contract, and change shape to such a great extent, but are used in reconstructing the tongue's stance and contact area with the roof of the mouth during the articulation.

Start by scanning the midsagittal tracing and the contour map of the palate into your computer graphics program (here again, NIH Image or Adobe Photoshop contains the appropriate tools.) Turn on rulers and grid lines in the program, and use them to draw horizontal height lines on the midsagittal tracing, at 5 mm intervals, as shown in figures 19 and 20. Next, place the life-size palatogram below the midsagittal tracing, and superimpose the contour map of the palate on it. (Render the background of the contour map transparent, so that the palatogram will be visible underneath it.) Rotate this composite picture by 90 degrees so that the lips point left. Next, vertically align the rotated palatogram with the midsagittal tracing, by matching points on the contour map with the corresponding points on the midsagittal diagram. For instance, line 1 in figure 21 shows that the bottom edge of the incisors on the palatogram has been vertically aligned with the bottom edge of the incisors on the midsagittal section. Similarly, line 2 shows that where the 15-mm contour

circle on the palatogram crosses the sagittal midline, it is vertically aligned with the 15-mm contour line on the midsagittal section.

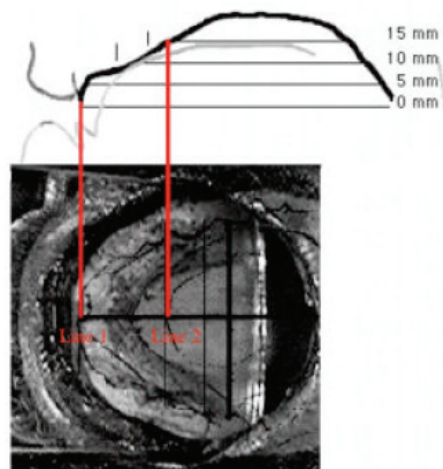


FIGURE 21: Vertically align rotated palatogram with midsagittal section.

Having aligned the palatogram with the midsagittal tracing, you can now draw vertical guidelines up from the front and rear points of articulatory contact on the palatogram to their corresponding points on the midsagittal tracing (lines 3 and 4 in figure 22.)

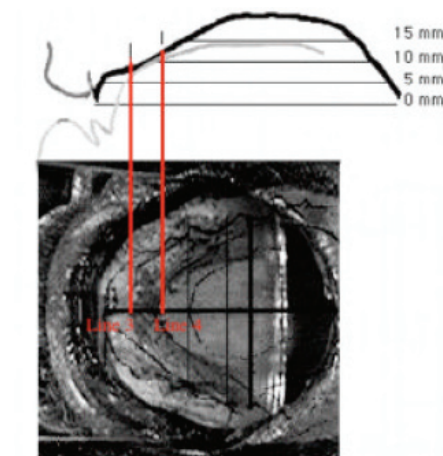


FIGURE 22: Draw vertical guidelines from points of contact on the palatogram to the midsagittal section.

After the known contact area on the roof of the mouth is in place on the midsagittal drawing, use the linguograms and palatogram together to infer both the active articulator

(i.e., tongue tip and/or blade, underside of tip, vertex, etc.) and the tongue's stance behind the closure. Tongue height behind the closure is shown by relative width of contact on the sides of the tongue in the coronal plane (on the linguogram) and width of contact in the area of the premolars and molars in the coronal plane (on the palatogram). In figure 19 the tongue has been drawn as fairly flat behind the point of closure, just under the 10-mm contour line. This is because the side contact shown at the molars on the aligned palatogram is just outside the 10 mm contour circle. Compare figure 20, in which the linguogram shows a wider area of contact at the sides of the tongue, and side contact at the molars (on the palatogram) almost reaches the 15-mm line.

4. MEASURING PALATOGRAMS AND CATEGORIZING LINGUOGRAMS FOR STATISTICAL ANALYSIS. In addition to drawing accurate midsagittal diagrams that show given speakers' articulations, it is often useful to quantify aspects of palatograms, and to classify contact patterns on linguograms according to various parameters, in order to submit them to statistical analysis of variance and chi squared tests, respectively.

4.1 PALATOGRAMS: ABSOLUTE AND RELATIVE MEASUREMENTS. There is no need to correct palatograms to life-size before taking measurements. Measurements can be made on uncorrected images and then directly converted to absolute dimensions (e.g., millimeters) or relative dimensions (e.g., percent of some reference measure), the latter being more appropriate for inter-speaker comparisons. For example, line "a" in figure 23 is a measure of frontmost contact: i.e., distance back from the base of the central incisors to the beginning of the black contact pattern. This and all other measurements in the vertical plane can be converted to millimeters via the vertical correction factor for the frame (apparent-to-actual ratio of line "v"), or to a percentage of a reference calibration line, like the apparent length of line "v."

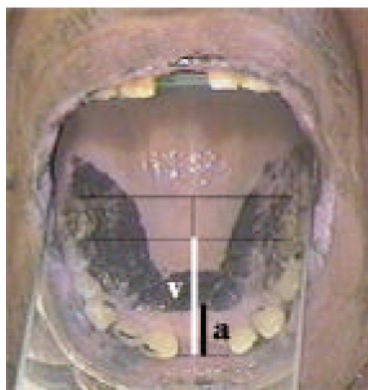


FIGURE 23: "Frontmost contact" (measure 'a') as a percentage of line 'v' (line 'v' taken to be 100%.)

Measurements of palatograms should be designed to reflect articulatory characteristics that have acoustic consequences. Useful measurements may include (a) where frontmost contact is made in the midsagittal line, (b) the breadth of that contact in the midsagittal line, and (c) the size of the space behind the constriction. These are illustrated as “a,” “b,” and “c,” respectively, in figure 24.

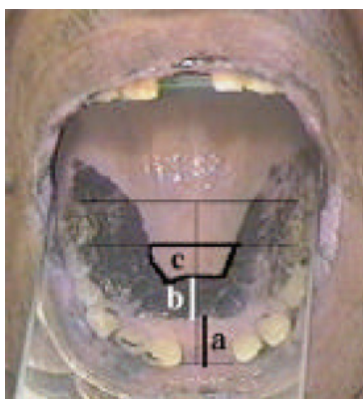


FIGURE 24: Possible measurements of palatograms.

Frontmost contact on the roof of the mouth in the midline is a common metric for indexing place of articulation (Butcher to appear, Dart 1991, and others). Since this measure reflects the size of the cavity in front of the constriction, it is associated with the spectral shape of bursts (Fant 1960).

Phonological distinctions such as *apical* versus *laminal* lead us to expect differences among categories of speech sounds based on *length of contact* from front to back in the midline. Acoustic correlates of contact length relate to the relative size and mass of the active articulator. The small tongue tip will make a short contact; the broader blade will make a longer contact. Moreover, it is reasonable to expect the tip to be a quicker articulator than the blade, because of its lighter mass and because, being on the periphery of the tongue, it is more independent of other areas of the tongue (cf. the lack of laminal trills versus the presence of apical trills, noted in Ladefoged and Maddieson 1996). In turn, the relative speed of the active articulator can relate to voice onset time, amount of frication at burst release, and relative amplitude of bursts (Stevens 1998).

Each still frame can be measured for contact length by drawing a line from the front to rear of the contact in the midline (line “b,” figure 21.) Again, actual contact length must be determined by using the vertical correction factor for the frame. To describe contact length in relative terms, express “b” as a percentage of line “v” (or another such vertical calibration line).

While the size of the cavity in front of the constriction can be expected to relate to spectral shape of bursts, the *cavity in back of the oral closure* can be expected to relate to formant transition loci at edges of neighboring vowels (Fant 1960). One possible index of oral cavity size behind the constriction involves measuring the uncontacted region behind the constriction. The size of this space is affected by the amount of raising of the sides of

the tongue body, as well as the rear extent of midline contact; the more contact on the palate, the smaller this area will be. To quantify the size of the back cavity, measure the area bounded by the rear line of contact and horizontal calibration line “h” (this is area “c” in figure 24.) To obtain an areal correction factor for a given palatogram, take a (two-dimensional) areal calibration measure, both on a two-dimensional scan of the plaster cast (and/or contour map) and on the still frame. Measure a reference area (“r”) bounded by line “h” and the juncture of the teeth with the gumline (this reference area is outlined in figures 25 and 26.) Use the ratio of apparent-to-actual size of this area as a correction factor to obtain measurements of “c” in square mm. To calculate relative measurements, express “c” as a percentage of the apparent area of “r.”

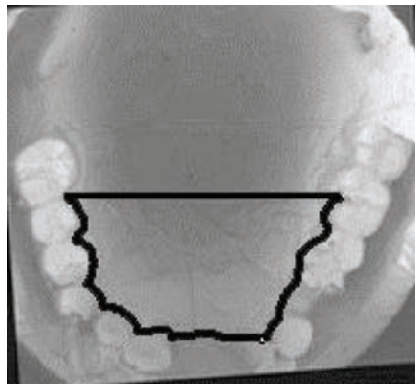


FIGURE 25: Reference area ‘r’ on two-dimensional scan of life-size plaster cast.

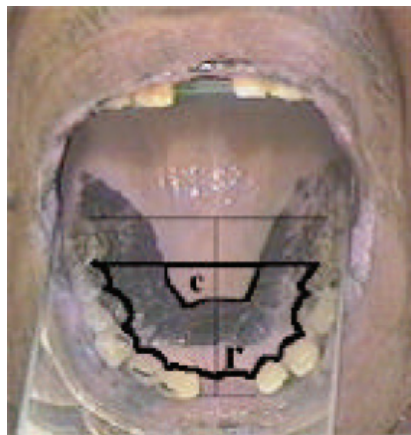


FIGURE 26: Area ‘c’ as a percentage of reference area ‘r’ on palatogram.

4.2 LINGUOGRAMS. Because the tongue is so flexible, it is not useful to measure linguograms quantitatively when comparing different speech sounds. However, it is possible to classify linguograms according to various parameters, and to then submit such classifications to chi squared statistical tests.

Linguographic classifications can include (a) whether *midsagittal contact* is broad or narrow; (b) the *rearward extent of contact* in the midline; (c) whether *contact on the sides of the tongue* in the coronal plane is broad or narrow; and (d) the *general shape* of the print. These variables and the sublevels shown in table 2 proved useful in my study of W. Arrernte coronal articulations.

<i>Midsagittal contact</i>	<i>Rearward extent of contact</i>	<i>Coronal width at tongue front</i>	<i>Shape</i>
vertex only	sublingual	no contact	parallel lines
short	vertex	narrow	u-shaped
medium	apex	medium	triangular
long	mid-blade	wide	butterfly
extra long	back of blade		
	tongue front		
	tongue center		

TABLE 2: Possible linguographic variables and their sub-levels.



FIGURE 27: Categorization of linguograms according to midsagittal contact: ‘vertex only.’

Figures 27 and 28 depict two extreme categories for *midsagittal contact*, shown by the superimposed white lines. The palatogram in figure 27 is classified as “vertex only,” while that in figure 28 is classified as “extra long”. (Gaps in the pattern of contact are due to missing upper teeth.)



FIGURE 28: Categorization of linguograms according to midsagittal contact: ‘extra long.’

Figures 29 and 30 show differences in *rearward extent of contact*, as shown by the superimposed crosshairs.



FIGURE 29: Categorization of linguograms according to rearward extent of contact: ‘vertex.’



FIGURE 30: Categorization of linguograms according to rearward extent of contact: 'tongue center.'

The relative amount of coronal contact on the sides of the tongue gives an idea of the extent of tongue raising behind the closure. Figures 31 and 32 depict "narrow" and "wide" contact, respectively.



FIGURE 31: Categorization of linguograms according to coronal width at tongue front: 'narrow.' The superimposed line is shown at an angle, to reflect the cupped position of the tongue in this frame.

Finally, the variable *shape* captures the general stance of the tongue during closure. Figures 33–36 show four print shapes that recurred in my W. Arrernte study. Figures 33a and b show the print contact pattern that was given the shorthand description "parallel lines." Note that contact includes the sublingual surface and vertex, but not the upper side of the apex. In contrast, figures 34a and b show a "u-shaped" contact pattern, which excludes the underside of the tongue.



FIGURE 32: Categorization of linguograms according to coronal width at tongue front: 'wide.'

The panel in figure 35 shows a third contact pattern, which involves a roughly triangular shape covering the tip and blade, with lines of contact extending back at the sides behind the central constriction. For clarity, the triangle has been outlined, because the speaker's lack of upper incisors causes the front of the pattern to be somewhat irregular.



FIGURE 33a: Categorization of linguograms according to shape: 'parallel lines.' Upper surface of tongue.



FIGURE 33b: Categorization of linguograms according to shape: 'parallel lines.' Lower surface of tongue.

Figure 36 shows the fourth print pattern, in which very broad contact was visible from the blade backward, but characteristically was slightly narrower in the midline than on the sides. This pattern was given the shorthand description "butterfly."



FIGURE 34a: Categorization of linguograms according to shape: 'u.' Upper surface of tongue.

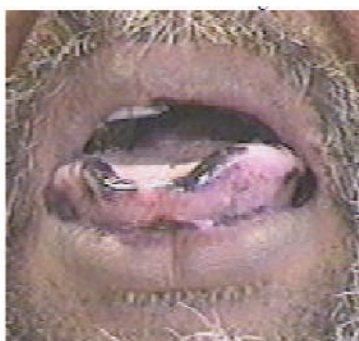


FIGURE 34b: Categorization of linguograms according to shape: 'u.' Lower surface of tongue.



FIGURE 35: Categorization of linguograms according to shape: 'triangular'.



FIGURE 36: Categorization of linguograms according to shape: 'butterfly.'

5. CONCLUSION. Static palatography is a “field-friendly” technique that can provide valuable, detailed information about the articulatory characteristics of speech sounds. Be aware, however, that the process is labor-intensive and time-consuming, both for language consultants and for the fieldworker. As such, the best results come about when the participants have developed a comfortable, trusting working relationship with each other. Moreover, appreciation for the relative complexity of this kind of fieldwork should be reflected in payments or gifts of up to twice the amount for other types of fieldwork. Finally, keep in mind that this is an aspect of fieldwork that properly requires review by your university’s Institutional Review Board for the protection of human subjects. You should not apply for exemption from review, but expedited review usually suffices. Permission to conduct a palatographic study may be facilitated if you point out that native speakers of under-documented languages are taking an increasingly active role in documenting their own languages, and as such often volunteer to participate in this kind of work. Moreover, many of the tasks that involve putting something in the speaker’s mouth can, after some training, be done by the speaker herself.

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