

Palatogram reading as a phonetic skill: a short tutorial

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1. Introduction

Dynamic electropalatography (EPG) (also known as dynamic palatography or palatometry) is a system for recording information about the tongue's contact with the hard palate over time. It is relatively inexpensive and technologically accessible. EPG is safe, provides spatial information on the shape of constriction contact, and allows the collection of reasonable acoustic data. Multiple sessions with a subject are possible and replicable. For these reasons, this method may be of interest to phoneticians. The purpose of this note is to serve as an introduction to interpreting palatograms. Much in the same way that phonetics students learn to read spectrograms, reading palatograms is a skill which can be honed by practice and experience. And just as looking at spectrograms of an unknown utterance can develop increased sensitivity to acoustic facts, reading palatograms can enhance awareness of details of articulation.

The electropalatograph uses an artificial palate of thin acrylic embedded with electrodes, usually over 60. The pseudopalate may be manufactured individually for each subject from a dental cast or be uniform for all speakers with similar palate sizes. The data are typically recorded by computer and are qualitatively examined visually in the form of diagrams showing the arrangement of electrodes on the palate and indicating contact or no contact at each electrode. With some systems, the sensor information from the palate can be converted into a real-time graphic moving image of tongue-palate contact.

Because EPG systems have no standardized electrode arrangement and do not all use the same sampling rate, this information is relevant in the interpretation of palatograms. We use the Kay Elemetrics Palatometer which has a thin acrylic palate that extends around the teeth. The Kay Palatometer uses a palate with 96 electrodes. It scans the palate at a 100 Hz sampling rate. The Palatometer is designed to interface with the Kay Computer Speech Lab, an acoustic analysis system allowing the simultaneous examination and analysis of spectrograms, waveforms, and palatograms. The speech acoustic signal is acquired simultaneously with the linguapalatal information at a sampling rate of 12,500 Hz.

2. Orientation

Figure 1 shows the electrode arrangement for our subject, a female speaker of American English from Southern California. The top part of the figure is a digitized image of the actual artificial palate. The circles mark the electrode locations. In the data presentation and analysis, the electrodes are depicted schematically in an identical arrangement for all speakers, as shown in the lower part of the figure. In this note, contact at an electrode is indicated by a dark circle on the schematic display while an uncontacted electrode is shown as an open circle, as in the figure.

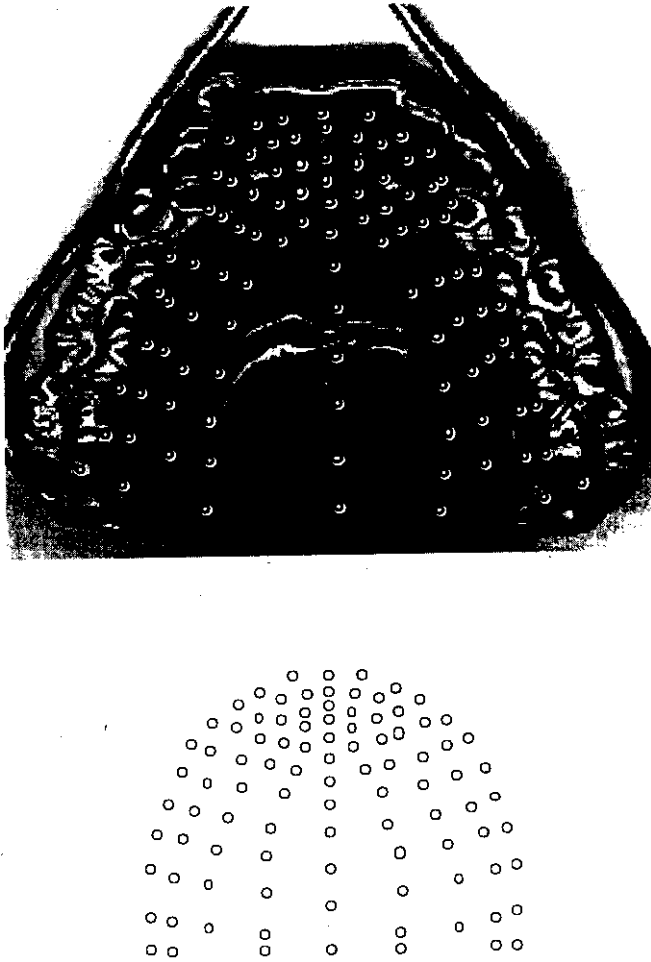


Figure 1. Artificial palate (upper picture) and corresponding schematic display (lower picture).

As an introduction to interpreting palatograms, we have chosen certain sounds for which to present "training" palatograms. These demonstrate this speaker's productions of selected sounds and will help you read the palatograms of unknown utterances that follow. Each example is either of a typical constriction for a particular consonant in an [aCa] context, or is of a vowel in isolation. Let us first consider the maximal contact patterns found for the three fricatives [z, ʃ, ð] produced in an [a] context, as shown in Figure 2.

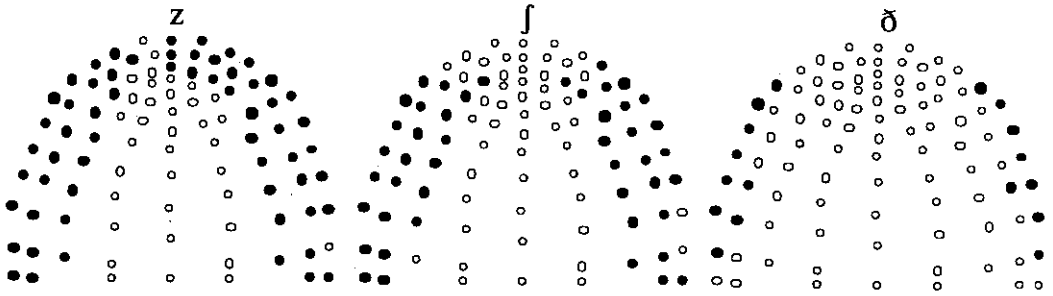


Figure 2. Fricative constrictions in [z], [ʃ], [ð].

In all these fricatives, we see the tongue braced against the palate along the sides. For [z] we see that there is a narrow, uncontacted channel at the front of the mouth in the alveolar region, just to the left of the midline. Often, as is the case here, constrictions aren't formed symmetrically on the palate. The constriction for [ʃ] has its narrowest point somewhat farther back on the palate than [z]. Additionally its narrowest point is wider than that of [z]. Note that [ð], the last fricative in Figure 2, is interdental, as is typical for speakers from Southern California. We therefore don't see the constriction itself, only the bracing of the sides of the tongue. The tip is located in a region with no electrode coverage.

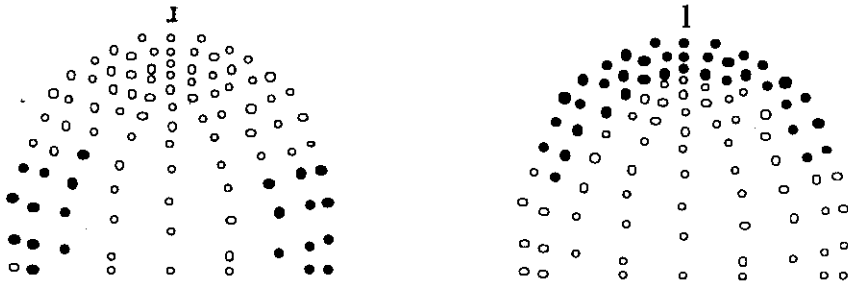


Figure 3. [ɹ] and [l].

The liquids have the patterns shown in Figure 3. For this production of [ɹ], we have no information on the position of the tongue tip except that it is not in contact with the palate. However, we can observe the raising of the rear of the tongue. In the [l], note that the sides of the tongue are not sealed along the palate, although a closure is formed in front. Other tokens of [l] by this speaker, particularly the more velarized ones, show linguapalatal contact only on one side and may lack any contact in the alveolar region. But whether on one side or both, there will be a lateral opening through which air can escape. The amount of contact in front is also highly variable. We will look further at [l] in our first palatogram sentence.

Next, let's consider two articulations with full closure. In the series of palatograms of [n] in Figure 4, the formation and release of a constriction at the alveolar ridge is evident. The displays are to be read from left to right and frames are shown in increments of .02 s. Note the times above each frame.

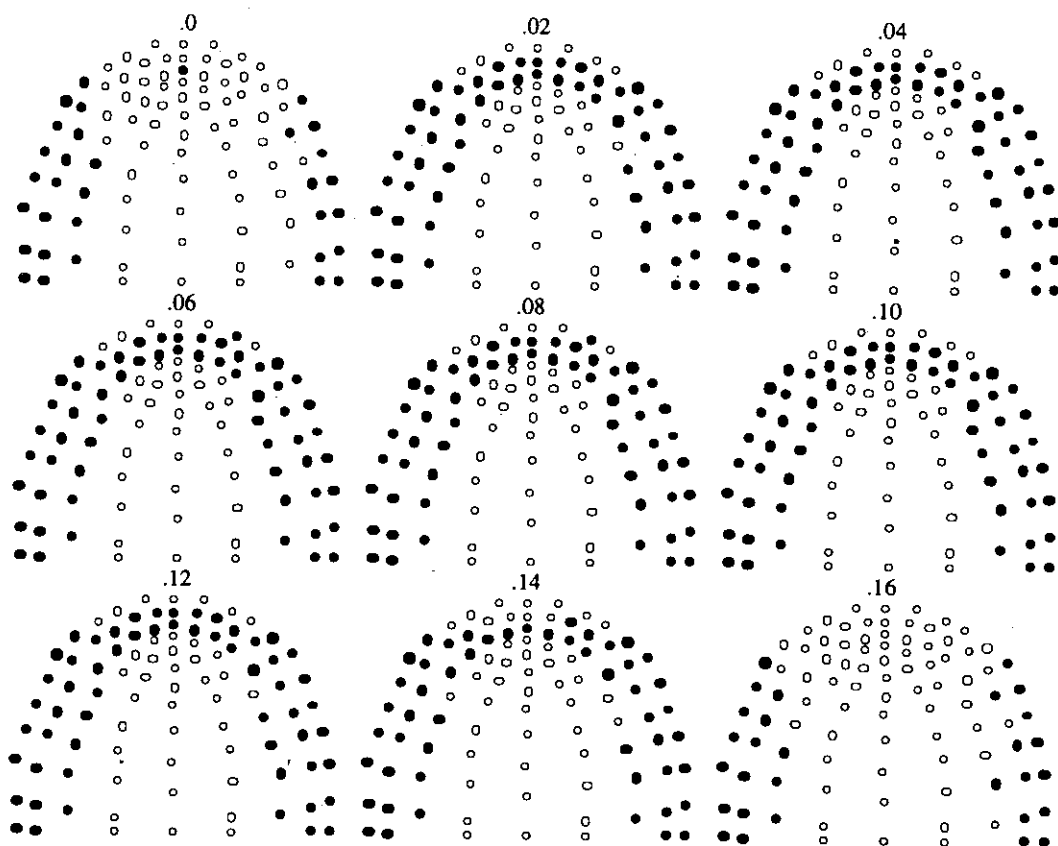


Figure 4. Sequence of frames showing [n] in [ana].

In the first frame we see the initiation of contact for the alveolar closure. The closure is formed and maintained through frame .14. We see the amount of contact for the closure decreasing in frame .14. Between frame .14 and .16 the oral closure is released.

Next consider the series of frames illustrating [k] in Figure 5. The presence of a closure is indicated by contact on all the electrodes of the rearmost (lowest) row in frame .02 and the contact area increases in frame .04. In frame .06 the tongue is still raising as the amount of lateral contact increases in this frame. In frame .12 the amount of observable contact begins to decrease. In .16, we no longer see velar closure. Interpretation of velar contact with electropalatography should of course be done in conjunction with the audio signal as there is the possibility, especially in back vowel contexts, that contact may exist on the soft palate behind the area shown in the palatogram. Be prepared in the "mystery" palatograms below to see substantially more fronting, *i.e.* a seal formed more toward the front of the mouth, for velar stops in the environment of front vowels.

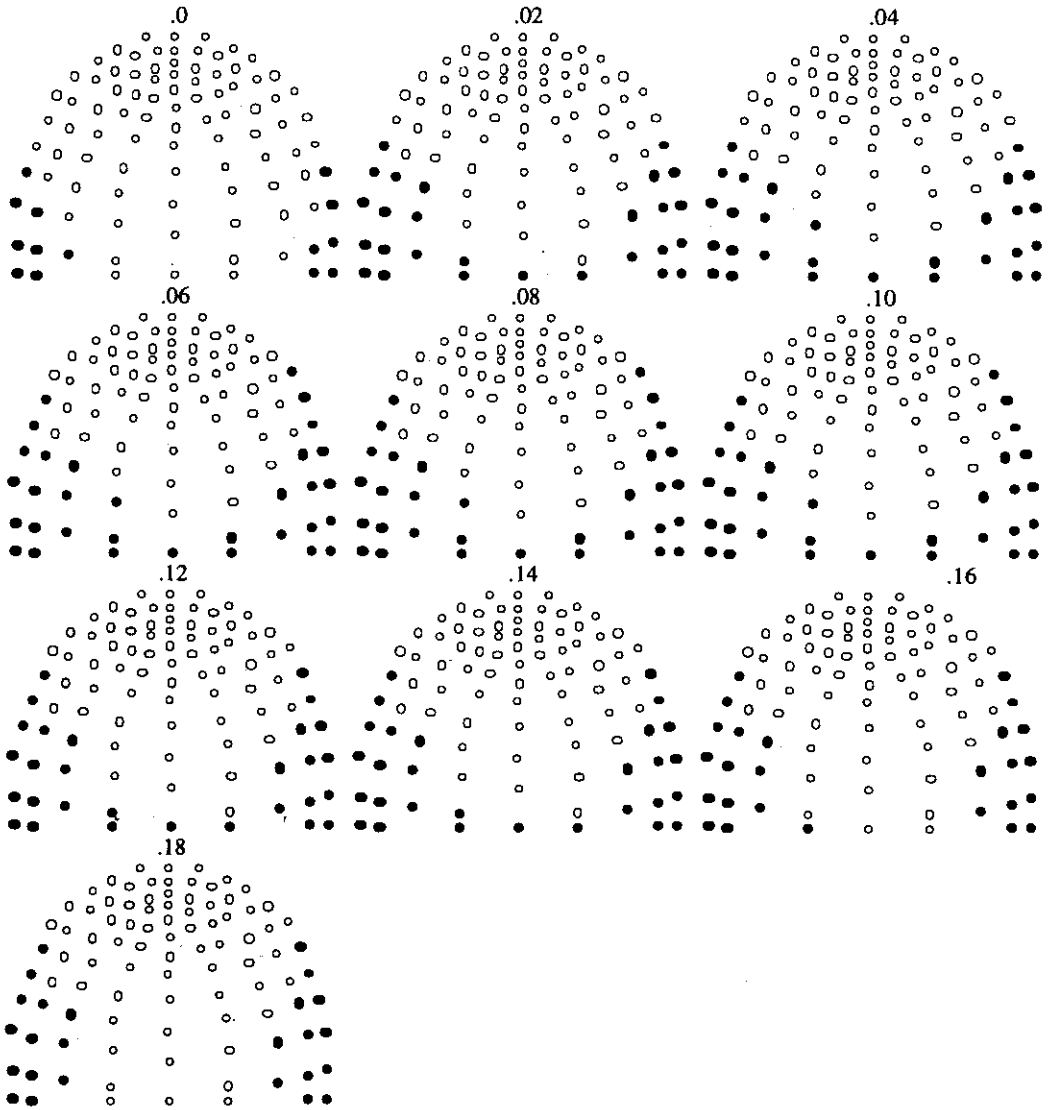


Figure 5. Sequence of frames showing [k^h] in [ak^ha].

Next, let's examine some vowel articulations. Typical contact patterns for [i], [ɛ], [æ], and [u] produced in isolation are shown in Figure 6. Notice the large amount of contact for the high front vowel. Although these demonstration vowels were produced in isolation, [i]'s in fluent speech for this speaker can be expected to have a substantial amount of contact as well. In [u], the tongue is raised enough to cause clearly discernable contact on the hard palate. [æ] shows a somewhat more front position of the tongue but less height, as evidenced by the lack of contact in the third arc of electrodes. [ɛ] not surprisingly displays a pattern somewhat intermediate between [i] and [æ], with the narrowest constriction clearly further forward than for [u].

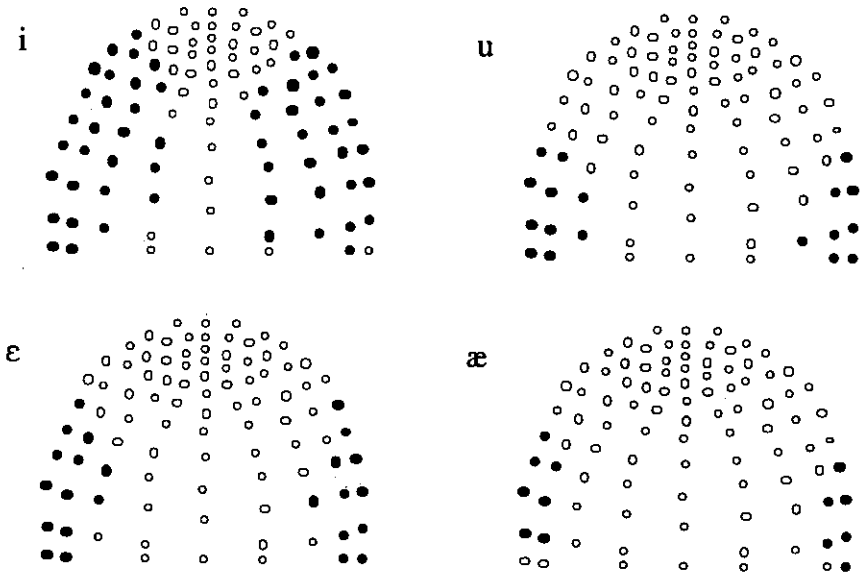


Figure 6. Contact patterns for steady-state vowels [i, u, ε, æ].

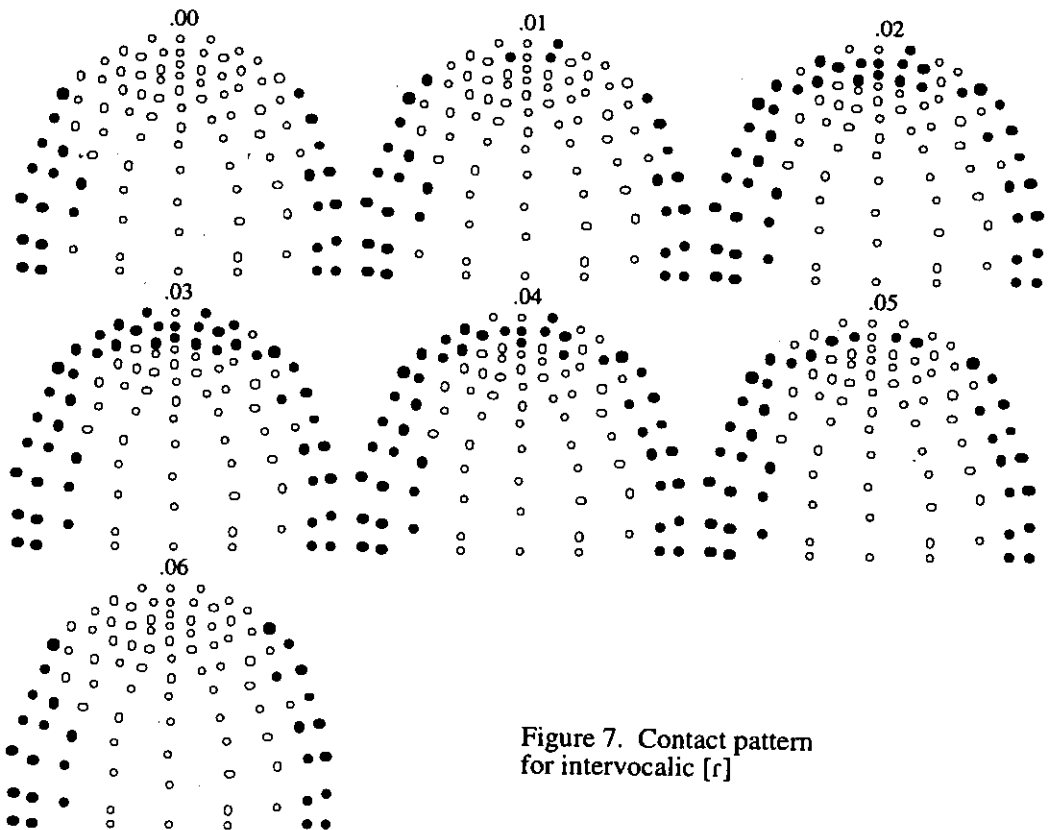


Figure 7. Contact pattern for intervocalic [r]

Finally, let's look at the American English tap [ɾ], an allophone of /t/ and /d/. The series of palatograms in Figure 7 is displayed in increments of .01s, due to the speed of this articulation. In determining whether a tap is present in the palatogram, consider the duration of the closure. Note that the seal for [n] above lasts for at least .12 s; however the closure for the tap is complete in only one .01 s frame, frame .3.

In reading palatograms, it is also very important to keep in mind what information you *won't* have. There are no explicit visual cues for voicing, nasalization, or bilabial articulations. Sounds with no oral constriction like [ʔ] and [h] are of course also not cued in the palatograms. For this reason, the waveforms are also provided to assist in reading the palatograms below. Pay special attention to amplitude changes which may reflect a change in voicing, nasal coupling, or a constriction which is not located on the palate. Finally, remember that coarticulation is pervasive and must be taken into account.

3. Sentence 1

In accordance with the "gentlemen's" rules of spectrogram reading, the following palatogram series are of complete sentences (in English) containing no proper names. The waveform of the sentence is shown at the top of the first panel. Capital letters in the waveform mark time points corresponding to the same letters in the palatograms. Sentence 1 is on pages 28 and 29. Each palatogram is separated by .04 s. We will refer to a specific palatogram by the frame number above it. The answer to Sentence 1 is given at the end of this section, following discussion of its interpretation. Sentence 2 is left to the reader to solve.

In examining Sentence 1, note that in .00 through .20 we have a complete alveolar closure being formed and released. This yields /t, d, n/ as likely candidates for the first phone. If we consult the waveform, we see that the sound appears to be an aspirated stop. We therefore select [t^h] as the best candidate.

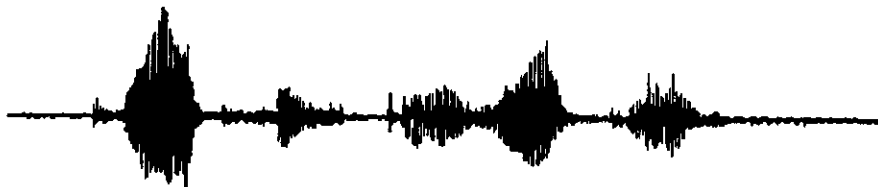
The tongue continues to lower until .32 but it is clear that what follows the alveolar stop is a vowel. It is relatively unconstricted and front when compared with the sample vowels in Figure 7. We can hypothesize [ɛ]. We should also allow [æ] to remain an option due to possible effects of coarticulation as a result of the upcoming constriction in .40. So, at this point, we have:

t ^h	ɛ
	æ

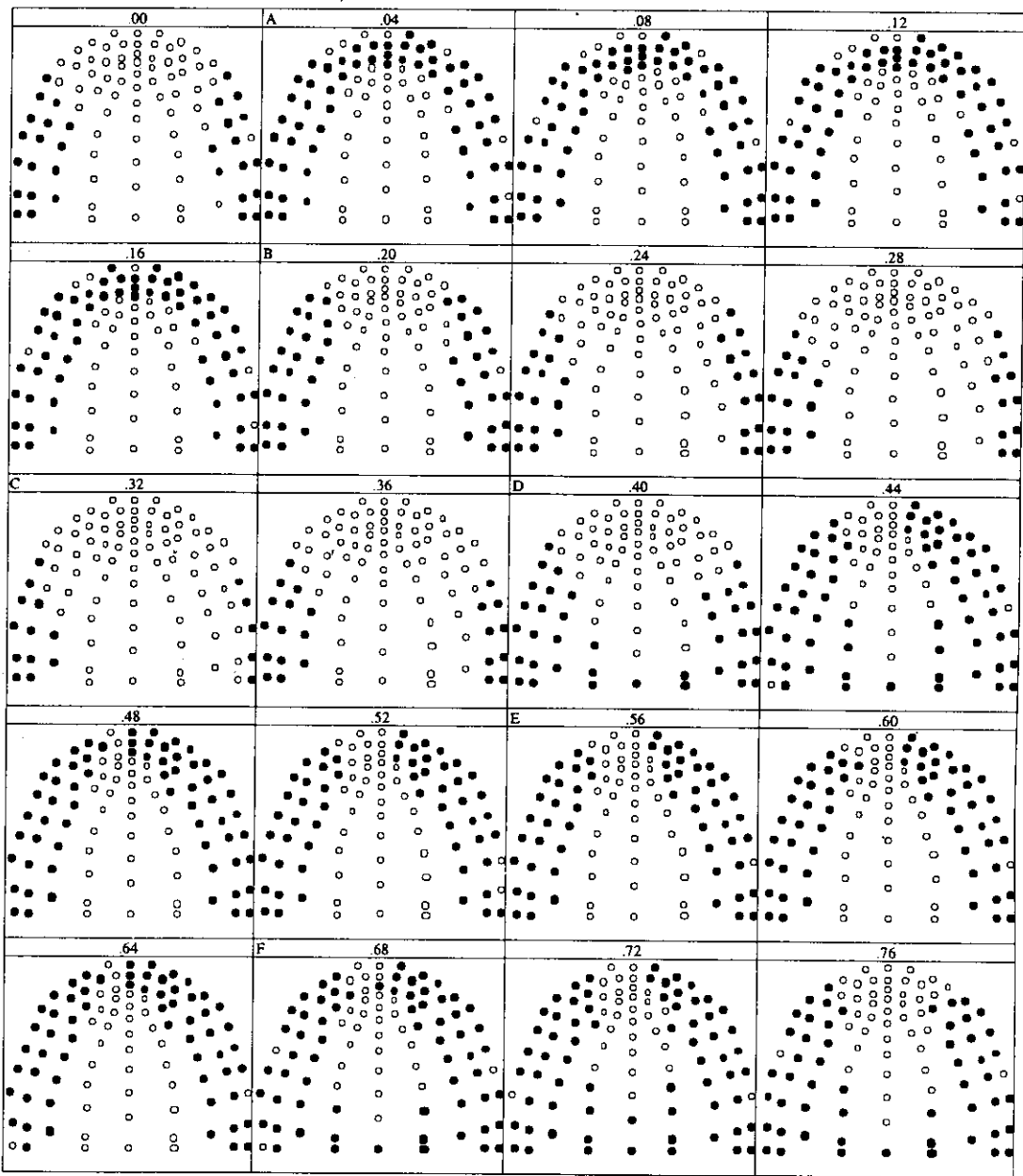
The constriction in .40 is clearly velar and forms a complete seal. This must be [k], [g], or [ŋ]. Now we have:

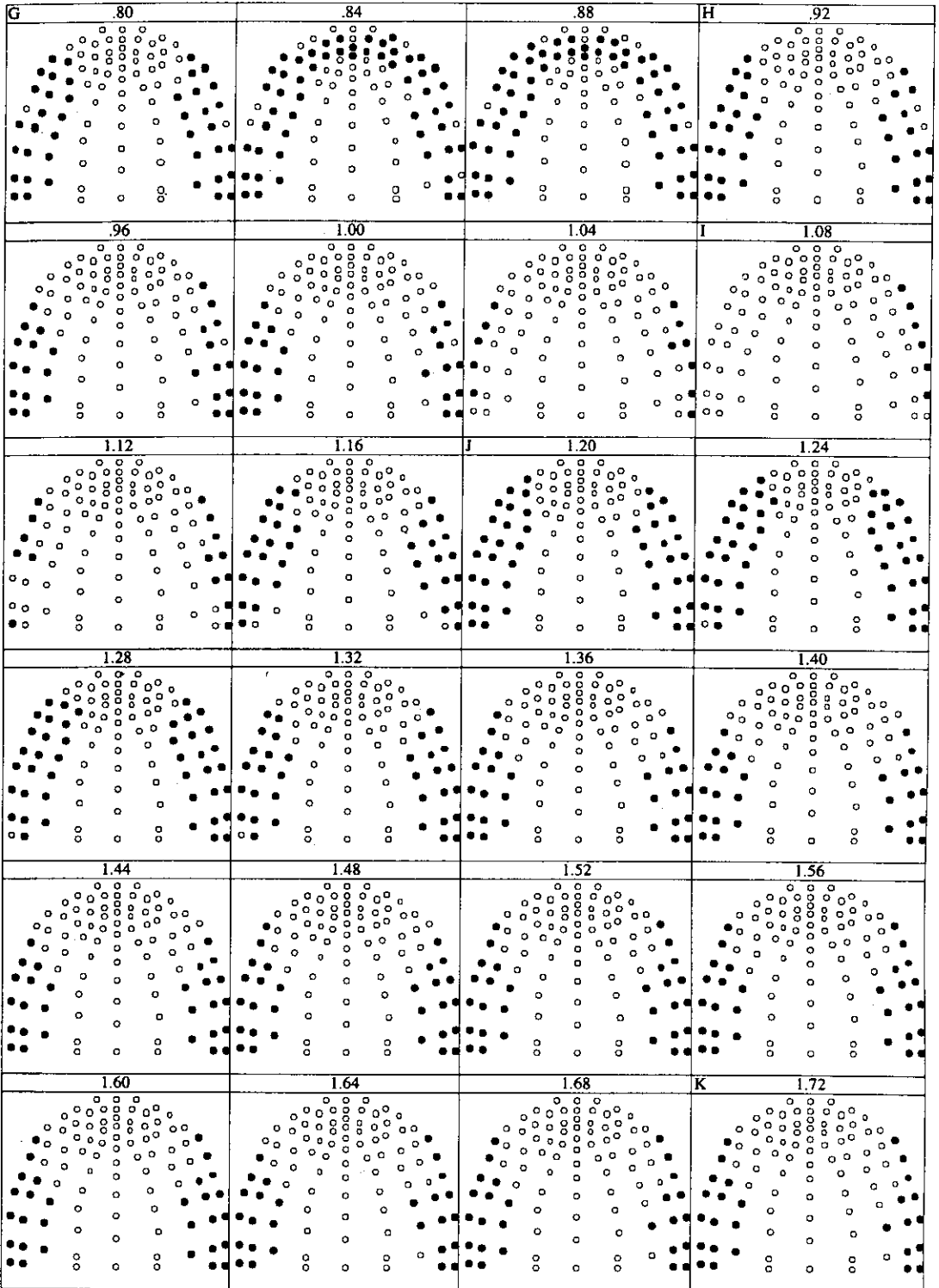
t ^h	ɛ	k
	æ	g
		ŋ

Immediately thereafter, in fact overlapping with the velar, is a partial alveolar constriction in .44 through .48. We see that a narrow channel has been formed. We hypothesize that this is an [s] or [z]. We now have:



A B C D E F G H I J K





t ^h	ɛ	k	s
	æ	g	z
		ŋ	

Note carefully however in .52 through .56 the alveolar constriction is releasing, *i.e.* the channel is widening. In .60 through .64, however, we see a similar constriction being formed again. During the .52 through .56 period in the waveform, around E, we observe a short amplitude increase and periodic striations. This would indicate the presence of a short vowel. As a default assumption, we'll call this [ə]. We now are through the second alveolar fricative to .64 and have:

t ^h	ɛ	k	s	ə	s
	æ	g	z		z
		ŋ			

In .68 we see another velar constriction being formed. From the waveform we can determine this to be a voiceless aspirated stop due to the near baseline amplitude during closure and the period of aspiration following the release. The release occurs between .77 and .79.

In .80 we see what is likely to be a vowel but cannot determine much about its quality as the sides of the tongue stay high and braced on the palate in preparation for the upcoming alveolar closure in .84 through .88. The vowel is relatively short and the waveform suggests it is not stressed, but it appears more open than the [ə] we have assumed at E. We will suggest [æ]. During this alveolar closure, we see some decrease in amplitude in the waveform—but not as much as we observe for the voiceless stops and less than we would expect even for an energetically voiced stop. We will hypothesize, then, that the alveolar stop in .84 through .88 is a nasal. We now have:

t ^h	ɛ	k	s	ə	s	k ^h	æ	n
	æ	g	z		z			
		ŋ						

Next, in .92 through 1.00 we have another vowel which is similar in constriction to the first vowel in the sentence, but somewhat higher. This can be seen by comparing the frames of minimum constriction. In .36 we have 23 electrodes contacted while in .92 and .96 we have 26 and 25 electrodes contacted respectively. We therefore hypothesize a similar or slightly higher vowel.

t ^h	ɛ	k	s	ə	s	k ^h	æ	n	ɛ
	æ	g	z		z				ɪ
		ŋ							

In 1.04 through 1.12 we notice something unusual. The linguapalatal contact pattern is asymmetrical, with minimal bracing of the tongue sides, and at one point the left side of the tongue is not in contact with the palate. This suggests, in conjunction with our example sounds, that a lateral is present. We hypothesize:

t ^h	ɛ	k	s	ə	s	k ^h	æ	n	ɛ	l
	æ	g	z		z				ɪ	
		ŋ								

We note that in this area of the waveform we observe a period of near baseline amplitude and what might be a release transient at J followed by a period of aspiration before the last vowel. But we see *no* evidence of a closure in the palatograms. The simplest explanation for this is that a voiceless stop was in fact produced, and that it was produced at the lips where we have no contact information. We therefore hypothesize:

t ^h	ɛ	k	s	ə	s	k ^h	æ	n	ɛ	l	p ^h
	æ	g	z		z				i		
		ŋ									

We are now at approximately 1.20. In the remainder of the sentence, we see a long vocalic period. The contact pattern indicates a great deal of contact in the initial portion of this vowel. We see that the tongue is very high in the mouth, touching the palate almost into the alveolar region and filling three rows inward on both sides. In the remainder of the sentence we see the narrowest point of constriction moving backwards but the sides of the tongue remaining relatively high. In sum for this lengthy vowel, we hypothesize a diphthongal movement from a high front vowel to a backer high vowel. In English, with some top-down knowledge, this suggests the word "you" [ju] (or in the case of this speaker [jʊ]). So, finally, we are finished and are ready to parse the string of phones:

t ^h	ɛ	k	s	ə	s	k ^h	æ	n	ɛ	l	p ^h	j	u
	æ	g	z		z				i				
		ŋ											

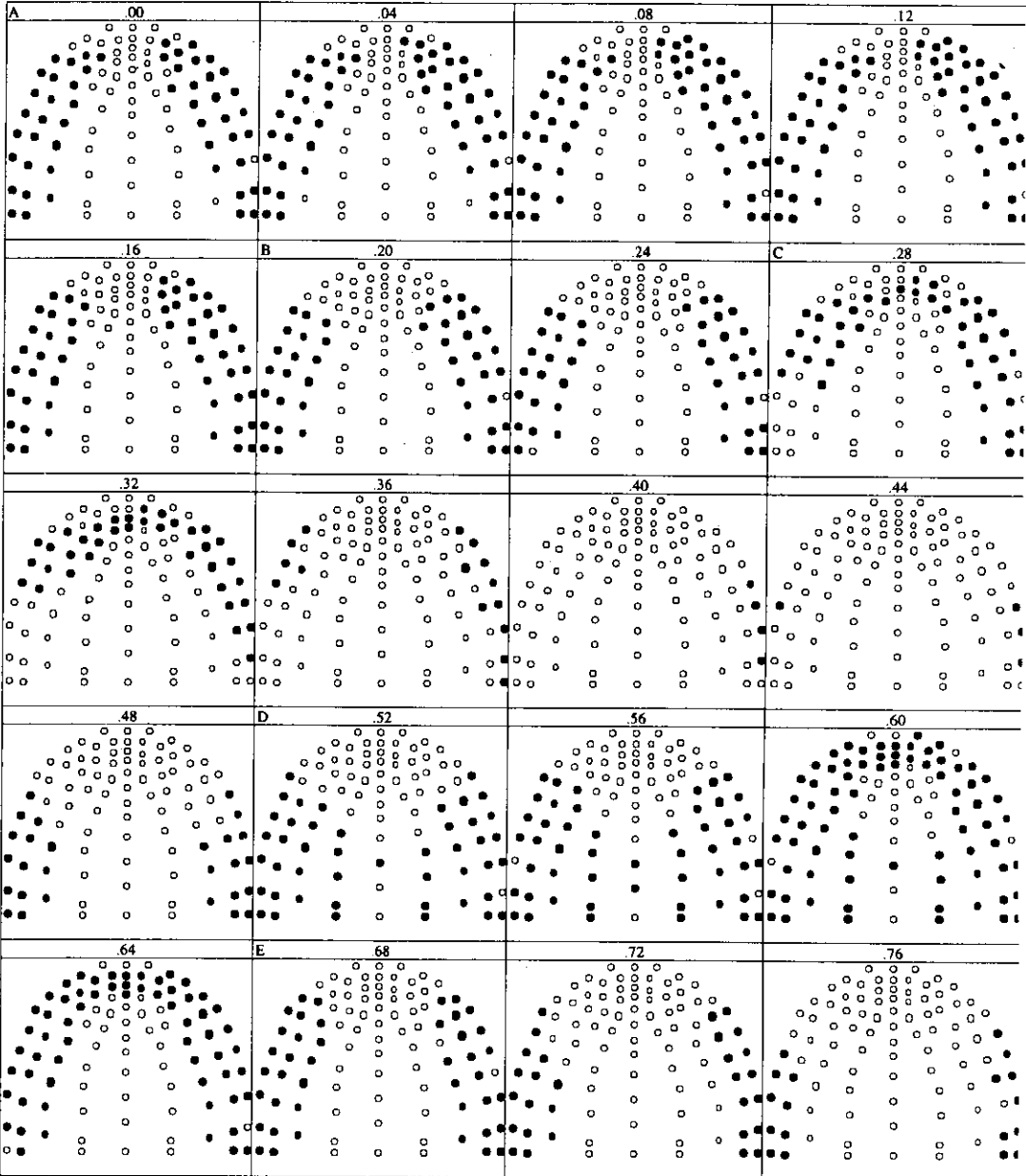
There are at least two readily recognizable words: *can*.....*you*. We expect a verb after "can." We have the phones [ɛ l p^h]. Clearly, this is not a word. We must have missed a segment, probably initially. Well, what sounds are we likely to miss with this type of data? Probably, we missed a labial, *or an [h]*! The waveform and lexical access both confirm [h] as the likely phone. We now have:*can help you*. For the initial word (yes, you're getting a clue that there is only one word left), the only lexically plausible path through our possible phones yields the word "taxes." (Note that *Texas* is excluded due to our rule forbidding proper names, and this speaker pronounces *taxis* with [i] in the second syllable.) Congratulations, we've solved the puzzle: *Taxes can help you*.

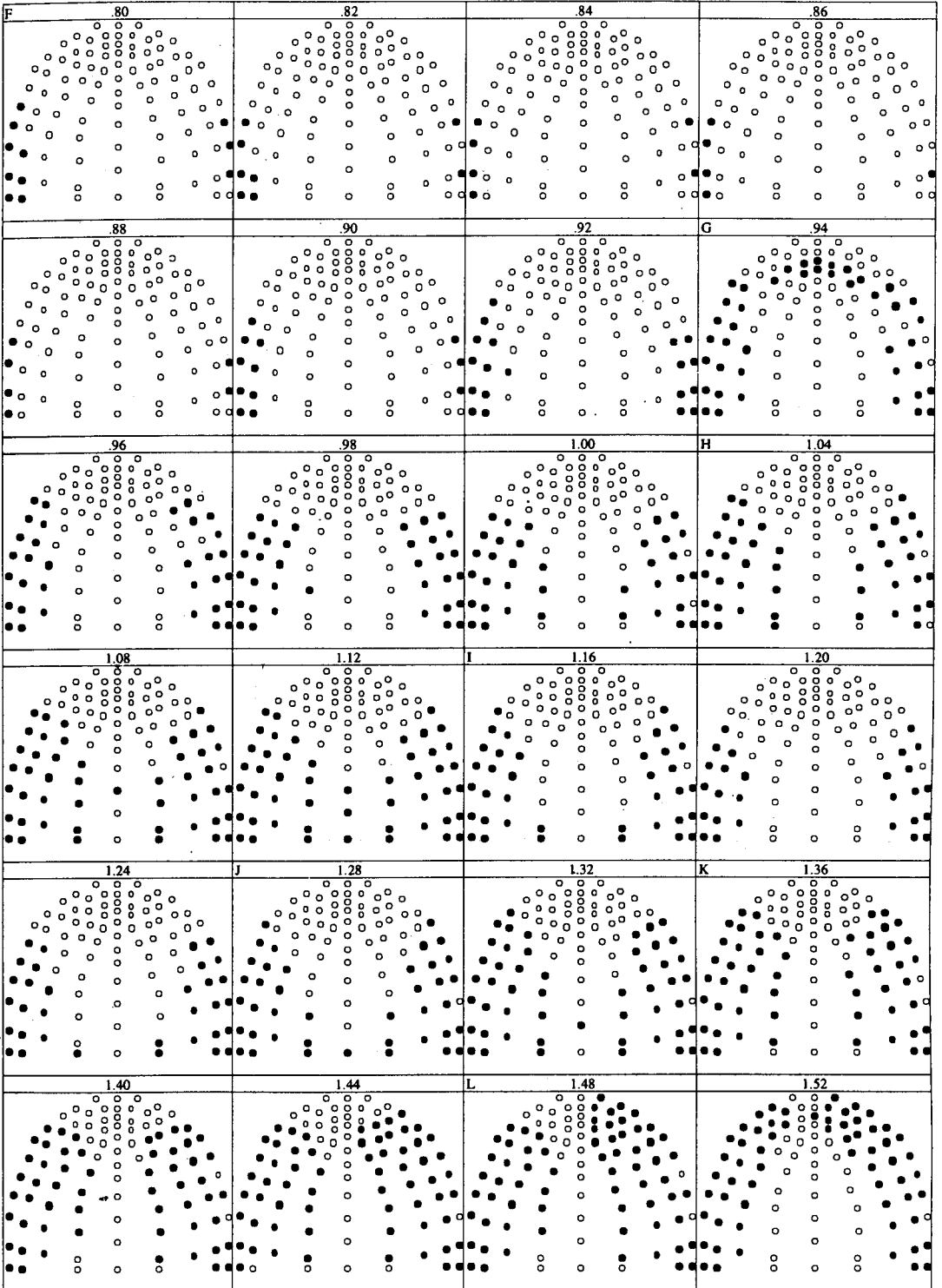
4. Sentence 2

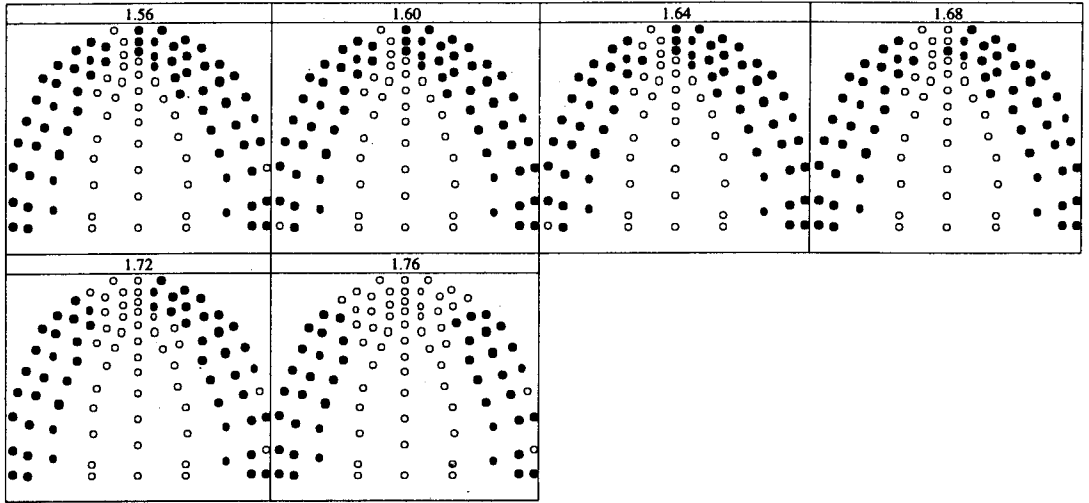
You are now ready to take on Sentence two, on pages 70-72, on your own. Remember what you've learned and keep the contact patterns from the example sounds in mind. Note that frames .82 - 1.00 are in increments of .02 s rather than .04 s as is the case for the rest of the sentence. If you are perplexed, some helpful hints appear printed upside-down after the end of the sentence. A discussion of the solution will appear in a future issue of the *Journal*. Good luck!!



A B C D E F G H I J K L







Acknowledgements

This data was collected in the Department of Linguistics at UCLA. Some of the introductory material here can be found in *UCLA Working Papers in Phonetics 86, Articulatory Timing in English Consonant Sequences* by the author. The author is grateful to the UCLA Phonetics Laboratory "spectrogram reading group" for their helpful remarks during a presentation of this material and to the speaker who participated. The research from which it is drawn was supported by an NSF Graduate Fellowship, by an NSF Dissertation Improvement Grant #DBS 9213604 to the author and Patricia Keating, and by the Department of Linguistics at UCLA.