62 vs. 96 electrodes: a comparative analysis of Reading and Kay Elemetrics EPG pseudo-palates

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62 VS. 96 ELECTRODES: A COMPARATIVE ANALYSIS OF READING AND KAY ELEMETRICS EPG PSEUDO-PALATES

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ABSTRACT

The pseudo-palates used with the Kay Elemetrics and Reading EPG systems mainly differ according to their number of electrodes, 96 vs. 62 respectively, and the spatial repartition of the electrodes over the palate. The two pseudo-palates also greatly differ in their price according to their number of electrodes. This study compares how variations in linguopalatal contact are reflected by the two pseudo-palates and evaluates the contribution of the extra 34 electrodes of the Kay system in terms of description of segments articulation, discrimination between articulatory patterns, and replication of attested coarticulatory effects. Results show that the Kay system reflects with greater precision the actual contact of the tongue against the palate and subtle articulatory variations. It provides additional information mostly in the palatal, velar and dental regions. However, with 62 electrodes, the Reading pseudo-palate is still able to reflect the articulatory variations studied and to discriminate articulatory patterns. Implications of these results for improving the resolution of the Reading pseudo-palate are discussed.

1. INTRODUCTION

Electropalatography (EPG) is a relatively old technique used for the investigation of lingual articulation via a measure of linguopalatal contact, that is the contact of the tongue against the hard palate, during time course of an utterance. Many EPG systems have been developed during the last 40 years and most share the same basic principle. Speakers are fitted with a custom made artificial palate (henceforth, pseudo-palate), on which a certain number of electrodes are embedded. When the tongue touches the electrodes on the pseudo-palate a contact is made and a signal is conducted via lead-out wires to an external processing unit (for more details, see Hardcastle 72; Marchal 88, Gibbon & Nicolaidis 99). Linguopalatal contact recorded by EPG provides spatial and temporal information on lingual articulation. Compared to other articulatory techniques, EPG is a relatively easy and fast way of acquiring data on lingual articulation. However, one of the main disadvantage of this technique is the expense and difficulty of making well-fitted pseudo-palates. A consequence of this is that there is usually a small number of speakers in EPG studies. In fact, different types of pseudo-palates are currently available on the market. These pseudo-palates mainly differ in their making, shape, and number and configuration of their electrodes. Consequently they also greatly differ in their price. In this study we have compared two of the three pseudo-palates frequently used in current phonetic research: the pseudo-palate used by the Kay Elemetrics Palatometer, and that used by the Reading EPG2 or 3 system. This comparison is based on the production of a single French speaker recorded successively with the two pseudo-palates.

1.1 Pseudo-palate description and main differences

The 2 pseudo-palates studied differ according to 4 main points. (1) The plate containing the electrodes do not have the same size and shape. As shown in Figure 1, the Kay pseudo-palate is molded to fit the speaker's hard palate and to cover the external border of the upper teeth. On the contrary, the Reading pseudo-palate covers only the hard palate and stops at the gingival border. Moreover, the plate used by Kay goes further back in the mouth toward the soft palate (up to the back of the molars) particularly in the mid-sagittal plan. (2) The two plates differ also in their thickness: 1 mm for Kay, 1.5 mm for Reading. The speaker who wore these two pseudo-palates had the feeling that the sensory-feedback was better with the thinner Kay palate, although after a sufficient training period the adjustment to the Reading palate was fairly good. (3) The main difference between the Kay and Reading pseudo-palates is the number and repartition of the electrodes embedded on the pseudo-palates. The Reading system has 62 (silver, 1.4 mm diameter) electrodes, while the Kay has 96 (copper gold plated electrodes, 1 mm diameter). The electrodes are arranged in 8 horizontal rows for Reading, while their placement may vary from study to study for the Kay palate. In the present case, the electrodes are arranged in arches around a mid-sagittal line. For this pseudo-palate made for a French speaker two electrodes usually placed on the last molars were moved to the mid of the inner surface of the incisors in order to cover the dental area. Thus, compared to Reading, the Kay pseudo-palate show an additional coverage of the dental area, the inner surface of the upper teeth on the sides, and the velar region in the back at the border between hard and soft palate. Extra electrodes are also spread out in the palatal region. (4) Last but not the least, these two pseudo palates differ greatly in their price according to their number of electrodes.

1.2 Purpose of the study

The objective of this study is to compare how variation in linguopalatal contact is reflected by the two pseudo-palates and to evaluate the contribution of the extra 34 electrodes of the Kay system. With greater electrode coverage, the measure of linguopalatal contact with the Kay pseudo-palate has a larger variation range. Also, because data acquisition is less discrete, it is expected that this system reflects the actual contact of the tongue against the palate with greater precision. Consequently, it is possible that some subtle variations in linguopalatal contact may be shown by the Kay pseudo-palate but not with the Reading. However, it is also possible that the information lost by the Reading pseudo-palate does not imply a lack of significant distinction in observed linguopalatal contact. In that case, the information carried by the additional 34 electrodes of the Kay pseudo-palate could be regarded as redundant.

Three types of analyses and comparisons were conducted in this paper. The first analysis was done by looking at the differences between the number of electrodes contacted with each pseudo-palate for a particular segment in order to evaluate if the addition of contact information is more pertinent for the description of some segments. However, having a more realistic

picture of the actual linguopalatal contact (with more contacts) may not be pertinent or useful in experiments where the goal is to distinguish articulatory patterns. Therefore, in the second and third analyses, we have tested the pertinence of the additional information given by the 34 extra electrodes of Kay by determining whether this information increase the distinctive potential of the pseudo-palate.

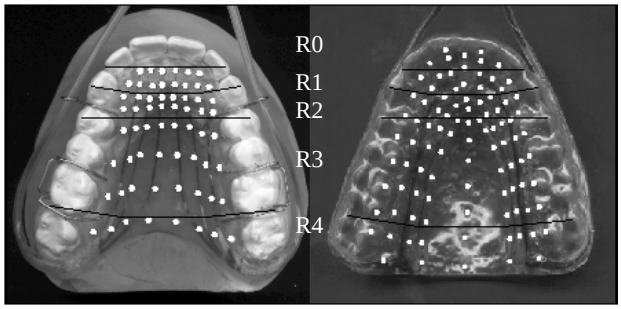


Figure 1: Reading (left) and Kay (right) pseudo-palates. Electrodes shown with white circles and articulatory regions with black lines.

Regions	Sagittal plan	Frontal plan	# electrodes	
			Kay	Read.
R0 dental	back of the front teeth to front of gingiva	from incisors up to 1st canine	8	0
R1 alveolar	front part of the alveolar ridge	up to mid of 2nd canine	11	14
R2 post-alveolar	mid of alveolar ridge	up to mid of 1st premolar	16	16
R3 palatal	mid hard palate	up to first molar	47	24
R4 velar	back of hard palate	up to last molar	14	8

Table 1: Regions defined for the study with their articulatory landmarks and number of electrodes.

2. METHOD

Comparison are made on a set of French EPG data acquired with the two pseudo-palates by the same speaker, reading the same speech material and with a parallel experimental procedure. Data were recorded with the Kay Elemetrics Palatometer 6300 in the Phonetics Laboratory at UCLA, in different sessions spreading from 1996 to 1999, and in a single session in 2000 with the Reading EPG2 system in the Phonology Laboratory at ULB in Brussels.

The corpora used here are part of a larger data-base recorded with Kay for other purposes (cf. Fougeron 1998). The first part of the corpus includes the consonants /n, l, s, k/ in /a_a/ context and the vowels /y, u/ in /n_m/ context, and aims at describing a variety of segments differing in place and manner of articulation; the second part contains the consonant /k/ in /a_a/ vs /a_la/ contexts in order to compare /k/ produced as a singleton and in a /kl/ cluster; the third part is made of the consonant /n/ in /a_y/ vs /a_u/ vs /a_a/ contexts showing variation in articulation depending on the following vowel. All these sequences have been produced in the same meaningful carrier sentence with 10 to 20 repetitions for each condition.

Only spatial aspects of lingual articulation will be treated here. Measurements in terms of number of linguopalatal contacts were done by computing the number of electrodes contacted in the frames showing the largest number of contacts for the consonants and the lowest number of contacts for the vowels. In the following analyses, number of contacts is considered either over the whole palate or in specific articulatory regions. These regions, which were not easy to define, are basically made for comparison purposes, they are presented in the Table 1 and Figure 1.

3. RESULTS - ANALYSIS 1

The contribution of the additional 34 electrodes of Kay is evaluated by comparing the two pseudo-palates in terms of additional linguopalatal contact information provided for different types of segments. The objective is to determine whether the presence of these 34 additional electrodes results in significant differences in the number of electrodes contacted, that is, in a better reflection of the linguopalatal articulation. Moreover, we try to determine whether this additional information is more pertinent for some segments.

	Whole palate	By region				
		R0 (+8)	R1 (-3)	R2 (0)	R3 (+23)	R4 (+6)
/n/	+ 19	+ 8	- 3		+ 9	+ 4
/l/			- 3	- 4	+ 10	
/s/	+ 16	+ 2	- 4		+ 13	+ 4
/k/	+ 34			+ 3	+ 25	+ 5
/y/	+ 24				+ 20	+ 4
/u/	+ 18				+ 12	+ 5

Table 2 : Significant differences in number of contacts between Kay minus Reading pseudo-palates depending on the segments and the articulatory region. Differences in the number of electrodes available in each region between the two pseudo-palates are given in parentheses.

The analysis of the number of contacts (i.e. contacted electrodes) over the whole palate shows that the information difference given by Kay and Reading depends on the nature of the segment articulated (interaction $F(5, 90)=49.16$; $p<.0001$). As expected, with an overall greater number of electrodes, Kay provides additional contact information for most of the segments studied except /l/ (Table 2, 2nd column). Furthermore, the differences between the two pseudo-palates are not equally distributed over the articulatory regions defined. Recall that the Reading pseudo-palate lacks a dental region and that differences in the number of electrodes covering each region vary from one pseudo-palate to the other. As shown in the 3rd to the 7th columns of Table 2, additional information given by Kay appears principally in the dental and palato-velar regions. The biggest difference in number of contacts is located in the palatal region (R3) for all segments studied. This is not surprising since the difference in electrode coverage between the two pseudo-palates is the largest for this region (Kay:47, Reading:24). Recall that the electrode coverage in the velar region (R4) extend more backward with Kay (up to the last molars). This difference appears to be informative to describe the articulation of all segments except /l/. In figure 2, the additional information given by Kay in the palatal and velar regions appears as a widening of the contact area on the sides of the palate (along or on the teeth) for all segments. For the palatal stop /k/, a wider palatal closure area (as wide as the two molars) appears with Kay, while Reading only shows a smaller area in the middle of the palate. The addition of a dental region (R0) in the anterior part of the Kay pseudo-palate appears to be informative to describe the articulation of /n/ and /s/.

The pattern is different in the two other regions. In the alveolar region (R1), the difference in the number of contacts between the two pseudo-palates corresponds to the difference in the number of electrodes included in this region (3 electrodes more for Reading). The apparent loss of information with Kay for /n, l, s/ (negative differences) reflects the fact that with both pseudo-palates all the electrodes in this region are contacted

during the articulation of these anterior consonants. The Kay has 3 contacts less because it has 3 electrodes less. In the post-alveolar region (R2), a contact difference between the two pseudo-palates occurs for both /l/ and /k/. However, the directionality of this difference depends on the consonant (positive for /k/, negative for /l/). Since there is no difference between the number of electrodes available in this region (16 for both), this difference in contacts may reflect the difference in the placement of the electrodes over the two pseudo-palate. If this is the case, the configuration of the electrodes in the post-alveolar region for Kay gives a better information for the description of /k/, but a poorer one for /l/.

In sum, additional information is seen in 4 out of 6 articulatory regions for the Kay compared to Reading pseudo-palate.

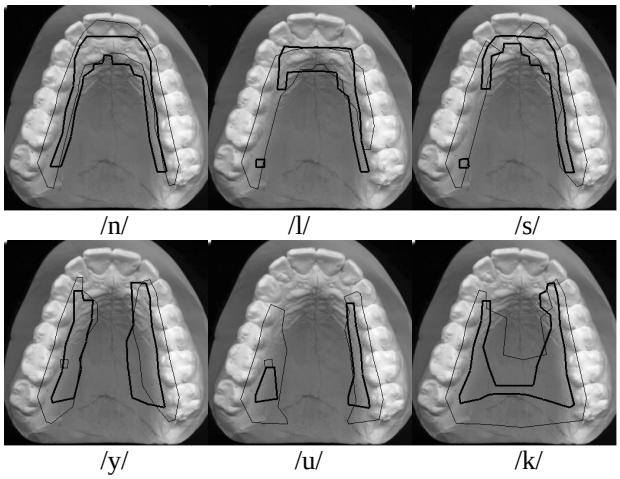


Figure 2: Cumulative contact area for the segments studied, Thin lines for Kay and thick lines for Reading.

4. RESULTS – ANALYSIS 2

In this second analysis, the two pseudo-palates are compared by looking at how they reflect segmental opposition via a variation in linguopalatal contact. This type of comparison could be interesting for automatic speech recognition based on articulatory cues (e.g. Soquet et al. 99).

From a two factor Anova analysis (EPGsystem * segment) and a post-hoc Scheffe test, we counted the number of significant segmental oppositions made by each pseudo-palate. These are presented in Table 3. When considering the total number of contacts over the whole palate and by making a cross comparison between all the segment considered, results show that the Kay pseudo-palate reflects more segmental oppositions (11) than the Reading one (7). The oppositions shown by the Reading pseudo-palates are in fact restricted to an opposition between front (/n, l, s, y/) and back (/k, u/) articulations, while Kay reflects more subtle distinctions within these broad categories. Again, the apparent superiority of Kay in showing more segmental opposition has to be tempered by an analysis region by region. As expected, the extra dental region (R0) in the Kay pseudo-palate provides pertinent information for distinguishing the anterior consonants. The number of contacts in the alveolar (R1) and post-alveolar (R2) regions appears to be quite informative to distinguish most of the segment studied. Both pseudo-palates perform as well in showing these distinctions in these regions. In the palatal region (R3), Kay presents a distinction between different consonants (for e.g. /k/>/s/>/l/-/n/, $p<.05$) while Reading mainly shows distinctions between consonants (/n,l,s,k/) vs. vowels (/y,u/). In the velar region (R4), Kay allows a distinction between /y/ and /u/ but not Reading.

In sum, more segmental distinctions are shown by the Kay pseudo-palate (76% of all the possible comparisons in all the regions) than by Reading (53%). Thus, the richer electrode coverage of Kay seems to improve the capacity of capturing segmental distinctions from linguopalatal patterns.

	Whole	R0	R1	R2	R3	R4
n K	l s u	l s k y u	l s k y u	l k u	s k y	l k y u
R	k u	-	l s k y u	l k u	y	k y u
l K	n s k y	n s	n s k y u	n s k y u	s k y	n s k y u
R	k u	-	n s k y u	n s k y u	k u	k y u
s K	n l k y u	n l k y u	n l k y u	l k u	n l k y	l k y u
R	k u	-	n l k y u	l k u	y	k y u
k K	l s u	n s	n l s	n l s y u	n l s u	n l s y u
R	n l s u	-	n l s	n l s y	y u	n l s y u
y K	l s u	n s	n l s	l k u	n l s u	n l s k u
R	u	-	n l s	l k u	n l s k u	n l s k
u K	n s k y	n s	n l s	n l s k y	k y	n l s k y
R	n l s k u	-	n l s	n l s y	l k y	n l s k
total	K:11	K:9	K:12	K:12	K:10	K:14
	R:7	R:0	R:12	R:11	R:7	R:11

Table 3: Segmental oppositions shown by Kay (K) and Reading (R) pseudo-palates. Each cell shows the segments that have a significantly different amount of contacts (over the whole palate or by region) from the test segments considered in column 1.

5. RESULTS – ANALYSIS 3

The two pseudo-palates are compared in the third analysis in order to evaluate their efficiency to replicate previously attested articulatory variations. Here, two cases of spatial variation due to coarticulation are considered.

5.1. Replication of C-to-C coarticulation effect in /kl/ cluster

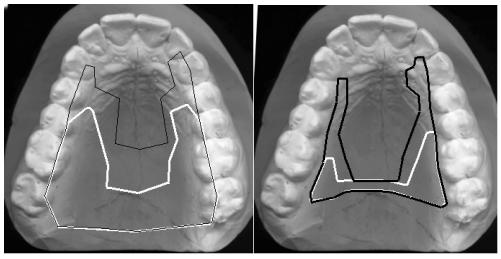
In several articulatory studies, it has been shown that the lingual constriction for /k/ is further back in a /kl/ cluster than in a singleton /k/ due to lingual coarticulation with the following /l/ (e.g. Gibbon et al. 93, Hardcastle et al. 96). The purpose of the present comparison is (1) to see whether this variation in articulation is reflected by both systems, and (2) more interestingly, to evaluate how the richer electrode coverage in the back region in the Kay pseudo-palate might be useful to reflect this variation in /k/ articulation.

Results from a 2 factors Anova (pseudo-palate*sequence, with a Scheffe post hoc test) on the number of contact over the whole palate show that the articulatory difference between /k/ in /aka/ and /akla/ is reflected by both pseudo-palates with an interaction between the two factors ($F(1, 56)=56.9$; $p<.0001$). In both cases, singleton /k/ has more contact than the /k/ in /kl/, but this difference is: 5 more contacts with Reading while it is 21 more with Kay. Moreover, while both pseudo-palates show a significant difference in contact number over the whole palate, differences in contact number reach significance in the post-alveolar and palatal regions only for Kay. Indeed, it can be seen on the cumulative contact areas in Figure 3, that the articulatory differences between the two /k/s appear differently on the two pseudo-palates. On both pseudo-palates, /k/ in /kl/ cluster has fewer lateral contacts that do not extend as far toward the front of the palate compared to singleton /k/, but with Kay, additional information on the backing of the lingual closure is also apparent. In the mid-sagittal plane, the closure area for /k/ in /kl/ is narrower and it does not extend as far in the palatal region compared to the singleton /k/. Therefore, the larger number

(and/or placement) of electrodes in the palatal region for the Kay palate appears to allow a better description of the extent of the back closure toward the center of the palate for singleton /k/ vs. a more back closure in /kl/.

In the velar region, the richer electrode coverage of Kay is not more efficient to distinguish singleton /k/ from /k/ in /kl/ in terms of number of contacts than do the Reading pseudo-palate. As shown in Figure 3, singleton /k/ and /k/ in /kl/ have the same contact pattern in this region. However, what does not appear from this cumulative figure is that, for singleton /k/, several repetitions with the Kay pseudo-palate (11/16) show electrodes not contacted on the last row of electrodes (one, central, or more) with a full closure on the more anterior rows. On the contrary, the backing of the closure in the /kl/ cluster appears on the Kay pseudo-palate with an area of contact that always spreads up to the last row of electrodes. Furthermore, while the Reading pseudo-palate often presents a pattern of contacts with an "incomplete" back closure (8/16 for /kl/ and 1/16 for singleton /k/ showing a last row with one or more central electrodes not contacted), this did not appear with Kay.

In sum, while both pseudo-palates account for the variation in the articulation of /k/ in singleton vs. in /kl/ context, it appears that the Kay pseudo-palate gives a better information on the location of back closure along the anterior and posterior dimensions. This additional information in the back of the palate would be particularly informative in a study considering the temporal dimension of the linguopalatal articulatory events, although this is not tested here.



Kay Reading

Figure 3: Cumulative contact area shown by the Kay and Reading pseudo-palates for singleton /k/ (white) and for /k/ in /kl/ cluster (black).

5.2. Replication of V-to-C coarticulation effect

EPG has been used in several studies for examining lingual coarticulation between consonants and vowels in several languages (e.g. Recasens 91). In the present analysis, we compare how the two pseudo-palate reflect the variation in the lingual articulation of the dental stop /n/ depending on the nature of the following vowel (V2): /n/ is observed in the context of a front /y/ vs. back /u/ high vowels with a base-line comparison made with a central open /a/ vowel.

Considering the number of contact over the whole palate, both pseudo-palates reflect the influence of V2 on the articulation of /n/. As expected, /n/ has significantly more contacts in the high vowels contexts compared to the open vowel context, and it has more contact with the front high vowel compared to the back high vowel (/na/<nu/<ny/, $p<.05$ for both systems). This variation in the number of contacts is particularly salient in the palatal region (R3) were the lateral contact of the vowels (see Figure 2 for /y/ and /u/) is anticipated during the consonant. In this palatal region, both pseudo-palates show a significant difference between the three vowel contexts. In the post-alveolar region (R2), there is also an effect of the vowel context, but the three way distinction between the vowel contexts appears only with Kay (/na/<nu/<ny/, $p<.05$), while the distinction between the two high vowel contexts is lost with Reading (/na/<ny/-/nu/, $p<.05$). In the velar region (R4), the two pseudo-palates do not show the same trend of differences (/na/-/nu/<ny/, for Kay and /na/<nu/-/ny/, for Reading). In the front, the lingual articulation of /n/ does not seem to be affected by the vowel contexts in the alveolar region (R1) for both pseudo-palate. However, a subtle coarticulatory effect appears in the dental region (R0) of the Kay pseudo-palate (no dental region for Reading) that consists in a reduction of the number of contact for the /_y/ context compared to the others two. It is possible that this variation reflects a backing of the front closure of /n/ with a laminal lingual articulation in a /_y/ context.

In sum, while both pseudo-palates reflect the V-to-C coarticulatory effect, the Kay pseudo-palate appears to be more efficient to capture subtle articulatory variations of /n/ in the post-alveolar and dental regions.

6. CONCLUSION

One of the main question of this study was to evaluate how much information is lost and how sufficient is the information given by the 62 electrodes of the Reading pseudo-palate. This study shows that the same articulatory effects can be shown by both systems, but that the Kay pseudo-palate has a better definition to describe segments articulation with 96 electrodes.

This study also demonstrates that although there are some important similarities between the two pseudo-palates in the alveolar and post-alveolar regions, the Kay pseudo-palate adds information in the dental area and in the posterior regions. The differences found can be interpreted by the effect of a different coverage with a greater number of electrodes in the Kay pseudo-palate, but they can also be due to the repartition and placement over the palate. This would need further investigation with a wider variety of segments. Concerning this, one could suggest that an improvement of the Reading pseudo-palate would be to add a second row of electrodes in the back of the velar region, in the gap left open between the last molars; also more electrodes could be added between the 6^{th}-7^{th} and 7^{th}-8^{th} rows in the palatal region. Finally, a small extension in the front of the mouth would be informative to capture dental articulations.

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