Analysis of the symmetry of electrodes for Electropalatography with Cone Bean CT Scanning

Jo Verhoeven,[1,3], Naomi Rachel Miller[1], and Constantino Carlos Reyes-Aldasoro[2*]
[*] Corresponding author: constantino.reyes-aldasoro.1@city.ac.uk

[1] School of Health Sciences, Division of Language & Communication Science, Phonetics Laboratory, City, University of London, UK.
[2] School of Mathematics, Computer Science and Engineering, Department of Electrical Engineering, Research Centre in Biomedical Engineering, City, University of London, UK.
[3] Department of Linguistics & CLIPS, University of Antwerp, Antwerp, Belgium.

Abstract. The process of compression of air and vibration of activity in the larynx through which speech is produced is of great interest in phonetics, phonology, psychology and is related to various areas of biomedical engineering as it has a strong relationship with cochlear implants, Parkinson's disease and Stroke. One technique by means of which speech production is analysed is the use of *electropalatography*, in which an artificial palate, moulded to the speakers' hard palate is introduced in the mouth. The palate contains a series of electrodes, which monitor contact between the tongue and the palate during speech production. There is interest in the symmetry or asymmetry of the movement of the tongue as this may be related to languages or right- or left-handedness, however, this has never been thoroughly studied. A specific limitation of electropalatography for symmetry studies is that palates are hand-crafted and the position of the electrodes themselves may be asymmetric. In this work, we analyse the positioning of electrodes of one electropalatography setting. The symmetry was analysed by locating the electrodes of the palate through the observation of the palate with Computed Tomography. An algorithm to segment the electrodes and find the symmetry of left and right sides of the palates is described. No significant asymmetry was found for one specific palate. The methodology presented should allow the analysis of palates to be used in larger studies of speech production.
Keywords Computed Tomography, Segmentation, Speech Production, Electropalatography.

1 INTRODUCTION

The production of speech sounds consists of the co-ordinated and synchronised movements of an estimated 160 muscles operating the articulators such as the lips and the tongue to change the overall shape of the vocal tract. The technique of electropalatography (EPG) [1, 2] records the location and timing of tongue contacts with the hard palate during continuous speech. The location is recorded by way of contact between a series of electrodes and the tongue, as the electrodes will react electrically to the humidity of the saliva on the surface of the tongue. The experimental palate is a thin artificial acrylic palate custom-made to fit against a speaker's hard palate by obtaining a plaster dental impression of the upper jaw [3]. The cast is then used to produce a palate with the electrodes (Fig. 1) [4]. Once a contact is recorded by an electrode, an electrical signal is sent to an external processing unit [5] and a graphical display of the electrode is shown either on a screen or printed on paper (Fig. 2). When palatograms are shown on a screen, the EPG provides a dynamic real-time visual feedback of the location and timing of tongue contacts with the hard palate. As EPG can record and display details of tongue activity during speech in real time, it can provide useful direct articulatory information. For instance, it can be used during therapy to monitor and improve articulation patterns, especially with children [6]. Visual feedback is particularly important in the success of treating hearing-impaired children.

EPG has been widely used in many areas, for instance, to study speech disorders [7], in cases of aphasia following a stroke [8], for cases of hearing impairment and the effect of hearing aids and cochlear implants [9], effects of bilingual influence in the cerebellum [10], contact patterns for different sounds in languages with different number of vowels and consonants [11, 12].

In phonetic studies of speech production, it has been implicitly assumed that the different postures for speech are symmetrical in the left-right plane of the vocal tract: i.e. the contact between the tongue and the right side of the palate is assumed to be equally extensive as that with the left side. Nevertheless, published palatograms visualising tongue-palate contact patterns generally show left-right asymmetry, although this finding is rarely mentioned. Characterisation of articulation asymmetry in native speakers would improve understanding of the process of speech production and its relationship with both neural organisation and the anatomy of the organs of speech. From a practical viewpoint, it could help learners of English as a foreign language to achieve a native pronunciation and could provide a reference for Speech and Language Therapists when treating speech deficiencies in which asymmetry plays a role (e.g. dysarthria).

Asymmetries in tongue posture during the articulation of speech sounds have only been systematically investigated in a very small number of electropalatography studies [11, 13, 14]. The general conclusion was that the vast majority of palatograms show asymmetrical tongue-palate contact, irrespective of the language involved. There was, however, little consistency in the direction of the asymmetry, which seems to differ depending on the individual speaker and/or the speech sound. Furthermore, these conclusions are based on the data of a very small number of speakers (i.e. a grand total of 15). A recent meta-analysis of palatograms (visualisation of contact patterns between tongue and hard palate) from a large number of instrumental phonetic studies suggested that the tongue

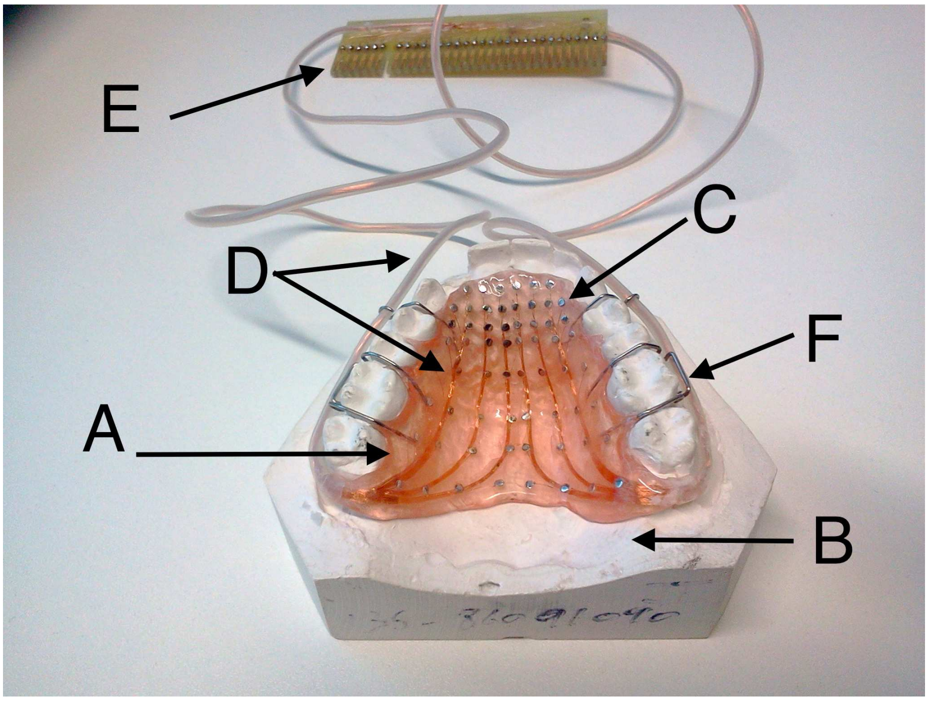

Fig. 1. Illustration of a palate used for Electropalatography. The palate (A) is crafted over a stone cast of the upper jaw (B) produced by a dentist. The electrodes (C) are placed manually over the palate and connected through electrical wires (D) to the interface (E) of the external recording unit. The palate is kept in place with wires (F) that are not in contact with the electrical wires or the electrodes. Whilst the electrodes are positioned carefully when constructing the palate, the process is rather artisanal and there is little verification on the position of the electrodes. A careful observation of the image can reveal some variation on the central electrodes.

touches the palate in an asymmetrical manner [15]. This study reviewed 1,500 previously published palatograms representing a total of 225 speakers in 10 different languages. It was found that 83% of these published palatograms showed asymmetrical contact between the tongue and the hard palate. Palatograms with more tongue-palate contact on the left (45%) outnumbered those with more contact on the right (38%). As far as the direction of the asymmetry is concerned, it was found that in trills, taps and approximants there is more elaborate tongue-palate contact on the left, whereas in plosives and fricatives, contact is more elaborate on the right. Furthermore, there is a significant relationship between the direction of the asymmetry and the place of articulation, with more elaborate contact on the left for all places of articulation except for palatals. The results of this extensive review will be used to design an empirical electropalatography study in which the direction and amount of asymmetry in tongue-palate contact

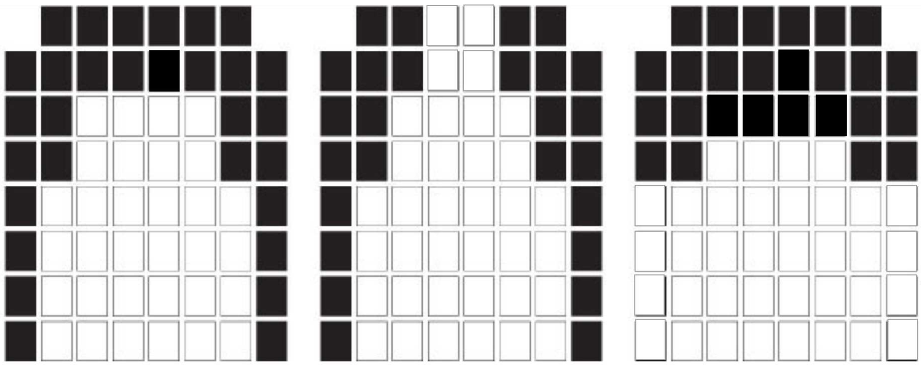

Fig. 2. Illustration of three different palatograms where contact between electrodes and the tongue is indicated by black rectangles and electrodes without contact are indicated by white rectangles. The top of the graph refers to the anterior side of the palate, the bottom the posterior part.

will be studied as a function of (a) the type of speech sound, (b) anatomical asymmetries in speakers' palates, and (c) speaker handedness.

The main hypothesis in [15] is that articulation asymmetries may be related to anatomical asymmetries in the shape of the speakers palate, speaker handedness and/or the class of speech sounds involved. However, there is a strong confounding factor in the analysis, namely, the fact that the palate has been custom-made and thus the location of the electrodes may be irregular and asymmetrically positioned. In this work, we design an image processing framework that segments the main elements of a palate of EPG to analyse the location of the electrodes with respect to the sagittal plane to observe the possible asymmetry of the palate.

2 Materials and Methods

2.1 Images of the palates

Images of the stone cast and the palate shown in Fig. 1 were acquired with a SCANORA® 3Dx Cone Beam CT system by Soredex. Two hundred and fifty DICOM® axial images of resolution 333×333 pixels with pixel and slice spacing of 0.3 mm at a power of 85 kVp were acquired (Fig. 3). The images of the palate and the cast showed a difference in intensity between the background (black), the cast (dark grey) and the metallic elements (light grey to white). However, the metallic elements created some artefacts streak lines that can be seen in the molars of Fig. 3(a); these artefacts complicate the segmentation.

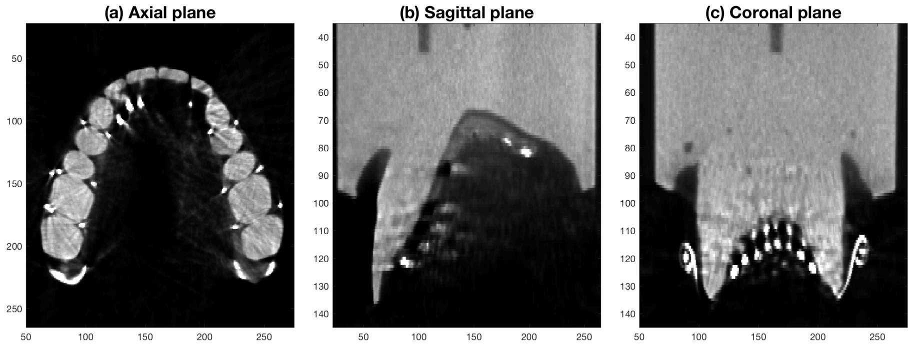

Fig. 3. Representative slices of the CT scan of the palate. (a) Axial slice showing the tip of the teeth with the molars below and the incisives at the top. (b) Sagittal slice with the frontal teeth at the lower left. (c) Coronal slice showing the cusps of the canines. The circular lines in (c) correspond to the metallic wires that hold the electrical cables. Notice that although there are differences in intensity between the cast of the palate and the electrodes and wires there are some regions of the cast that are as bright as the electrodes. These are especially noticeable in the lower molars in the axial plane and the canines on the coronal plane. See figure 4 where the regions have been incorrectly segmented by intensity alone.

2.2 Methods

Intensity segmentation. Since the metallic elements of the electrodes and wires are denser than the cast of the palate, it is possible to exploit the corresponding difference of intensity on the CT images. However, the material of the cast of the palate is not perfectly uniform and the artefacts previously mentioned did not allow the segmentation by a single threshold. Thus a two threshold segmentation [16], inspired by the Schmitt trigger [17], was followed: a lower threshold to segment the background and a high threshold to segment the metallic elements were selected. The background was easily segmented with a low threshold, however a high threshold was not sufficient to adequately segment the metallic elements as some voxels of the cast presented a very high intensity and were confused as metal (Fig. 4).

A further division with two high thresholds, which roughly corresponded to the wires that held the palate in place and the electrodes and its connections, was performed. The stone cast was refined with a series of morphological operators, closing, opening and filling holes (Fig. 5a). This allowed a solid region to be determined and subsequently all high intensity voxels detected in that region were discarded. The wires (Fig. 5b) were morphologically segmented from the electrodes (Fig. 5c) by size. Once the electrodes were segmented from the cast and the wires, these were uniquely labelled (Fig. 5d).

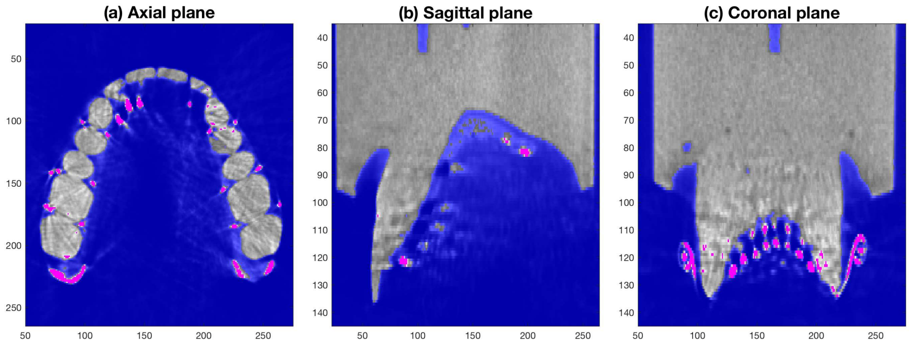

Fig. 4. Segmentation with double thresholding. The images of (Fig. 3) were segmented with an low threshold to segment background (blue shade) and a high threshold to segment the metallic elements (pink shade). Notice that the high threshold does not select all the electrodes in (b) nor it discards high intensity pixels of the cast clearly visible in (a,c).

Plane of symmetry. Since the cast had been correctly oriented in the acquisition of the CT, the plane of symmetry was considered as a sagittal plane in the front-back direction, and was located in the separation between the two frontal teeth and was further used to divide the electrodes into left and right side of the palate (Fig. 6a).

Projection of the electrodes. The final step of the algorithm consisted of a projection of each electrode through the plane of symmetry to the opposite side of the palate. If the electrodes had been perfectly located, the projection should land exactly over the corresponding opposite electrode. Figures 6(b,c,d) show the electrodes and their corresponding projections shown as green and blue dots in the three views.

All the image processing was performed in Matlab® (The Mathworks™, Natick, MA, USA) and the code is available upon request.

3 RESULTS AND DISCUSSION

The segmentation steps previously described provided a successful segmentation of the electrodes as single elements which were uniquely located in the three-dimensional space.

From figure 6(b) it can be seen that the majority of the electrodes corresponded to their mirror position, especially in the anterior section of the palate and the bottom row, as the dots are barely visible as these land over the electrodes. A few electrodes seem to be displaced in the front-back direction (electrodes 35, 36, 41, 42) and others in the left-right direction (electrodes 1, 2, 3, 5).

The displacement in the up-down direction can be appreciated in figures 6(c,d) and it can be seen that the displacement is very small as there are no dots to be seen in the sagittal view and in the coronal view the dots visible are mainly due to the left-right displacement seen in the axial view.

It should be appreciated that the displacement of electrodes seems to be relatively small compared with the distance between electrodes and, at least in the case of this particular palate, any asymmetry observed in a palatogram is due only to the positioning of the tongue and not due to the shape of the palate.

This work provides a foundation that will be used to analyse a larger number of palates, which will also be correlated with the information of electropalatography. A series of individuals will be selected into two groups, each with different hand-dominance to assess if right- or left-handedness impacts in the movement of the tongue.

Future work will consider the analysis of the cast (Fig. 5(a)) as there is considerable interest in the asymmetry of the mandibule [18, 19] and the shape and morphometry of the palatal rugae measures [20, 21]. The asymmetry may have several dimensions; the palatal shape, the positioning of the electrodes in the palate and the movement of the tongue itself.

Another future direction will be the creation of visualisation outputs, which reflect better the anatomy of the phenomenon than the palatograms previously shown. This may be particularly useful in therapy where the provision of real-time visual feedback of tongue movement can be effective in the remediation of certain types of intractable speech problems.

Acknowledgements

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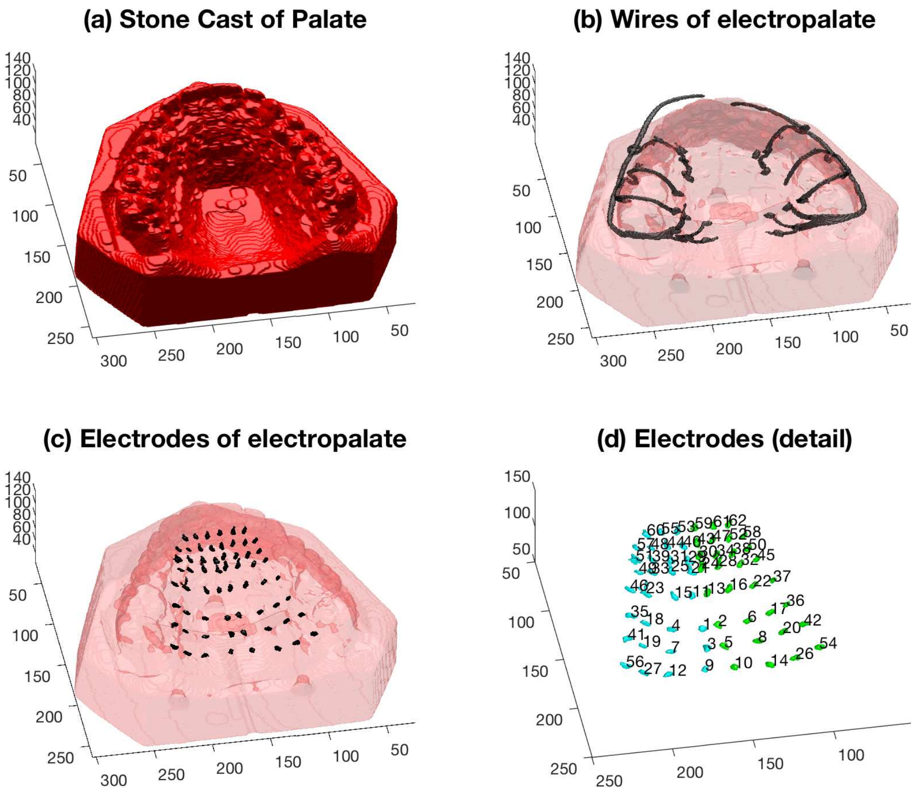

Fig. 5. Segmentation of the structures of interest. (a) Segmentation of the cast of the palate. (b) Segmentation of the wires that hold the palate in place, notice the detail that is captured with the segmentation in the small loops that go through the teeth. The segmentation of the cast is shown with transparency for reference. (c) Segmentation of the electrodes. (d) Electrodes shown in more detail; the electrodes have been uniquely labelled and grouped into left (green) and right (cyan) sides. Notice that the palate corresponds to the upper jaw and therefore is upside down.

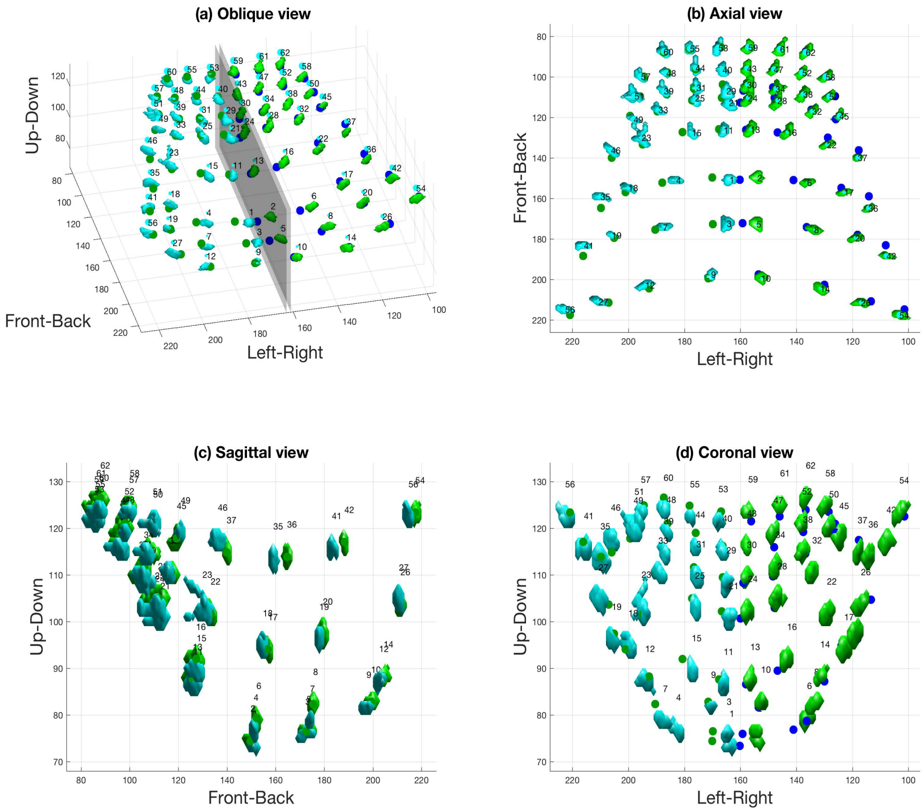

Fig. 6. (a) Illustration of the plane of symmetry used to group electrodes into sides. (b) Axial view. (c) Sagittal view. (d) Coronal view. In all cases, each left electrode are shown in green, right electrodes are shown in cyan and these have been projected to the opposite side and denoted with a blue or green dot to illustrate the asymmetry in their positioning.