ASYMMETRIES IN SPEECH ARTICULATION AS REFLECTED ON PALATOGRAMS: A META-STUDY

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ABSTRACT

This paper presents the results from an investigation of asymmetries in speech articulation on the basis of 1,502 previously published palatograms of a wide variety of speech sounds in a range of languages. For each palatogram, the direction and degree of tongue-palate contact was quantified by means of an index capturing the degree of lateral asymmetry. The results of this investigation show that lingual asymmetry in the articulation of speech sounds is substantial: 83% of the palatograms are asymmetrical. With respect to the direction of the asymmetry it is found that the asymmetry is more often towards the left side of the palate (45%) than to the right side (38%). Further analysis reveals that there are significant differences in both the direction and the degree of the asymmetry as a function of manner and place of articulation.

Keywords: Speech Production, Articulation asymmetry, Palatography.

1. INTRODUCTION

In studies of speech production, it has often been implicitly assumed that articulation is symmetrical in the transverse plane of the vocal tract. In terms of tongue contact with the hard palate, this means that contact with the right-hand side of the palate is equally extensive as contact with the left. Nevertheless, palatograms visualising tongue-palate contact patterns published in instrumental studies of speech often show asymmetrical tongue-palate contact, although this finding is rarely explicitly mentioned.

To the best of our knowledge, asymmetries in articulation have not been subject to widespread investigation. There have been a few studies on asymmetry in mouth opening during the articulation of speech sounds. These studies have suggested that there is significantly greater right-sided (as opposed to left-sided) mouth opening during speech, in both left-handers and right-handers and in men as well as women [1]. In addition, it was found that mouth asymmetry is related to task factors: there was greater right-sided asymmetry in purely verbal tasks (i.e., generating words lists, rhyming, verbal definition) and less right-sided asymmetry in more emotional/visual tasks (describing recalled situations) [2]. This could suggest differential involvement of the hemispheres in different types of tasks in that the left hemisphere subserves verbal tasks, while the right hemisphere is more actively involved in emotional and affective processing. This finding was consistent with an earlier study on mouth asymmetry in aphasic speech [3], which showed more right-sided asymmetry during propositional speech and more left-sided asymmetry in automatic and emotional speech. Taken together, these observations suggest that mouth asymmetry may be a reflection of the relative participation of the two hemispheres of the brain in controlling an individual's expressive speech. According to this premise, the left hemisphere is more involved in propositional language tasks, while the right hemisphere is more involved in automatic and emotive language tasks associated with concurrent emotional or visual activities.

Asymmetries in tongue posture during the articulation of speech sounds have only been systematically investigated in [4], [5], [6] and [7]. [4] is an electropalatography (EPG) study of tongue-palate contact in the pronunciation of /s/ and /l/ in five native speakers of American English (2 males and 3 females). The results of this study revealed (1) that there was significant lingual asymmetry in tongue-palate contact in both speech sounds and (2) that the direction of the intraspeaker asymmetry was not necessarily the same in /s/ and /l/. While articulatory asymmetry was predominantly towards

the right for /l/, asymmetry in /s/ was often towards the left.

The relationship between articulatory asymmetries and handedness was investigated in [5] based on 357 speakers. Data were collected relating to the asymmetry in the articulation of /l/, the direction of the air channel in /s/, and self-reported handedness. For /s/ the asymmetry was determined on the basis of the greatest resonance response in a cocktail straw that was moved left and right just below the edges of the upper teeth. The asymmetry of /l/ was determined by asking speakers to pronounce the lateral while breathing inward. The tongue will feel colder on the side that is not in contact with the roof of the mouth. This study reported that symmetrical articulations were substantially more frequent than asymmetrical articulations (57% vs. 43%). Furthermore, of the articulations that were found to be asymmetrical, those with greater left-sided tongue contact outnumbered those with more right-sided contact (24% vs. 19%). The conclusion of this study is that a relationship between the incidence of asymmetries and speaker handedness cannot be substantiated.

[7] investigated the relationship between cross-sectional tongue shape and tongue-palate contact patterns in a native speaker of English. This was done by means of ultrasound (to investigate cross-sectional tongue shape) and electropalatography (to investigate tongue-palate contact patterns). This study showed that there was a clear correlation between cross-sectional tongue shape and tongue-palate contact patterns: higher tongue contours reflected greater tongue-contact on the right. The asymmetry did not originate from an anatomical asymmetry in palate shape since the left side of the palate in this speaker was lower than the right side. Thus the greater contact on the right suggested a "greater movement and possibly a greater effect in right tongue elevation" (p. 269).

[8] was an EPG study of the lingual dynamics of the consonants /t/ and /k/, as well as the combinations /lk/ and /kl/ in three native speakers of Italian. This study was part of a larger investigation which reportedly also collected data for English and French [7]. All the Italian participants showed some degree of asymmetry, which was variable both in direction and degree. As far as the lingual dynamics are concerned, it was suggested that "the lingual approach to the palate occurs earlier with one side of the tongue, and that the break of the closure is first made with the opposite side of the tongue" (p.212).

From this literature, it can be concluded that there is a great deal of inconsistency in the reported data, with some studies showing that asymmetries are common, while others have found symmetrical articulations to be more frequent. Furthermore, it is not clear what causes asymmetries: anatomical differences between speakers, motor preference, language dominance, physiological differences in muscle strength and geometry of the hard palate.

While some of these aspects are presently being investigated in a series of experiments, the objective of this study is to first and foremost document articulatory asymmetries on the basis of palatograms that have been published in professional journals. More specifically, the aim is to examine tongue-palate contact during the articulation of speech sounds in a wide variety of languages, speakers and contexts.

2. METHODOLOGY

The starting point of this study was a substantial collection of palatograms published in scientific journals that have a prime interest in the investigation of speech. Palatograms are visualisations of the contact patterns between the tongue and the hard palate. Thus they provide objective information about the spatial distribution of tongue contact with the palate. Only palatograms obtained by electropalatography were included in this study, since static palatograms are not very representative of dynamic speech. Furthermore, the contact area between the tongue and the palate is much more difficult to quantify objectively than in EPG.

2.1. Journal selection

For this study, the contents of 5 scientific journals were scrutinized for articles on electropalatography that contained pictures of speech-sound palatograms. These journals were: Journal of the International Phonetic Association (JIPA), Language and Speech (LAS), Journal of the Acoustical Society of America (JASA), Journal of Phonetics (JOP) and Clinical Linguistics and Phonetics (CLP). These were chosen because their main focus is the study of speech. Furthermore, these journals have a high reputation in the field: 2017 impact factors were 0.75, 1.235, 1.572, 1.519, and 1.191 respectively. Finally, articles submitted to these journals are peer-reviewed, implying that the quality of the research has been verified externally by specialists in the field.

Each journal was screened from 1970 onwards, except for Clinical Linguistics and Phonetics and Journal of Phonetics, which were screened from 1995 onwards. In collecting the palatograms, only those originating from native adult speakers (over 18), in a non-clinical population, were considered. EPG studies focusing on pathological speech and swallowing were excluded.

2.2. Information processing

The number of EPG papers considered per journal were as follows: JIPA 25, LAS 10, JASA 17, JOP 18, CLP 33. All these articles were checked for the presence of palatogram pictures. Each picture was photocopied and information was recorded about the speech sound involved, the language (variety) and the speaker (age, gender). Furthermore, the total number of active electrodes for each palatogram was determined, as well as the number of right-sided and left-sided activations with respect to the midsagittal line of the palate.

In total, 1,502 palatograms were collected. The distribution of palatograms in the different journals was as follows: JIPA 424, LAS 205, JASA 150, JOP 150, CLP 443, other journals 130.

The palatograms represented speech sounds in 10 different languages (Spanish, English, Norwegian, Japanese, Italian, Greek, German, French, Croatian, Tamil). This includes 6 varieties of English (American, Australian, British, Hiberno, Canadian and Scottish), 2 varieties of Catalan (Majorcan and Valencian), and 3 varieties of Spanish (Peninsular, Argentinian and Cuban). A total of 225 speakers were represented, 94 of whom were female (41.77%) and 111 were male (49.33%). In 20 palatograms (8.88%) the gender of the speaker had not been specified in the source.

2.2. Data Analysis

For each palatogram, an index of asymmetry was calculated which reflects the degree and the direction of the asymmetry [6]:

$$I_{as} = (N_r - N_l) / (N_r + N_l)$$

In this formula, N is the total number of contacts, r is the number of contacts on the right side, and l is the number of contacts on the left side. This index captures the direction of the asymmetry (negative values have more contacts on the left, positive values have more contacts on the right) as well as the size of the asymmetry (values range between 0 and 1 with higher values representing greater asymmetry).

3. RESULTS

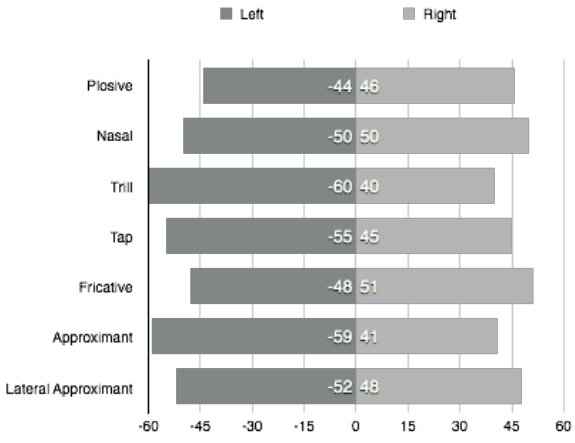
3.1. Number of asymmetries

As far as the total number of asymmetries in the data is concerned, it is found that palatograms showing an asymmetrical pattern are the most frequent observation, comprising 83% of images. The asymmetries with more extensive tongue-palate contact on the left (45%) outnumber those with more contact on the right (38%).

3.2. Direction of asymmetry

The direction of the asymmetry can be specified as left or right on the basis of the index of asymmetry. A negative index has more tongue-palate contact on the left, while a positive one has more contact on the right. The factors affecting the direction of asymmetry were analysed by means of a nominal logistic fit. Asymmetry direction (left vs. right) was the dependent variable, while gender, voice, place and manner were the independent variables. The results show a significant main effect of both the manner of articulation and the place of articulation on the direction of asymmetry: manner $\chi^2 = 21.0887$, $p < 0.0036$; place $\chi^2 = 15.6584$, $p < 0.0157$. Gender and voicing were not significant. The proportions of the asymmetries for the different manners of articulation are summarized in Figure 1. Thus, for each manner of articulation, the bars in dark shading show the proportion of palatograms that exhibit left-sided asymmetry and the bars in lighter shading denote right-sided asymmetry. From It is clear that the manners of articulation with the strongest directionality (with regards to asymmetry) are trills, taps and approximants. Figure 2 shows that asymmetry is most strongly directional for alveolar and velar sounds.

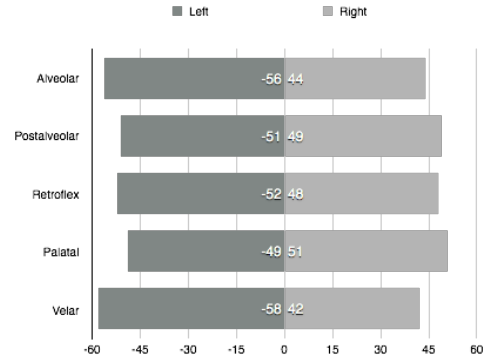
Figure 1: Proportions of palatograms showing left and right asymmetry as a function of manner of articulation.



3.3. Degree of asymmetry

The degree of the asymmetry was analysed using linear mixed models in R [9]. The models consisted of two components: a random and a fixed part.

Figure 2: Proportions of palatograms showing left and right asymmetry as a function of place of articulation.



The random effect was speaker ID. This part controls for the random variation at the individual level. The fixed effects consisted of gender, voicing, place of articulation and manner of articulation. These main effects were also crossed to look at the interactions between effects. Although the interactions are not discussed in this paper, they contributed to the best-fit model to the data. The models were built up hierarchically by adding one fixed effect at a time and comparing the new model to the old model using the Anova function in R. The goal was to arrive at the best-fit model for the data, i.e., the model explaining the largest amount of variance with the fewest predictors. The Tukey HSD procedure was used for subsequent post-tests on interaction effects. Only the best-fit model is reported.

The multilevel analysis of the size of asymmetry revealed that gender has no significant effect on the degree of asymmetry (Estimate = -0.005, S.E. = 0.01, t = -0.48, p = 0.62). The post-tests on place of articulation revealed no significant effects. However, the post-tests on manner of articulation revealed a number of significant differences. As shown in Table 1, significant differences always involve fricatives.

Table 1: Significant effects in the post-tests concerning manner of articulation.

Contrast	Estimate	Standard Error	z-value	p
Fricative-Affricate	0.46	0.07	6.74	<.001***
Approximant-Fricative	-0.49	0.09	5.52	<.001***
Nasal-Fricative	-0.12	0.04	3.21	0.2*
Plosive-Fricative	-0.41	0.07	5.71	<.001***
Tap-Fricative	-0.58	0.13	4.56	<.001***

The effects summarized in Table 1 indicate that the degree of asymmetry in fricatives is larger (x = 0.146) than in the other manners of articulation (x = 0.104).

4. DISCUSSION AND CONCLUSIONS

This study set out to collect a large number of EPG palatograms from studies investigating aspects of lingual articulation. For each of these 1,502 palatograms an index of asymmetry was calculated.

The most important conclusion from this study is that the overwhelming majority of palatograms (83%) show asymmetry. This corroborates previous studies on lip asymmetry, which found that asymmetrical mouth opening was a consistent characteristic of spontaneous speech. The conclusion also agrees well with [6], where the authors found asymmetrical tongue-palate contact in the speech of all their subjects. Consequently, this study does not confirm the findings of [5], where it was reported that symmetrical articulations were the more common scenario (i.e., an incidence of 57%).

As far as the direction of the asymmetry is concerned, it was found that there is a significant relationship between the direction of asymmetry and the manner of articulation: in trills, taps and approximants, there is more tongue-palate contact on the left, whereas in plosives and fricatives, contact is more extensive on the right. Furthermore, there was a significant relationship between the direction of asymmetry and the place of articulation of the speech sound, with more contact on the left for all places of articulation except for palatals. These findings are consistent with [6] in the sense that the latter study also reported differences in asymmetry depending on the place and manner of articulation.

In this study it was not possible to investigate the relationship between the direction of asymmetry and handedness because handedness was never reported in the collected articles. However, the study of [5] seems to suggest that such a relationship cannot be substantiated.

Finally, this study also investigated the degree of asymmetry as a function of the different speech sounds. Although there was no significant relationship with place of articulation, it was found that there is significantly more asymmetry in fricatives than in most other manners of articulation. This may suggest that speakers maximize articulatory asymmetries in fricatives in order to, e.g., most efficiently generate the optimal aerodynamic conditions for creating turbulence in this sound class. This implies that lingual asymmetry

for specific classes of speech sound is learnt by speakers as a dimension of articulation.

5. ACKNOWLEDGEMENTS

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