Consonant articulation in glossectomee speech evaluated by dynamic MRI

K. Mády[1], R. Sader[1], A. Beer[2], P. Hoole[3], A. Zimmermann[1], C. Hannig[2]

[1] Department of Oral and Maxillofacial Surgery, University of Technology, Munich

[2] Department of Radiology, University of Technology, Munich

[3] Department of Phonetics and Linguistic Communication, Ludwig Maximilian University, Munich

mady@mkg.med.tu-muenchen.de

ABSTRACT

Consonant production after glossectomy was investigated by means of acoustic and articulatory analysis. Articulatory movements in the midsagittal plane were recorded by real-time MRI (8 images/sec). With this method, near-natural production of sounds embedded in real words could be observed. Relying on measurements between the tongue and alveolar-palatal-velar-pharyngeal contours, a typical distance diagram for normal articulation was compared with the postoperative recordings. We found that two factors have to be fulfilled for a sufficient /s/-production: a narrow constriction in the dental-alveolar region and a restriction of the contact surface to this area. Absence of these characteristics was directly related to the lowering of the centre of gravity measurements of the spectra. If the constriction site was changed towards the palatal direction, the centre of gravity was lowered from ca. 3.5 kHz by ca. 1 kHz. If no narrow constriction was achieved at all, the centre of gravity was even lower.

1 INTRODUCTION

Speech assessment after glossectomy is an important tool for evaluating the functional outcome of the surgery and reconstruction methods. For practical reasons, this is mostly done by means of intelligibility tests and/or acoustic recordings (references). However, as Mackenzie Beck et al. (1998) note, speech outcome is always influenced by individual articulatory skills that cannot be detected via acoustic analysis. Furthermore, not much is yet known about the consequences of oral surgery for articulatory processes [1, 4, 6, 7].

In the present study, we will attempt to make a link between the acoustic outcome of speech production and articulatory skills of subjects who have undergone surgery due to oral cancer. In each case, a primary closure or a myocutaneous flap (platysma) was used for reconstruction, and a part of the tongue was fixed at the floor of the mouth. This method is said to cause less complications but lead to a more restricted tongue mobility than reconstruction techniques with a free flap taken from the leg, chest, jejunum etc. [5].

For the articulatory imaging, dynamic MRT was used for the following reasons: (1) better imaging of soft tissue than in X-ray or ultrasound recordings that are commonly used in clinical studies, (2) no AD-interface is necessary as the original recording format is digital, and (3) the lack of radiation damage to the patients. Our aim was to create an interface between speech motor processes and acoustics in order to be able to show some important characteristics of the production that lead to an efficient auditory impression, with or without compensatory mechanisms.

For the articulation of the dental-alveolar sibilants /s/ and /z/, a narrow constriction between tongue blade and alveolar ridge is required. The spectogram of /s/ shows higher intensity in the high frequency areas (above 3 kHz). /s/ is regarded as a very sensitive sound in the sense that even a small deviation in articulation can lead to an audible acoustic impairment [2, 8]. Therefore, it can be considered as a good indicator for articulatory and acoustic impairments connected with anatomical changes of the anterior oral cavity.

2 MATERIALS AND METHODS

2.1 Subjects

Eight male persons (GL 1–8) with a cancer of the anterior and lateral oral cavity participated in our study. All tumours were relatively small (not larger than 4 cm), and none of the subjects had any speech disorder prior to surgery, nor were preoperative tongue movements restricted due to the tumour. The tumours were located either on the floor of the mouth or in the tongue body, both resulting in a tongue fixation as a primary reconstruction, except for GL 3 who underwent a minor lateral tongue resection without any need of reconstruction.

2.2 Test material

Recordings were made a few days before and approximately four weeks after the operation (but before any optional radiotherapy had begun). The test material contained existing German words with a simple CV-structure. (Real words proved to be the only possible test material, since the communication environment during the MRI recordings would make understanding of nonwords very difficult.)

2.3 Methods

Acoustical recordings were made by a DAT-recorder and were analysed by Praat, version 4.0.45. Each word was spoken three times.

For the MRT, Philips ACS NT Gyroscan with the gradient echo (GR) imaging technique (and partly the sensitivity encoding system SENSE) was used, and the midsagittal plane with a slice thickness of 10 mm was recorded. The sample rate was 8 images/sec, with a sequence duration of 10 seconds. This time unit allowed for 5–11 repetitions of the target word. Segmented scans (see Figure 1) with the image of the target sound were used for further analysis that was based on distance measurements between the tongue and the alveolar–palatal–velar–pharyngeal (APVP-)

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contour. Distance was calculated along the radii of a semicircle beginning from the inferior apex of the alveolar ridge and finishing at the anterior inferior edge of the third cervical vertebra. Along this scheme, two points were measured for every tongue position, beginning from the origin of the grid: (a) the outer edge of the tongue and (b) the closest point of the palate, thus the origin–palate distance is identical with the maximal possible tongue extension (100%) along the line (Figure 2).

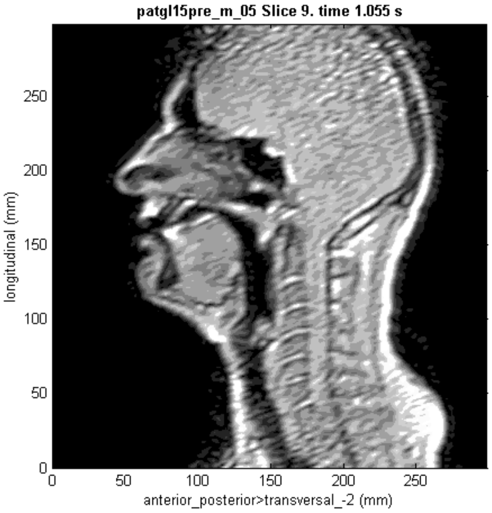

Figure 1: Preoperative articulation of /z/ in the word 'Rosi' by GL 8.

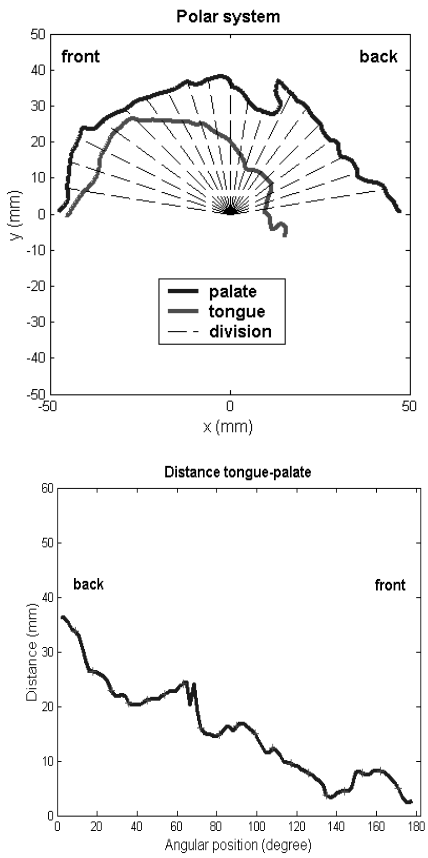

Figure 2a & b: Distance measurement between tongue and the alveolar-palatal-velar-pharyngeal contour. Articulation for /z/ by GL 1, here with a division into 20 segments.

3 RESULTS

3.1 Acoustics

The evaluation of the acoustic outcome involved perceptual judgement by the author and spectral analysis. As shown in Table 1, all subjects had an unimpaired articulation of /s/ prior to surgery, whereas subjects GL 1, GL 5 and GL 7 (group 2) did not achieve an unimpaired acoustic image postoperatively. For these subjects, the frication spectrum of /s/ that is normally located in the spectogram above 3 kHz [Stevens] was lower (GL 2), less intense (GL 7), or not visible at all (GL 5). Values for Centre of Gravity (CoG) were calculated above 1000 Hz, firstly in order to reduce effects of any low frequency environment noise, and secondly to reduce sensitivity to presence or absence of voicing. As some of the recordings had to be made at a sample rate of 11 kHz, the CoG was computed for the filtered spectrum (1–5 kHz) for all subjects.

The preoperative variation in the voicing of /s/ is due to regional and individual allophonic differences in German. Interestingly, while the three subjects of group 2 utter /s/ without voicing preoperatively, they all have at least partial voicing postoperatively. However, the decrease of CoG for this group cannot purely be explained by the postoperative voicing, as the unvoiced realisations of GL 1 and GL 7 have still a significantly lower CoG than the preoperative values (GL 1: 2416 and 2320 Hz vs. 3260 Hz; GL 7: 2398 Hz vs. 3674 Hz). Figure 3 shows that a notable decrease of the CoG values for /s/ can be interpreted as a reliable indicator of acoustic impairment.

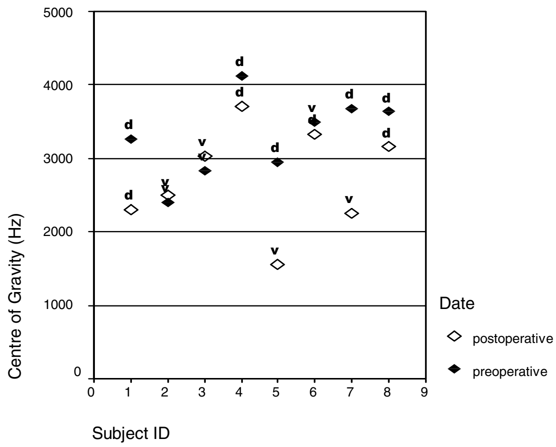

Figure 3: Centre of Gravity for /s/, subjects GL 1–8 (d: devoiced, v: voiced).

3.2 Articulation

In the following, we will present raw data averaged for each patient and will only view the anterior part of the semicircle, beginning from 90°, i. e. from the frontal velar area. In Figure 4, the preoperative distance diagram for all patients is shown. Relying on the unimpaired acoustic impression of the production, these diagrams are regarded as representing the normal articulation of the alveolar fricative /s/. Around 138°, there is a slight increase of the distance diagram, followed by a steep fall from around 153°. In one case, the distance remains around 20 mm until it is finally reduced at 177°. This is due to the unnatural head position of this subject during the preoperative MRT recordings.

		preoperative recordings				postoperative recordings			
	Subject ID	Perception	Voicing	CoG (1–5 kHz)	CoG (above 1 kHz)	Perception	Voicing	CoG (1–5 kHz)	CoG (above 1 kHz)
Group 1	GL 2	unimpaired	+	2398		unimpaired, some affrication	+	2492	3460
	GL 3	unimpaired	+	2831		unimpaired	+	3036	
	GL 4	unimpaired	–	4123	5596	unimpaired	–	3712	4197
	GL 5	unimpaired	–	2948		strongly impaired, weak labial frication	+ (weak)	1564	1700
	GL 6	unimpaired	+	3490	3845	unimpaired	–	3324	4432
	GL 8	unimpaired	–	3635	6104	unimpaired	–	3154	3801
Group 2	GL 1	unimpaired	–	3260		palatalized, weak frication	– (2 of 3)	2301	
	GL 5	unimpaired	–	2948		heavily impaired, weak labial frication	+ (weak)	1564	1700
	GL 7	unimpaired	–	3674	4373	palatalized, weak frication	+ (2 of 3)	2259	2379

Table 1: Perceptual and acoustical evaluation of /s/ (CoG: Centre of Gravity). Group 1: no postoperative impairment, group 2: postoperative impairment.

The rising and falling pattern between 138° and 177° results partly from the form of the palatal arch (s. Figures 1 and 2), partly from the fact that the MRT recordings include only the midsagittal plane. As Ladefoged and Maddieson [3, p. 147] report, the longitudinal centre of the anterior tongue is hollow, whereas the tongue side takes a convex form. This results in an apparent “secondary constriction” in the palatal area, what is in fact caused by the central groove in the tongue.

The postoperative findings are presented in Figure 5. Subjects who show the same rise-fall pattern as in the preoperative diagram are marked by dotted lines. In two postoperative cases, the rise around 135° is not as obvious as before, but there is still a steep fall between 153°–171°. Three curves show a very different pattern. GL 5 has a floating curve from 135° without much movement in any direction. This results coincide with the acoustic-perceptual impression of a nearly completely missing frication and an unclear place of articulation observed for this patient.

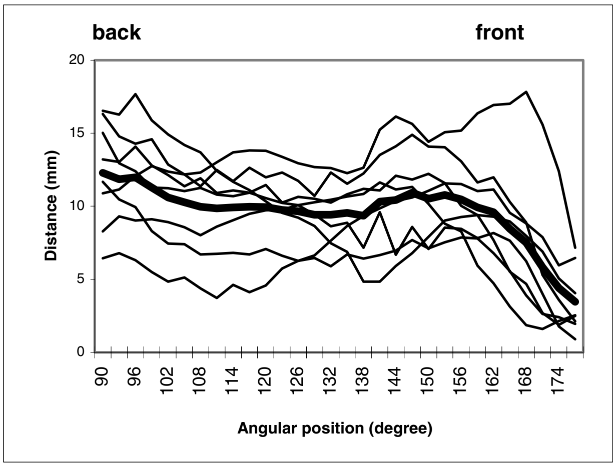

Figure 4: Preoperative tongue-palate distance diagrams for all patients and mean diagram (bold line) for unimpaired /s/ articulation in the pre-velar area.

Two curves decrease steadily from around 123° (velar area) and reach the minimal distance already at 160–166°. These diagrams belong to GL 1 and 7, who produced /s/ somewhat palatalised and with a lower CoG. Both the acoustic and articulatory characteristics point to an /ʃ/-like sound production. Although two other subjects also produce a constriction beginning from 162°, this point is preceded by a steep fall beginning at 153°, as was seen in the preoperative data.

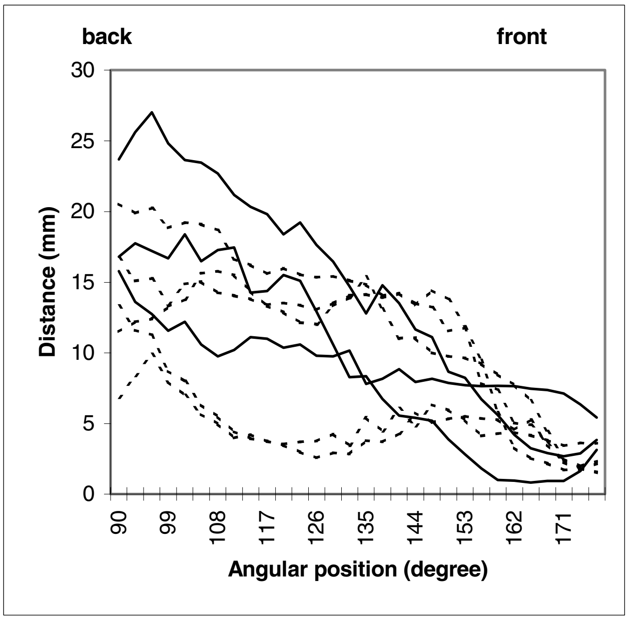

Figure 5: postoperative distance diagrams, dotted line: group 1, continuous line: group 2.

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4 DISCUSSION AND CONCLUSIONS

In this paper, a method for articulatory analysis of MRT recordings has been presented and tested on speech production after glossectomy. The possibility of real time imaging allowed us to study consonants while produced in a near-natural, speech-like setting (as opposed to sustained consonants).

Relying on a perceptual description and CoG measurements, a group of three subjects was found to have an impaired /s/ production postoperatively. The analysis of tongue movements, which included distance measures along the radii of a semicircle that covered the lingual part of the oral cavity, lead us to similar findings. It seems that for the production of /s/, not only a narrow constriction in the dental-alveolar area is needed, but also an exact positioning of the tongue at the alveolar ridge. In other words, the tongue must not only reach the upper alveolar ridge but also keep a sufficient distance from the palatal region. GL 5 was not capable of a closure as his tongue was fixed, even though his intrinsic tongue muscles were not involved in the surgery. In the case of GL 1 and GL 7, tongue tissue loss might have lead to the disability in a proper control of the movements of the tongue tip.

Our findings show that dynamic MRT is a promising tool for articulatory analysis as it gives us detailed information about given segments of the oral cavity as opposed to other imaging techniques.

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