

ACOUSTIC ANALYSIS OF /l/ IN GLOSSECTOMEES

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ABSTRACT

The production of /l/ is examined for pre- and post-operative patients who have undergone surgery in three distinct areas (anterior, posterior or lateral tongue) followed by radiotherapy and reconstruction. Results show F1 and F2 to be raised after surgery in all cases. Normalised measures of tongue height (F1-F0) and extension (F2-F1) revealed no significant change after surgery to the side of the tongue but in the other two categories, results indicated a change normally associated with both raising and fronting of the tongue. The paper compares these results with findings from other studies and considers possible mechanisms for the observed changes.

1. INTRODUCTION

Previous work [1] by the authors has focused on the production of /s/ and /sh/ in pre- and post-operative glossectomee speech. Although, these phonemes can be objectively shown to be affected by surgery, change in dentition also plays a critical role and in a large number of cases speech therapy must wait until new dentures can be fitted. We have therefore moved on to look at another phonemic category which is suitable for immediate remedial treatment. It has been reported by speech and Language Therapists who treat glossectomees that production of laterals is frequently perceived to be abnormal, but the basis for these judgements has not been objectively tested. This study is designed to address two issues.

1. There has been little research involving instrumental or acoustic measurement of lateral production following glossectomy. Objective measurements are needed to compare the changes which take place in lateral production after surgery.
2. There has been little research into the relationship between precise site and extent of surgery and the resulting speech outcome. This makes it difficult to counsel patients about likely speech difficulties they may face as a result of their planned program of treatment.

2. BACKGROUND

There is confusion in the literature about the extent to which production of /l/ is affected by intra-oral cancer surgery. Skelly *et al* [5] state that the liquids /r/ and /l/ are the most deviant sounds. However, La Riviere *et al* [10] state that “as expected bilabial and labiodental sounds were highly intelligible, it was striking to note that many phonemes which traditionally call for tongue-surface occlusion in ‘normal’ production were equally intelligible, notably /t,s,l,n/”.

In Southern Scottish accents, as in many other accents of English, the /l/ phoneme is typically realized as a light /l/ (i.e. a palatalized alveolar lateral approximant) in pre-vocalic positions and as a dark /l/ (i.e. a velarized alveolar lateral approximant) in post-vocalic or word final position. Although loss of such allophonic variation may not affect intelligibility, it may have a significant impact on the acceptability of speech (i.e. the extent to which naïve listeners judge it to be “normal”).

2.1. Production Mechanisms

Production of the /l/ phoneme as an alveolar lateral of any sort requires elevation of the tip/blade of the tongue so as to make contact with the anterior portion of the alveolar ridge. The lateral margins of the tongue are lowered, so as to allow airflow around the sides of the tongue. This complex gesture results from the co-ordinated contraction of several muscles. The posterior genioglossus and the superior longitudinal muscles are thought to be involved in bringing the tongue tip up and forward, while contraction of the transverse and vertical intrinsic muscles of the tongue will pull the sides of the tongue inward and downward from the lateral alveolar ridge. Additional muscle adjustments will be required to produce the normal allophonic variants. Damage to any of these muscles may thus affect the production of lateral consonants.

2.2. Acoustic Characteristics

According to Narayanan *et al* [6] the first formant frequency (F1) for /l/, which typically occurs between 250 - 500 Hz, can be associated with the Helmholtz resonance which occurs between the relatively large back cavity volume and the front oral constriction.

Furthermore, changes in F1 at the release of /l/ (e.g. preceding a vowel) can be expected to be somewhat abrupt as a result of rapid changes in the corresponding area functions resulting from release of the anterior tongue body configuration.

The second formant frequency (F2) can be associated with the half wavelength resonance of the back cavity (for example lengths of 12 - 14 cm would approximately correspond to resonances in the range of 1250 - 1460 Hz). Retracting and raising the tongue body, as in the case of dark /l/, results in an increase in the effective length of the front cavity and hence lowering of the F2 values. Dark /l/ is thus characterized acoustically by relatively low F2 and a higher F1 when compared with light /l/. It is expected that inter-vocalic /l/'s would show formant values somewhat intermediate between those of light and dark /l/'s.

The formant frequencies reported by Narayan *et al* [6] are in broad agreement with Ladefoged [3], who found the formants to be in the neighbourhood of 250-500, 1200-1460 and 2400 Hz. A normative study carried out in conjunction with this study found the mean formant frequencies of laterals produced by Scottish males to be in the region of 460, 990, and 2690 Hz for F1, F2 and F3 respectively [7].

3. METHOD

3.1. Subject Selection

Normative Data. 8 subjects (4 male and 4 female) were chosen, in order to gain information on normal lateral production. The subjects were all from the south east of Scotland and were aged between 19 and 33 years. All of the subjects reported having normal anatomy and no history of speech problems.

Glossectomy Data. Patients were selected from a speech database of over 300 patients from the west of Scotland, presenting with oral cancer. All the chosen subjects had surgery with tissue reconstruction, and in most cases this was followed by radiotherapy. The following selection criteria were applied:

1. Patterns of treatment were clearly defined and surgical mappings were available.
2. Pre- and post-operative acoustic recordings of speech had been made.
3. The original tumour and subsequent surgical intervention were confined to one of three lingual regions. These were:
 - a) floor of mouth, including tongue tip (N = 4)
 - b) Unilateral side of tongue (N = 4)
 - c) posterior third / base of tongue (N = 3)

The subjects were matched, as far as possible, for tumour staging (only T1 and T2 subjects were used, with one exception), accent (all were from the west of Scotland) and approximate tissue mass removed (as estimated from the surgical maps).

3.1. Data Collection

Both normal and glossectomee subjects were recorded reading the same sentence set. This was a subset of a larger speech sample, which was routinely recorded at intervals during treatment of glossectomee patients. These four sentences (see below) were selected because they include the /l/ phoneme in a variety of phonetic contexts (as shown in bold).

1. The price range is **smaller** than any of us expected.
2. They asked if I wanted to come along on the barge trip.
3. John could lend him the **latest** draft of his work.
4. The bulb blew when he switched on the **light**.

Normative Data. Each subject was recorded reading the 4 sentences shown above. The recordings were made directly into a computer in a relatively quiet room. The subjects were initially given time to read the sentences to themselves, then asked to read them one at a time into a dynamic microphone. The speech recordings were digitized at 16 bits per sample at 20 kHz with an effective bandwidth of 10 kHz.

Glossectomy Data. Pre-operative recordings of the 4 sentences were compared with post-operative recordings of the same sentences. The data used for analysis in this study was taken from a large corpus of longitudinal data, which has been collected over a number of years at Canniesburn Hospital in Glasgow. The data selected for this study consists of speech samples taken at the pre-operative stage (at the time of biopsy, about 1 week prior to surgery) and at 13 - 17 weeks post surgery (3 - 7 weeks after the completion of radiation therapy, where given).

The speech samples were recorded directly to computer by a Speech and Language Therapist in a quiet clinic room. The subjects were requested to read aloud the 4 sentences from the computer screen and spoke into a SHURE SM10A close-talking head-mounted microphone. The recordings were digitized at 16 bits per sample at 20 kHz.

The surgeons compiled a surgical map for each patient, which details the site and extent of resection along with details of method of surgical reconstruction [8].

3.3. Data Analysis

Two instances of pre-vocalic laterals ("latest", "light"), two of inter-vocalic laterals ("smaller", "along") and 1 post-vocalic lateral ("bulb") were analyzed for each subject (see the sections shown in bold in the sentence set above).

Procedure. Each lateral was initially measured for duration. The beginning and ends of the laterals were judged initially by visual means (where there was an obvious change in formant frequency) and secondly by auditory means (so that no traces of the surrounding contexts were perceived).

The mid-point of the lateral was calculated and a cursor set at this point. A spectral analysis of the formants at the mid-point of the lateral was displayed and F1, F2, F3 and F4 were noted by means of cursor placement (on the highest point of the formant) using software which automatically gave a frequency reading.

Where the glossectomee productions of the target segment were perceived to deviate from a lateral production, impressions of the sound produced in its place were noted. Where no attempt at a lateral production was made, a phonetic transcription of the context surrounding the lateral was taken.

The fundamental frequency during the target segment was then determined. The duration (in msec) of 10 cycles of the lateral was measured from the waveform and from this measure F0 was calculated. This facilitated normalisation for gender differences in the presentation of the results on a 'Bark' scale.

4. RESULTS

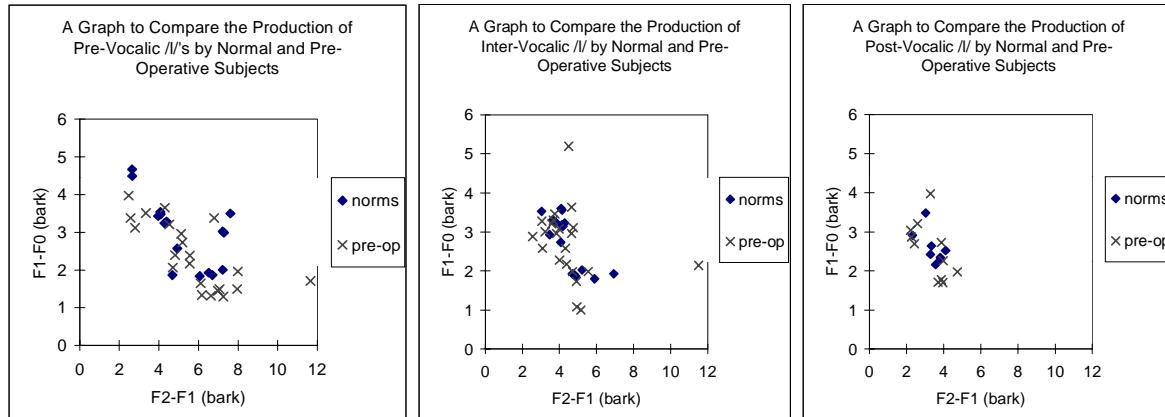


Figure 1: Comparison of the acoustic characteristics of pre-vocalic, inter-vocalic and post-vocalic /l/ by normal subjects and pre-operative glossectomy subjects.

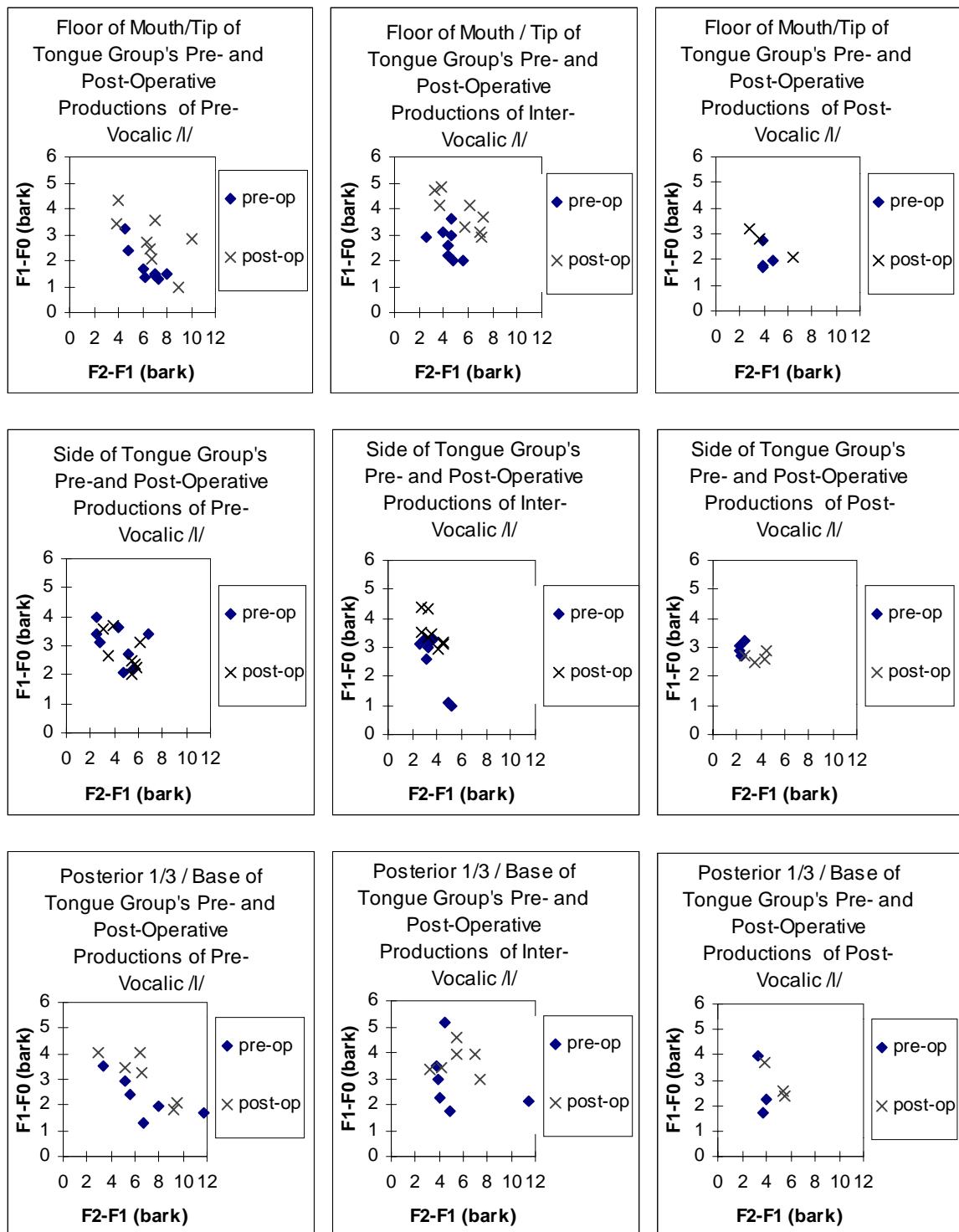


Figure 2: The acoustic characteristics of pre-vocalic, inter-vocalic and post-vocalic /l/ from pre-operative and post-operative speech samples, classified by site of surgery.

Figure 1 compares the acoustic characteristics of pre-vocalic, inter-vocalic and post-vocalic /l/ by normal subjects and pre-operative glossectomy subjects. An ANOVA one way test of variance followed by a post-hoc Scheffe's Test shows significant differences ($P<0.0001$) between pre-vocalic and post-vocalic tokens and between inter-vocalic and post-vocalic tokens, but not between pre-vocalic and inter-vocalic tokens. Figure 2 shows the acoustic characteristics of pre-vocalic, inter-vocalic and post-vocalic /l/ from pre-operative and post-operative speech samples, classified by site of surgery. It is clear that the side of tongue group shows less change post-operatively than the other two groups. A general trend towards increased values of F1 and F2 is apparent in the latter two groups.

5. DISCUSSION

Although the normal and pre-operative results shown in Figure 1 indicate some clear contextual differences, they do not suggest any significant difference between normal and pre-operative production of /l/. The overall findings are consistent with the expectation that pre-vocalic /l/ tokens tend to be produced with palatalization, whilst post-vocalic tokens tend to be produced with velarization. Inter-vocalic tokens appear to be somewhat intermediate, but statistical analysis suggests more similarity to pre-vocalic tokens. Pre-vocalic tokens are less tightly clustered, but this may be explained by the strong co-articulatory effect of the following vowels.

The most striking finding is a general trend for glossectomy subjects (especially those in the floor of mouth/tip of tongue and posterior third/base of tongue groups) to produce an increase in formant frequencies for all instances of /l/ following surgery. In articulatory terms this may be interpreted as a shortening of the resonating cavity. This finding is similar to findings of Alme, Oberg and Engstrand [9] who discovered that there is considerably less differentiation between vowels and a highly reduced vowel space where distances (in Bark) between front and back vowels were substantially shorter for the glossectomee than for a normal speaker.

It is interesting to speculate about the articulatory patterns which may cause such acoustic differences in the post-operative speech samples. One interpretation of raised values of both F1 and F2 is that the articulation of /l/ combines the qualities of a light and dark /l/, i.e. it involves limited tip extension (as in dark /l/) and limited constriction at the back of the tongue (as in light /l/). This may indicate a palatal articulation of some sort, where the blade or front of the tongue forms a constriction in the palatal area. One of the results of surgery may be a loss of the normal partially independent function of the tongue body and tip/blade, which would mean that /l/ could only be articulated using an undifferentiated movement of the whole tongue towards the alveolar/palatal area, without tongue tip extension. Further support for this interpretation of the acoustic results comes from the auditory perceptions of the Speech and Language Therapist, who reported a tendency to palatal production of /l/ in many cases.

Another factor which may have an impact on formant frequencies is the physical impact of the lip and mandibular split which is commonly performed to access the tongue. The acoustic consequences of the combined effects of tooth loss, lip scarring and potential loss of lip mobility are hard to predict, but loss of the normal co-articulatory lip rounding for /l/ in some phonetic contexts could be another cause of raised formant values.

Any anatomical or articulatory explanation for the acoustic results is necessarily tentative at this stage, and more extensive research based on a larger range of /l/ tokens and incorporating more extensive acoustic, perceptual and articulatory analysis is required.

The number of subjects in this study is too small to allow a proper statistical comparison between the post-operative effects of surgery at different sites within the oral cavity, but Figure 2 does suggest that the side of tongue group show a better approximation to the pre-surgery production of laterals. The production of an alveolar lateral involves the tongue tip (for the apical gesture) and base (for the dorsal gesture) but there seems to be considerable tolerance in terms of the configuration of the sides of the tongue [3]. As long as one side of the tongue is sufficiently lowered to allow relatively unimpeded lateral airflow, an intelligible /l/ phoneme can be produced. Subjects in the side of tongue group thus appear to have all the articulatory apparatus that is necessary for the production of the phoneme, whereas the other two groups have not. This finding is in keeping with results from a study by Skelly et al [5] which concluded that "excision of the left or right half of the tongue appeared to require fewer speech adaptations than did excisions including the entire tip".

Figure 2 also suggests that the side of tongue group are able to retain some acoustic distinction between /l/ in pre-, inter- and post-vocalic positions, but the situation is less clear for the other groups. It may be suggested however, that if all the formant frequencies are increased following surgery (as would be the case if the tongue changes to a higher, more forward position), then all instances of /l/ would be perceived as being may become slightly "lighter", or more palatalized. Whilst this would not necessarily on its own affect intelligibility, it could have a considerable impact on the acceptability of speech in an accent where post-vocalic /l/ is normally "dark" or velarized. If, as may be the case in Glasgow, the use of light /l/ in post-vocalic position is perceived to be "effete" or affected, an inability to velarize may be a considerable embarrassment to the patient. It is important to remember that the quality of life following surgery may be affected by relatively subtle changes in speech output, such as co-articulation, which are often overlooked in speech analysis. There is a need for further research into details of speech output of this sort and into their influence on acceptability of speech.

The omission of higher formant data from the results section is due to the finding that a very inconsistent pattern of change was found following surgery, and their role in /l/ identification is thought

to be relatively insignificant. They are probably correlated more with supra-segmental aspects of speech production, such as phonation. At a perceptual level, it seemed that some subjects showed a marked change in voice quality, whilst others were unaffected. Some subjects appeared to have increased harshness and pharyngeal constriction, which may equate to the gutteral quality noted by Skelly et al. [5], whilst some patient's speech was accompanied by extraneous noise which may have been due to excess saliva in the mouth.

6. CONCLUSION

A key conclusion from this study is that glossectomees do appear to have significant difficulty in the production of laterals following surgery, but that where surgery affects only the side of the tongue, lateral production is relatively well preserved. Loss of muscle function following surgery in the floor of mouth/tip of tongue or posterior third/base of tongue areas seems to have a greater impact on lateral production, presumably because of the requirement for precise articulatory control of the tongue tip and dorsum. This finding goes some way to enabling professionals to counsel patients about likely speech problems following surgery.

The general tendency for F1 and F2 values to increase following surgery, which may be associated with a rather undifferentiated tongue gesture towards the alveolar/palatal area, may have an impact on both intelligibility and acceptability of speech. Even where intelligible laterals may be produced, the normal allophonic differentiation of pre- and post-vocalic laterals may be lost. Speech and Language Therapists working with glossectomees should be alert to the potential presence and impact of such changes, and be prepared to counsel patients appropriately.

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8. REFERENCES

1. Wrench, A., Jackson, M.S., Soutar, D.S., Robertson, A.G. & Mackenzie Beck, J. "Evaluation of a system for segmental speech quality assessment: voiceless fricatives", *Proceedings European Conference on Speech Communication and Technology*, Vol. 3, 1879-1882, 1995.
2. Hardcastle, W.J., and Barry, W.J., "Articulatory and perceptual factors in /l/ vocalisations in English." *Journal of International Phonetics Association*, 15, 3-17, 1989.
3. Ladefoged, P., *A Course in Phonetics*., College-Hill Press, Massachussets, 1993
4. Logemann, J., Pauloski, B., Rademaker, A. W., McConnel, F. M., Heiser, M. A., Cardinale, S., Shedd, D., Stein, D., Beery, Q., Johnson, J. and Baker, T., "Speech and swallow function after tonsil / base of tongue resection with primary closure.", *Journal of Speech and Hearing Research* 36, 918-926, 1993.
5. Skelly, M., Spector, D. , Donaldson, R., Brodeur, A. & Paletta, F., "Compensatory physiologic phonetics for the glossectomee.", *Journal of Speech and Hearing Disorders*, 36, 101-111, 1971.
6. Narayanan, S.S., Alwan, A.A. and Haker, K., "Toward articulatory - acoustic models for liquid approximants based on MRI and EPG data.", *Journal of the Acoustical Society of America*, 101, 1064-1077, 1997
7. J.Lunn, *A Study of the Production of /l/ by Partially Glossectomised Speakers.*, Honours Dissertation for BSc(Hons) in Speech Pathology and Therapy, Dept. Speech and Language Sciences, Queen Margaret College, Edinburgh 1998.
8. Mackenzie Beck, J., Wrench, A., Jackson, M., Soutar, D., Roberston, A.G., and Laver, J., "Surgical Mapping and Phonetic Analysis in Intra-oral Cancer", *Clinical Phonetics and Linguistics*, Ch. 51, 485-497, 1997.
9. Alme, A., Oberg, E. and Engstrand, O., "An acoustic - perceptual study of Swedish vowels produced by a subtotally glossectomised speaker.", *Phonetic Experimental Research*, Institute of Linguistics, University of Stockholm (PERILUS), 10, 157-184, 1989.
10. La Riviere, C., Seilo, M.T. and Dimmick, K.C., "Report on the speech intelligibility of a glossectomee: perceptual and acoustic observations.", *Folia Phoniatrica*, 27, 201-214, 1975