THE RELATIONSHIP BETWEEN INTENSITY AND SUBGLOTTAL PRESSURE WITH CONTROLLED PITCH

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ABSTRACT

This paper present a study of the relationship between subglottal pressure (SGP) and intensity of the speech signal in the case of sustained French oral vowels with controlled pitch. The corpus is based on a male and a female subjects, the SGP is measured directly by tracheal puncture. The results show that the relationship between intensity and subglottal pressure varies when one considers the vowel or the pitch parameter. This experiment is useful in the framework of speech production model design. These preliminary results emphasize the need to investigate thoroughly the relationship between all the parameters involved and to do so on abundant and accurate experimental data.

1. INTRODUCTION

This study concerns the relationship between subglottal pressure (SGP) and intensity of the speech signal in the case of sustained French oral vowels, [a], [e], [i], [o] and [u]. The distinctive feature of this study is the direct measurement of SGP by means of tracheal puncture. Intensity control is a complex problem. Indeed, according to Titze, [8], intensity can vary by means of three different mechanisms: (i) lung pressure adjustment, (ii) larynx adjustment and (iii) vocal tract adjustment. Many authors investigated points (i) and (ii), among others Ladefoged and McKinney [3], Isshiki [2], Strik and Boves [6], by direct measurement of SGP, Holmberg et al. [1], McAllister and Sundberg [5], by indirect measurement of SGP.

In a previous study we carried on continuous speech, Demolin and Lecuit [4], it appeared that the relationship between SGP and intensity could not be approached without taking into account the value of the pitch. In this study we attempt to investigate the contribution of subglottal pressure variations to changes in intensity while controlling larynx adjustment (through the specification of a definite pitch) and vocal tract adjustment (by considering each vowel separately).

Subglottal pressure measurements can be achieved directly or indirectly. There are different methods for indirect measurement. Derivation of subglottal pressure from oesophageal pressure measurements, this necessitates a careful calibration procedure which has to be performed often during the experiment. Interpolation from the measure of intra-oral pressure, this method being limited to vowel intervals between stop consonants. Direct measurements can be obtained by using a catheter with pressure transducers or by tracheal puncture. We used tracheal puncture because it is the only method which provides directly the subglottal pressure without interfering with speech production.

2. METHOD

The subjects, a male and a female, are two native speakers of French with a normal larynx and no voice problems. A simultaneous recording was made of intraoral and subglottal pressures as well as oral and nasal airflows. Recordings were made at the O.R.L. Unit of the Hopital Erasme, Free University of Brussels. A small flexible plastic tube (ID 2mm) was inserted through the nasal cavity to the oropharynx, for the measurement of intraoral pressure. A needle (ID 2mm) was inserted in the trachea for the measurement of subglottal pressure. The needle was placed after local anesthesia with 2% Xylocaine, including the subglottal mucosa. The tip of the needle was inserted, right under the cricoid cartilage. A plastic tube (ID 2mm) linked to a pressure transducer was connected to the needle. Oral airflow was measured with a flexible silicone rubber mouthpiece. Nasal airflow was measured through an olive inserted in one nostril. The olive was connected to a 0.5 cm platic tube. The tubes and rubber mouthpiece were connected to a Physiologia workstation, Teston [7], consisting in a PC computer and an acquisition system equipped with various transducers and the signal editing and processing software Phonedit. The intensity is computed by means of the root mean square method applied to the speech signal. The pitch is computed by the COMB method applied to the speech signal.

The subjects task was to pronounce sustained vowels [a], [e], [i], [o], [u], while hearing a tone through hearphones connected to a synthesizer, the sound level of the tone defining the intensity level. Three tones were selected, a-c-e for the male subject, and c-f-a for the female subject. For each tone three different sound levels were selected. This method allowed to gather data within a narrow pitch band and covering a wide range of intensities. This allowed us to consider the relationship between intensity and SGP at almost constant pitch. These experimental conditions gave us the opportunity to freeze the effects of larynx adjustment. Indeed, any significant variation of larynx condition would affect the value of the pitch, or we do our analysis where the pitch is almost constant, thus avoiding the effects of variation, and to partially freeze the effects of vocal tract adjustment by considering each vowel separately. Nevertheless, we cannot exclude small vocal tract adustment around the mean position for the vowel considered.

	Female					Male				
	[a]	[e]	[i]	[o]	[u]	[a]	[e]	[i]	[o]	[u]
level 1	12.55	15.75	9.96	13.12	10.75	12.68	7.97	8.06	7.05	6.86
level 2	14.55	17.60	15.85	13.69	10.10	11.12	10.30	6.45	9.15	13.78
level 3	15.68	11.49	15.79	15.93	25.20	10.98	9.12	8.07	9.70	12.43
all	12.62	12.81	13.34	13.00	11.31	10.24	8.33	6.11	8.83	9.18

Table2: Increment of intensity in dB corresponding to a doubling of subglottal pressure for each vowel, at each pitch level, and for each subject. The line labeled "all" corresponds to the grouping of all the data points of the three levels for each vowel.

3. RESULTS

Figure 1 and Figure 2. show the data points on 3-D plots for the female subject (left) and the male subject (right). Each plot corresponds to a vowel. The axis of the plots are the pitch in Hertz, the subglottal pressure in hPa, and the intensity in dB. For each subject and for each vowel, the points are gathered in three sets corresponding to the three different pitch levels, a-c-e, for the male subject, and c-f-a for the female subject. Most of the intensities lay in the range from 50dB to 75dB.

Before any type of analysis it is important to note a striking difference between the two subjects, where the male subjects succeeds in covering the whole range of intensities, the female subject stays in the upper range, such as for [i] and [u] at pitch level 3. This is due to the fact that the female pitch level 3 was at the limit of the subject comfortable range. The analysis of the data was carried on with the following procedure. Since for each pitch level the data points are spread around a central value, for each pitch level, we extracted the data points corresponding to a slice of width equal to 5 Hz or less centered on that value. A linear curve fit was applied to find the relationship between the intensity and the logarithm of the subglottal pressure. The correlation coefficients for each subject and each vowel at each level are presented in Table 1.

Female	[a]	[e]	[i]	[o]	[u]
level 1	0.97	0.96	0.90	0.97	0.92
level 2	0.97	0.78	0.97	0.96	0.87
level 3	0.97	0.97	0.70	0.91	0.94
all	0.93	0.92	0.93	0.94	0.94
Male	[a]	[e]	[i]	[o]	[u]
level 1	0.88	0.91	0.95	0.89	0.94
level 2	0.90	0.94	0.80	0.95	0.98
level 3	0.90	0.83	0.90	0.92	0.91
all	0.84	0.85	0.74	0.90	0.87

Table1: Correlation coefficient of the linear curve fit between the intensity and the logarithm of the SGP, for each vowel, at each pitch level and for each subject. The line labeled "all" corresponds to the grouping of all the data points of the three levels for each vowel.

The value of these coefficients is high enough to prove the linear relationship between the intensity and the logarithm of the SGP.

The equations obtained with the linear fit provided the increment in dB corresponding to a doubling of subglottal pressure. Table 2 regroups the values obtained. In general, the increment of intensity is higher for the female subject than the increment for the male subject. At this point there is no proof that this is the manifestation of a gender difference, it could be related to subject difference. The high value of the increment for the [u] level 3 for the female subject is puzzling. As mentionned earlier the data concerned is mostly in the high intensity range. But this was also the case for the [i] level 3, where we do not observe the same effect.

If one considers one vowel, there are significant differences between the three levels, both for the male and the female subject. If all the data points for the three levels and for one vowel are merged, the differences between the vowels are less important.

4. CONCLUSION

This experiment allowed us to consider the relationship between intensity and SGP at constant pitch. It showed that this relationship vary a lot across vowels and across the two subjects. It would be necessary to increase the number of subjects so as to detect gender differences. Another interesting point would be to compare the data obtained on continuous speech with the data on sustained vowels, and most importantly, to consider the data in a three dimensionnal space containing pitch, SGP and intensity. This will be done in future experiments.

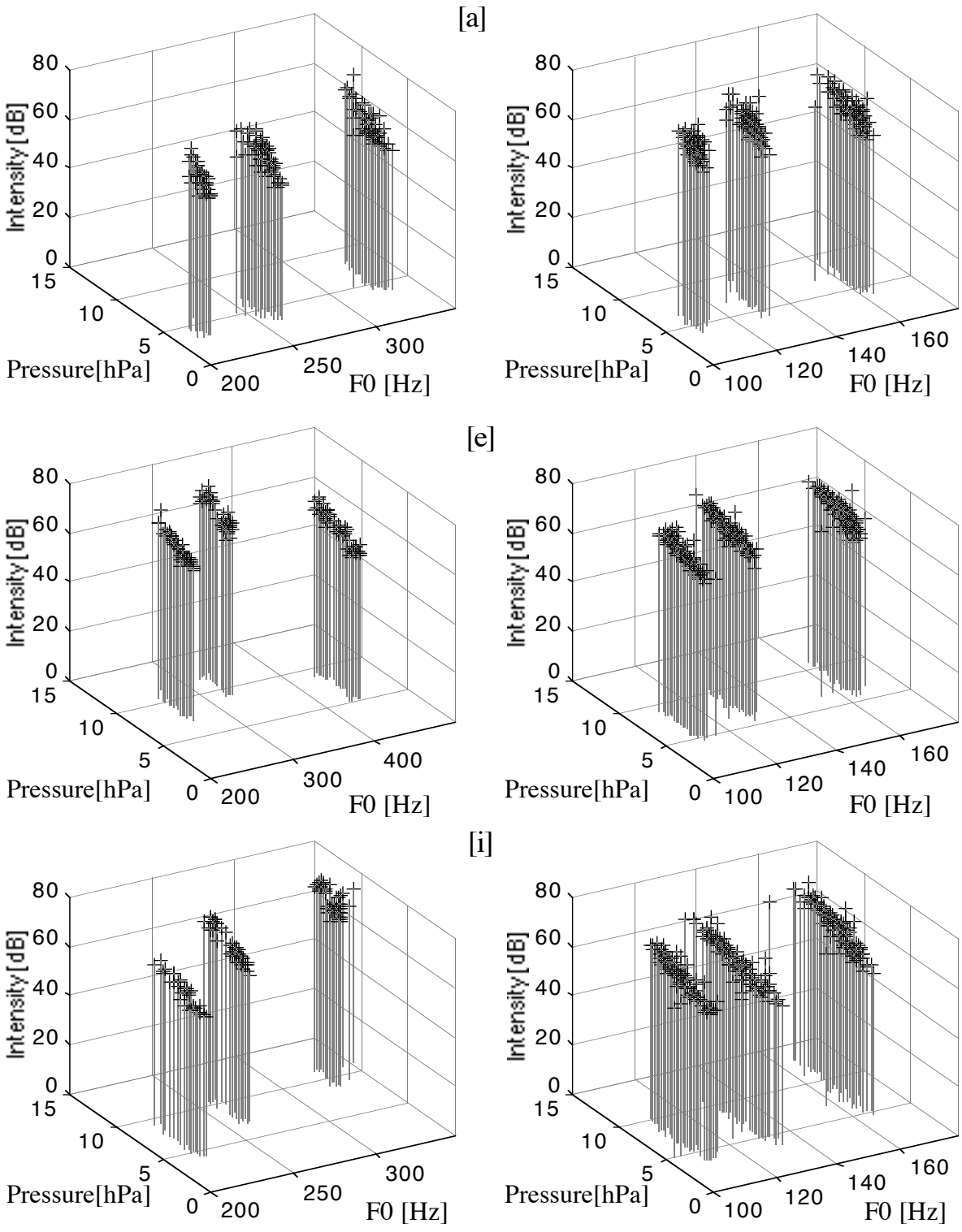

Figure 1: 3-D plot of the data points for the vowels [a], [e] and [i], for the female subject (left) and the male subject (right). The axis of the plots are the pitch in Hertz, the subglottal pressure in hPa, and the intensity in dB. For each subject and for each vowel, the points are gathered in three sets corresponding to the three different pitch levels, a-c-e, for the male subject, and c-f-a for the female subject. most of the intensities lay in the range from 50dB to 75dB.

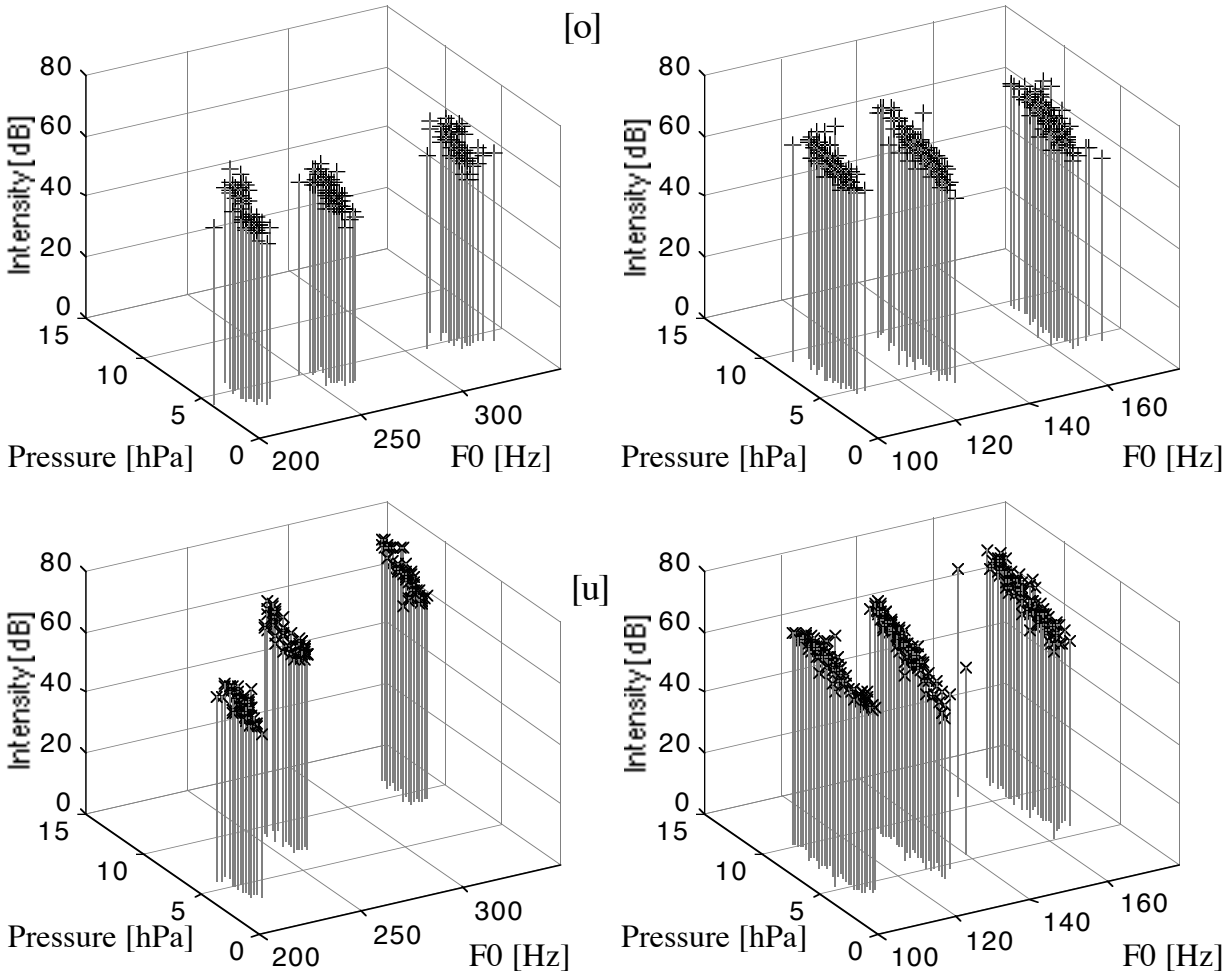

Figure 2: 3-D plot of the data points for the vowels [o], and [u], for the female subject (left) and the male subject (right). The axis of the plots are the pitch in Hertz, the subglottal pressure in hPa, and the intensity in dB. For each subject and for each vowel, the points are gathered in three sets corresponding to the three different pitch levels, a-c-e, for the male subject, and c-f-a for the female subject. most of the intensities lay in the range from 50dB to 75dB.

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