INTRINSIC PITCH OF VOWELS : AN EXPERIMENTAL STUDY ON ITALIAN

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ABSTRACT

Many researches have studied the Intrinsic Pitch of the vowels in different languages and from different points of view. There is a general agreement on the existence of this phenomenon and various hypotheses have been formulated in order to explain the mechanism controlling the I. P. The aim of this experimental study is, on one hand, to verify whether the Intrinsic Pitch of vowels does exist in Italian; on the other hand, on the basis of the spectrographic data and Fo tracings obtained from normal and oesophageal speech and from singing, to try to give an account for the phenomenon. The relationship between Fo, opening degree and place of articulation is discussed.

INTRODUCTION

For more than fifty years there has been a general agreement among phoneticians about the existence of an Intrinsic Pitch of vowels. Many experimental studies have dealt with the phenomenon from different points of view and all of them have demonstrated that in many languages, as for instance English /1/, Danish /2/ and German /3/, high vowels tend to have a higher pitch than low vowels, other things being equal.
Even if there isn't disagreement on the existence of the I.P., problems start when we try to explain why this phenomenon happens.
In fact different hypotheses have been formulated to give an account for the I. P. beginning from the so called "dynamo-genetic" theory proposed by Taylor /1/.
According to Taylor the higher muscular tension of the tongue required to realize a high vowel, radiates to muscles of the larynx causing a higher tension of the vocal folds that, therefore, vibrate at a higher fundamental frequency.
However, Taylor's theory is no longer accepted since "electrical insulation in muscles and nerves is good enough to prevent serial contraction of adjacent muscles by an osmotic spread of excitability" /4/.
Subsequent theories can be grouped into three main categories: "acoustic coupling", "aerodynamic" and "tongue pull" theories.
The first one, based on Flanagan's model /5/ and elaborated by Atkinson /4/, takes into consideration the formant pattern of the vowel: a low F1 attracts Fo giving rise to a higher pitch. This explains why /i/ and /u/, having a very low F1, have a fundamental frequency higher than that of /a/.
The second theory, formulated by Mohr /6/, relates the width of the pharynx with the glottal pressure. According to him, as the low vowels are characterized by a smaller pharyngeal cavity, the supraglottal pressure increases and consequently the transglottal pressure gradient decreases leading to a lower fundamental frequency.
According to the "tongue pull" theory, high vowels have a higher pitch because when the tongue rises it pulls the larynx up via the hyoid bone causing an extra tension of the vocal folds, either vertically (Ladefoged's view /7/) or horizontally (Newelkowsky's view /8/).
All these theories, which were based on experimental data, have subsequently been confuted on the basis of further data. Therefore, as none of these hypotheses can explain the phenomenon of the I.P., Silverman /9/ is led to conclude that "the various physiological, acoustical and mechanical mechanisms that have been proposed to account for the IFO [I.P.] are not mutually exclusive, and probably are all operative during speech production" (p.13).
However, it seems to us that such an explanation is quite obvious because speech acts are complex and it always happens that a single articulation is characterized by many factors. The point is that, as regards I.P., it is necessary to distinguish between cause and effect, that is between what we really command to the articulators to do in realizing a high or a low vowel and what is merely a consequence of it.
The aim of this experimental study is, on one hand, to verify whether the I.P. of vowels does exist in Italian; on the other hand, on the basis of acoustic data obtained from normal and oesophageal speech and from singing, to try to give an account for the phenomenon.

PROCEDURE

A list of about 200 meaningful Italian words has been prepared. Vowels /i/ /e/ /ɛ/ /a/ /ɔ/ /o/ /u/ occur in initial and medial stressed position. The list includes words differing in the vowel only. The list has been read three times in a randomized order in an anechoic room by a native Italian speaker. Of each word a wide band spectrogram has been made using a Voice Identification Sound Spectrograph by Electronic ApS in order to have the formant pattern of the vowel. In order to calculate the fundamental frequency, a narrow band spectrogram at a linear expanded scale and the Fo tracing given by an FFM by F-J have been made. As in almost all cases the vowel had a rising-falling Fo movement with a maximum occurring at about its midpoint, we have measured the Fo value at that point.

RESULTS

Fig. 1 shows the average Fo values of the three utterances in normal speech.
As we can see, /a/ has always the lowest pitch, whereas the other vowels undergo an increase in pitch going from 4 to 20 Hz. Furthermore, we have to notice that /i/ and /u/ show an Fo increase higher than that of /e/ /ɛ/ /o/ /ɔ/, the former being in a range of 15 - 20 Hz and the latter of 4 - 10 Hz.
As we can see the data confirm the existence of an intrinsic pitch of vowels also in Italian.
In order to verify which of the different theories can explain the phenomenon of I.P., it seems useful to make further experiments.
If the I.P. is due to the raising of the tongue that causes an extra tension of the vocal folds, as suggested by the tongue pull theory, the phenomenon should be nullified in oesophageal speech. In fact, with the total laryngectomy surgery the whole larynx with the hyoid bone and all associated muscles and ligaments are removed. The voicing source, so-called neoglottis, is given by the surgically altered pharyngeal oesophageal sphincter. Therefore, as there aren't any direct interconnections between the tongue and the neo-glottis, according to the tongue pull theory, in oesophageal speech differences in I.P. between high and low vowels would not be expected.
In order to verify the tongue pull theory the same speech material has been uttered by a laryngectomized speaker. However we have restricted the list of words to /a/ /i/ and /u/ vowels because, as we have said above, the difference in pitch is most remarkable for these vowels.
The data show that the mean Fo of both /i/ (84 Hz) and /u/ (91 Hz) of oesophageal speech is higher than that of /a/ (75 Hz).
As we can see, the I.P. persists also in oesophageal speech and consequently we can exclude both the horizontal and vertical versions of the tongue pull theory.
These conclusions agree with the results obtained on oesophageal speech by Gandour and Weinberg /10/. They are in favour of

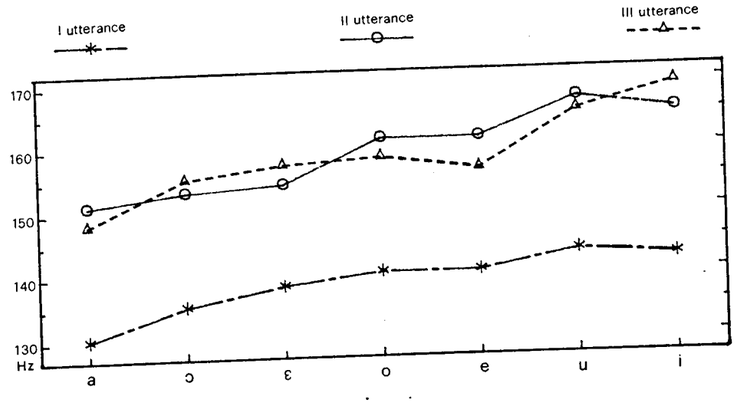

FIG. 1. Intrinsic pitch of Italian vowels.

the aerodynamic theory. In fact, according to them, the "impedance of the vocal tract is higher during the production of high versus low vowels. A natural response on the part of the speaker to this situation would be to increase respiratory drive or speech/vocal effort" (p.353),and in consequence of it high vowels would have a higher pitch.
However, it seems to us that the aerodynamic process is more complex and, therefore, it has to be reexamined in detail.
We know that glottal vibrations are determined by the difference between subglottal and supraglottal pressure : the lower supraglottal pressure is, the higher is the fundamental frequency. On the other hand as the supraglottal pressure depends on the opening degree of the constriction occurring along the vocal tract, there must be a close relationship between Fo and opening degree too.
In order to clarify this relationship, we have made an experiment on singing. We have analysed the Fo trend in monotone VCV sequences, where V was /a/ /i/ or /u/ and C was in turn a stop, a dental fricative, a lateral, a nasal or a trill.
Fig. 2 shows the average Fo values of the consonants.
As we can see, the data clearly demonstrate the existence of a direct relationship between Fo and opening degree of consonants. In fact we have the maximum pitch fall in stops and fricatives because of the high flow resistance at the articulatory constriction and it is nullified in nasals and laterals because of the free outscape of air through either the nasal cavities or the sides of the tongue. The clearest example of the existence of such a relationship is given by the Fo trend of the trill. In fact, in this case, Fo increases and decreases alternately of about 10 Hz and 40 Hz simultaneously with the dental openings and closings (fig. 3).

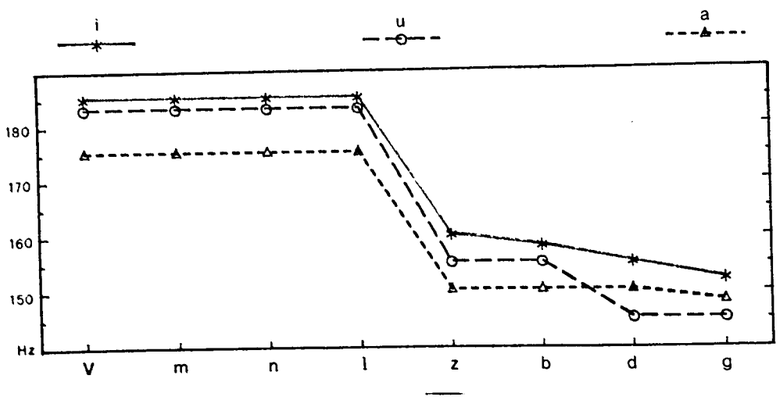

FIG. 2. Average values of Fo in singing.

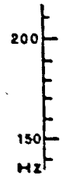

FIG. 3. Fo tracing of /arra/ in singing.

In the light of these considerations, we must conclude that the more open the consonant is, the higher is its pitch.
However, as regards the vowels, the data show that also in singing /i/ and /u/ have an increase in pitch of about 10 Hz respect to /a/.
At first sight the data seem to be contradictory because as regards the consonants the more narrow the constriction is the lower is Fo, whereas as regards the vowels it seems to happen the contrary, the more narrow the constriction is, the higher is Fo. The point is that when we classify the vowels as "high" and "low", or "close" and "open", we refer only to the oral cavity; conversely if we take the whole vocal tract into consideration, we realize how measleading is this kind of definition. In fact, as we can see in fig. 4, X-ray tracings of the Italian vowels /a/ /i/ and /u/ show that all these vowels are characterized by a same impedance occurring at different places along the vocal tract: at the pharyngeal cavity for /a/, at the soft palate for /u/ and at the hard palate for /i/.
From this point of view we must consider /a/ /i/ and /u/ as "close" vowels and consequently their different fundamental frequencies must be related to the point along the vocal tract where the maximum impedance occurs and not to the oral opening degree. From this point of view, we can easily understand why /a/ has an intrinsic pitch lower than that of /i/ and /u/. In fact a constriction in the pharyngeal cavity causes a sudden increase of the supraglottal pressure that leads

FIG. 4. X-ray tracings of /i/ /a/ /u/.

to a drop of the transglottal pressure and consequently to a lowering of the fundamental frequency.
In light of this, we can give also an account for the acoustic coupling theory. According to this theory, a low F1 attracts Fo giving rise to a higher pitch. Now, we know that from an articulatory point of view a low F1 corresponds to a constriction occurring in the front half of the vocal tract and, therefore, to a wide pharyngeal cavity. So, once more it is the pharyngeal width to determine the higher pitch for /i/ and /u/, that is just the opposite of what happens for /a/.

CONCLUSIONS

The data gathered in this experimental research confirm that the phenomenon of the intrinsic pitch exists in Italian in normal speech as well as in singing and in oesophageal speech. Furthermore, the phenomenon must be explained exclusively from an aerodynamic point of view, considering on one hand the configuration of the whole vocal tract during the production of the vowels and, on the other hand the pressure trend at glottal and supraglottal level.
As regards the tongue pull theory, even though many experimental studies have prooved that there is a mechanical connection between the tongue and the larynx, our experiment on oesophageal speech clearly shows that it has nothing to do with the phenomenon of I.P.
As regards the acoustic coupling theory, suffice it to say that, as we have said above, the rising or lowering of a formant must always be seen as the effect of an articulatory gesture, even though we must admit that such an explanation is less evocative than the hypothesis according to which two frequencies attract each other because of their closeness.

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