

Whistled speech: a natural phonetic description of languages adapted to human perception and to the acoustical environment.

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Abstract

The scientific study of the whistled speech of several languages has already provided an alternative point of view on many aspects of language. After a general overview on the phenomenon, this paper develops a comparative analysis of several whistled forms of non tonal languages which are still in use. Meanwhile, the vocalic and consonantal reductions observed in this type of whistled speech are detailed thanks to a typological approach. It sheds a new light on the main aspects of the encoding strategy thanks to results of acoustic propagation and perceptive tests. Actually, whistled languages naturally take advantage of a narrow band of frequencies to focus on key elements of the phonology. They carry an essential part of the linguistic information that the listeners are able to recognize if they have overcome a long period of learning. Therefore, they can be seen as phonetic descriptions of local languages. Such properties are enabled by whistles which are remarkably adapted to the perceptive capacities of human beings and to the natural acoustic environment.

1. Introduction

Several populations all over the world have developed a whistled form of their local language in response to the necessity to communicate in conditions of relative isolation (distance, noise, night) during vital social activities of their everyday life (hunting or fishing, agriculture, nomadic or semi nomadic shepherding, seduction, rituals and games, warning). These modes of communication have been called whistled languages because they use the acoustic properties of whistles to convey messages in a local language. The people who use them have a low density of population and live in topographic environments favoring the isolation in terms of time of communication (mountains, forests). The information that the inhabitants of these areas need to exchange in these conditions is sufficiently complicated and diverse to require the use of a system keeping the syntax, the vocabulary and the grammar of the local spoken language. As a consequence, the whistled speech is a complementary adaptation of a given spoken language: it enables the dialogue between individuals like a local and directional natural cellular phone. According to the whistlers, the articulated whistling is one of the multiple manifestations of their language, with whispered, shouted or sung speech. The phenomenon of whistled languages is international but the unintelligibility of the articulated whistles for untrained persons has encouraged the relative ignorance about them. The present study is based on new data collected in 7 different cultural communities during a 14 months fieldwork and on old data shared by several linguists and acousticians. Three of the whistled languages we documented

are taken as a reference line to a comparative discussion: Greek, Turkish, and Silbo (Spanish of the island of la Gomera).

1.1. Description of the variety of encoding strategies

Some linguists, anthropologists and acousticians have remarked that the encoding strategy of articulated whistles was correlated to some features of a local language. Two main ways of whistling have been described until now: (i) in the case of tone languages like the Mazateco of Mexico [1]: the pitch contours characterize strongly the meaning of the phonemes, therefore the whistles are mainly concentrated on supra-segmental features and reproduce the fundamental frequency of the spoken speech. (ii) In parallel, in the case of non tonal languages like Spanish or Turkish, the whistles reproduce mainly the segmental features of the spoken speech (fig.1): the vowels are emitted at different pitch levels (for example, the series [i e a o u] is decreasing in pitch in Silbo) and the consonants are pronounced by modulating the frequency or the amplitude of the vowels.

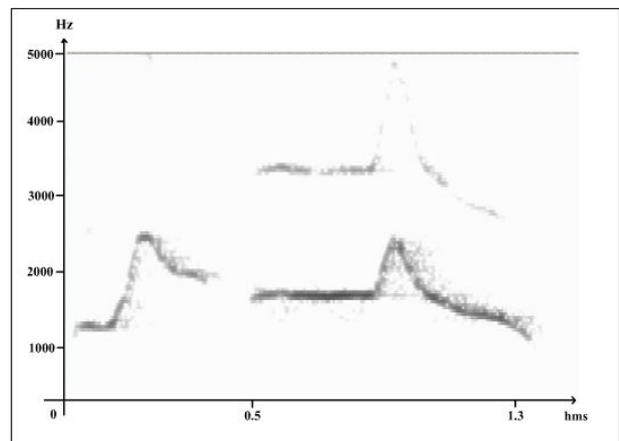


Figure 1: whistled word "kalimera": 'hello' in Greek

Detailed reference studies have been made in the past on Silbo Gomero [2],[3] and Turkish of Kusköy [4],[5]. They have shown that, when represented on spectrograms, the transitions of occlusive consonants have a resemblance to the second formant of the spoken equivalent. Their loci of articulation are reported to levels of frequencies adapted to whistles. Moreover they have underlined that liquid [l,r,j] and fricative consonants form respectively classes of concave or convex continue frequency shapes. For nasals, a distinction is made between [m] and the palatalized whistled [n] (the nasal cavity remaining closed). According to some of these studies

the amplitude modulations mark the transitions between the vowels: the syllabification is not always made of clear cut: voicing is sometimes reproduced by lowered continuations of the sounds during the transition. As far as the Greek whistled language is concerned, a general introduction and an acoustical study of the vowels give a first insight to the structure, but the consonants are not described in details [6], [7]. Whistled Chepang of Nepal has also been studied, it confirmed that the spoken language was not tonal [8]. In this case, the articulation of consonant transitions and vowel nuclei have been analyzed with an insight inspired by tone language. Yet, this Tibeto-Burman language shows a similar general behavior as Turkish, Silbo or Greek. Finally, two other non tonal languages have been studied in the past: Béarnais in the French Pyrenees and Tepehua of the Sierra Madre Oriental in Mexico. The results produced about these two languages couldn't be verified as both of these whistled forms of languages were found dead on the field during our scientific expedition.

These studies are complementary, they underline that whistled languages are particularly relevant to the sharp description of languages and to the study of the processes implicated in the intelligibility of speech. They show that the ability to articulate whistles uses selective acoustic cues to naturally extract the prosodic properties of linguistic systems.

1.2. Didactic value of the prosodic articulated whistles

Historical concerns in the linguistic studies resulted in a deeper understanding of non tonal whistles. However, the whistled forms of tone languages, which are very frequently used by linguists as a tool to help the elaboration of phonologic models (even if the language practice doesn't use whistled talk), have contributed to prove that the prosodic features were not independent of the other levels defined by the modern phonology [9],[10]. Non tonal whistled languages underline this link more directly because they rely on an "internal prosody" of vowels and consonants. They also revealed that vocalic and consonantal reduction take place in the acoustic whistled signal. To further elucidate the implications of articulated whistles, this study will focus on these reductions. They enable a comparative analysis taking into account both the typology of languages and the perceptive performances of human beings.

2. Material and method

The data discussed in this paper was recorded during a scientific expedition aimed at studying the whistled languages in a collaborative way with the local cultural leaders, the whistlers and the linguists working on the concerned languages. A methodology adapted to the practice of whistling has been developed by the author. All the recordings are based on natural speech. For each language, from 2 up to 8 whistlers collaborated with us. One half of the material is the result of spontaneous dialogues initiated thanks to the simulation of a natural context of use. The acoustic analysis was performed in a blind approach of the shapes (without knowing their linguistics) and of the statistical repartition of frequencies, secondly a phonetic treatment organized the former results, finally a typological comparison was performed using the tool of phonetics and phonology. It relies on data of male adult whistlers (women and children have a higher pitch).

3. Analysis of phonetic reductions

The acoustical analysis we conducted on the main whistled band of frequencies of the vowels and consonants of whistled Greek, Spanish of La Gomera and Turkish confirms that some phonetic reductions characterize the whistled signal when compared to the spoken signal.

3.1. Results for Vowels

The whistled systems of vowels follow the same general organization in all the non tonal languages. The highest pitch is always attributed to [i] and the lowest to [u] and [o] which are not easily distinguished. This first reduction is due to the impossibility to produce a whistle below 1kHz. Moreover, for a given distance of communication and individual whistler, the vowels do not have a fixed pitch: they occupy a frequency band of 150 Hz in average. The stressed vowels are very often whistled higher in pitch within each band. As these bands sometimes overlap, they are used by the whistler to adapt to the phonetic contexts of the words: when there is a potential ambiguity, they distinguish clearly neighboring vowels by making the effort to place the vowels at opposed extremes of their own band (cf. examples below). Therefore, the overlapping, in whistles, of two bands of frequencies corresponding to two different vowels doesn't mean that they are always interpreted in the same phonologic way.

3.1.1. Greek

The five vowels in the modern Greek (i, y, ε, a, o) are whistled in the village of Antia in five bands of frequencies among which four might overlap with the band of another vowel. This creates statistically three major bands of frequencies: [i, (y, ε), (a, o)]. The accentuation in modern Greek has an intermediary degree of liberty, we have noticed that the whistlers reproduce the spoken accentuation nearly systematically (80%), with variations between the whistlers.

3.1.2. Turkish

The 8 vowels of Turkish (i, y, ı, e, œ, a, o, u) are whistled in 8 bands of frequencies decreasing in pitch that might be grouped in three reductive bands as follows: [(i, y, ı), (e, œ), (a, o, u)]. Our results differ from the ones published by Leroy [5], only in the case of /u/, but we have the same results as Moles [11]. The influence of vowel harmony rules of Turkish help the whistlers to get rid of some ambiguities. However the ones which are not solved by the harmony system are sometimes overcome by the use of extremes of the bands of frequencies. For example for the common word "kolay" (/kolaj/), /o/ and /a/ are effectively distinguished because /a/ bears a higher pitch despite the fact that these two vowels are usually whistled in the same way.

3.1.3. Silbo

Silbo vocalic system is based on the Spanish spoken dialect of La Gomera island for which /o/ and /a/ are very near. The spoken vowels (i, e, a, o, u) are therefore whistled in five bands which can be grouped in three groups [i, e, (a, o, u)]. Similarly to Greek and Turkish, the three bands of frequencies of Silbo are around 2600 Hz for [i], 2100 Hz for [e] and 1600 Hz for [(a, o, u)]. Some of the best whistlers disagree with this classification. Their whistled description enables them to distinguish the five vowels. They can even differentiate /u/

from /o/ because its spectral envelope carries much more energy. This difference of point of view might be due to the survival of different whistled dialects in the island [3] and is always relative to the level of practice.

The accentuation in Silbo uses the set of possibilities of each band of frequencies: for example, in the word “abajo”, the second /a/ is whistled higher than the first and the /o/ is whistled lower than the two former vowels.

3.2. Results for consonants

3.2.1. First description of Greek whistled consonants

The main categories of whistled consonants described in Silbo and Turkish are still available in Greek. The occlusive stop consonants can be grouped in three types of loci movements: [P, T, K] equivalent to those of the formant 2 of spoken speech. /s/ and /dz/ behave as /t/ but with higher loci. The voicing is reproduced by a slight continuation in the amplitude. The shape of liquid and fricative continuants are displayed on Fig.2. together with [m]. The nasal [n] is usually whistled like [l] with sometimes a cut at the edge of the shape.

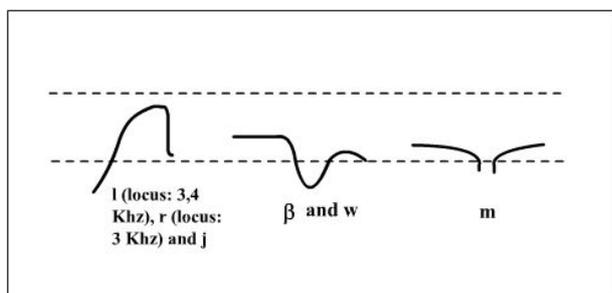


Figure 2: whistled continuants and [m]

From our study of Greek, we also concluded that from a cluster of consonants, only the most projecting consonant will remain in whistles.

3.3. Constraints of production

The whistling techniques vary in function of the distance of communication : intromission of a finger in the mouth (long distance), retro flexion of the tongue (middle distance) or bilabial (short distance).

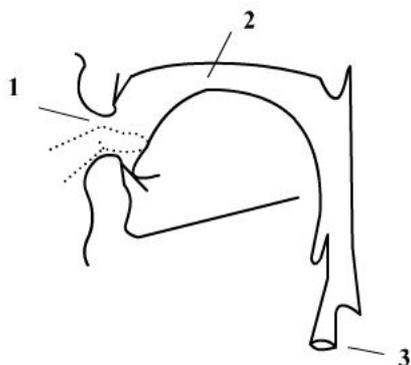


Figure 3: articulation of whistles

Whistling does not require the vibration of the vocal cords: it is produced by a shock effect of the compressed air stream inside the cavity of the mouth. When the jaws are fixed by the finger and/or the tighten lips (point 1 in Fig. 3), the size of the hole is stable. The air stream expelled makes turbulences at the edge of the mouth. The faster the air stream is expelled, the higher is the noise inside the cavities. If the hole (mouth) and the cavity (intra oral volume) are well matched the resonance is tuned and the whistle is projected more loudly. The frequency of this bio-acoustical phenomenon is modulated by the variation of the volume of the resonating cavity which can be, to a certain extent, related to the articulation of the equivalent spoken form. The movements of the tongue and of the epiglottis play the main roles for tuning the vowels and consonants (Fig. 3). The whistled signal is shaped by a kind of whistled aperture. Such a behavior is aimed at reaching an optimal listener’s intelligibility.

4. Acoustic adaptation of articulated whistles

The pitches of the main band of frequencies of whistles are concentrated in a narrow bandwidth (1 kHz to 3 kHz) where the audition of human beings is more sensitive and selective as shown on Fig 4.

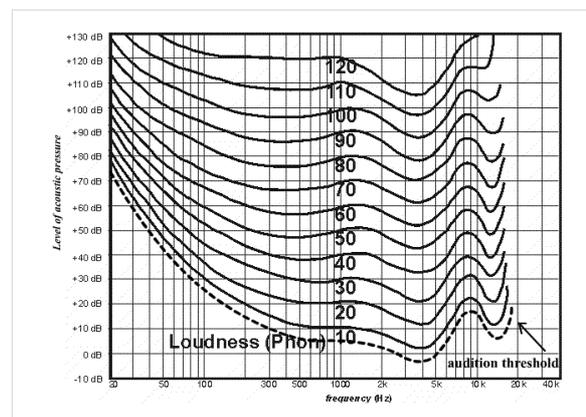


Figure 4: Isotonic lines and audition threshold

The amplitude of whistled speech has reasonable limits in its dynamic range (less than 20 dB) whereas the range of spoken speech is more than 50dB. Long distance whistled speeches are higher in frequencies (approximately 100 to 250 Hz) than short distance ones. This aspect underlines that the range of frequency is relative to the distance of communication.

Whistles are well carried in valleys which form a natural guide (the signal remains understandable at 8 km in La Gomera) and they exactly cover the central domain of frequencies for which the sounds resist to reverberation in forests [10]. Moreover, in natural conditions the background noise is weak in high frequencies (except in windy weather) so the signal to noise ratio is better than 6 dB at 1 km and is enough to be clearly heard. All these remarks show that whistled speech is particularly well adapted to human communication in noisy natural environments, and in long distance speaking in mountains or in forests.

5. Discussion

The comparative results obtained from several whistlers of various non tonal languages show how the properties of

whistles are exploited to encode linguistic information. As a whistled signal is limited to three features: pitch, loudness and duration; the frequency and amplitude modulations are used in a complementary way. In this context, the analysis of the acoustic cues exploited by whistlers for vowels and consonants underline that the intelligibility of these sounds is relative to the lexical environment and to the structure of the concerned language. Such a conclusion is supported by the performances to psychoacoustic tests realized by Moles [11] in Turkey which showed that the intelligibility of words was eased when they contain the most frequent segmental features and that much more confusions were made for words extracted from their lexical context. These results combined with our analysis meet the interrogations of some studies on spoken languages which look for the phonetic basis of phonological representations [12] by analyzing the degree of reduction in different contextual conditions [13].

5.1. A natural model for perceptive formants ?

Our results taking into account the articulation, the perception, the acoustics and the use of the vowels in different cultural and lexical context suggest a good match of the whistled main band of frequency and of the perceptive formant (called F2') defined by Carlson, Fant and Granström [14]. Their approach of the mechanisms of data reduction in vowel perception, together with other psychoacoustic studies tackling this subject, provide similar results to the natural evolution displayed in the phonetic description of articulated whistles. Whistles extend this approach to consonants.

6. Conclusions

Whistled languages are the result of the adaptation of the human perceptive and productive intelligence to a natural acoustic area (topography, vegetation, noise) and to a linguistic environment. They represent a strong model to investigate the perception of languages.

7. Acknowledgements

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