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WHISTLED TURKISH: STATISTICAL ANALYSIS OF VOWEL DISTRIBUTION AND CONSONANT MODULATIONS

Julien Meyer

Laboratori d'Aplicacions Bioacústiques, Universitat Politècnica de Catalunya, Barcelona, Spain
`Julien.meyer@univ-lyon2.fr`

ABSTRACT

Whistled Turkish is one of the best-preserved whistled forms of languages. The frequency distribution of whistled vowels and the modulations that characterize the whistled consonants are here analyzed. Their articulatory origin is also explained. Moreover, this study provides a detailed insight of the phenomenon of adaptation of whistled speech to the phonology of a given language.

Keywords: whistled languages, vowel distribution, modulation, formant perception, speech model.

1. INTRODUCTION

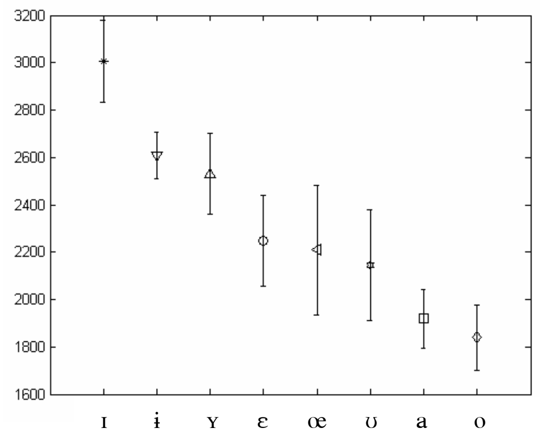
Whistled speech is used in Turkish as a complementary style of speech to overcome ambient noise and ease dialogues when speakers are far from each other in mountainous biotopes near the Black Sea. The few low-density populations using it are able to copy any sentence of this language in a simpler whistled signal while keeping articulatory features [1,2]. This transformation acts mainly at the frequency level: the complex frequency spectrum of the voice is reduced to a pitch variation produced by a narrow frequency band of whistles. Busnel [1] and Moles [3] showed that a spoken Turkish sentence transposed into whistles remains highly intelligible for a fluent whistler, even for non-standardized sentences. Similar observations were made also in other non-tonal languages like Spanish of La Gomera Island (Silbo) or Greek of Antia village [4, 5]. That is why the acoustic cues selected through this process to emulate the spoken voice of these languages represent valuable sources of information for phoneticians.

Among the several languages of the world compared according to their whistled behavior, different types of strategies were highlighted [5, 6]. These strategies are the result of an adaptation to the way each language structure combines differently two perceptual levels in frequency to encode the words. Studies in psychoacoustics have shown that a sound characterized by a complex frequency spectrum -like the spoken voice- bears simultaneously two perceptual qualities of height for the human hearing: pitch and timbre [7]. However, a whistler can focus in real time on only one of them to select in a simple pitch the salient acoustic cues effective for the intelligibility. As a consequence, in most tone languages (like Mazatec, Chinantec, Akha, Hmong) whistling selects primarily Fo cues carrying tone registers and tone contours. In most non-tonal languages (like Greek, Turkish, Spanish) it selects primarily segmental cues of the formants in the frequency spectrum; and in an intermediate category of languages it selects cues from both the Fo and the frequency spectrum by jumping in real time from one to the other (tonal Surui, non tonal Chepang) [5]. Up to now, Turkish is the language of the second category that has the highest number of vowels and consonants. As its whistled form is still practiced in the village of Kusköy and by the shepherds going in summer in the high plateaus, it can provide reliable data for a careful analysis. Even if several attempts to unravel the Turkish whistled system have been made [1, 3, 5, 8], they have not explained how the phonetic vowel reduction is balanced by the vowel harmony rules specific to Turkish phonology. Moreover none of them have detailed how the amplitude and frequency modulations combine to produce the consonants. The present study is based on data recorded in Kusköy in 1967 by an expedition organized by Busnel and on new material recorded in 2003 by the author. This large corpus of vowels and consonants enable an unprecedented statistical analysis for the study of whistled languages.

2. VOWELS

Each vowel is whistled as a rather stable, narrow band (or simple) frequency inside a frequency interval specific to each vowel type (encompassing the variability of articulation of the vowel). The eight types of Turkish vowels are whistled in a decreasing order of mean frequencies in intervals (ɪ, ʏ, ɨ, ɛ, œ, ʊ, a, o) that overlap a lot (figure 1). Such a pattern of frequency-scale distribution is the same for all the whistlers. The vowels [ɪ] bear the highest frequencies and [o] the lowest ones. In between, some intervals overlap much more than others: first, the vowels [ɨ] and [ʏ] have bands of frequencies nearly confused even if [ɨ] is meanly higher. Next, the intervals of frequencies of the vowels [ɛ], [œ] and [ʊ] overlap largely. Finally, the same occurs for the intervals of [a] and [o].

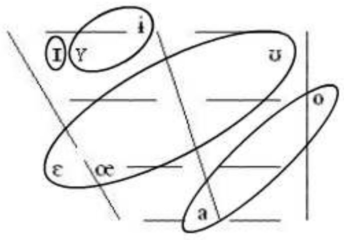
Figure 1: Frequency distribution of 280 Turkish whistled vowels of a single whistler (mean values and standard deviation).



2.1. Vocalic groups

Such a complex vocalic system of eight whistled frequency intervals highlights four groups [(ɪ), (ɨ, ʏ), (ɛ, œ, ʊ), (a, o)], which are statistically distinct (ANOVA: between (ɨ, ʏ) and (ɛ, œ, ʊ), (F (1,120)=46, p<.001); and between (ɛ, œ, ʊ) and (a, o), (F (1, 224)=186,4; p<.001)). These results attest that some phonetic reductions exist (see figure 2). But they don't imply a phonologic reduction of the whistled system in comparison to the spoken form (see also 2.2).

Figure 2: Vocalic triangle of Turkish with underlined statistic groupings of whistled speech.



2.2. The key role of harmony rules for identification

The preceding vowel groups are unravelled by the vocalic harmony rules that contribute to order the syllable chain in an agglutinated Turkish word.

2.2.1. Turkish vocalic harmony rules

Vocalic harmony rules in Turkish reflect a process through which some aspects of the vowel quality oppositions are neutralized by an effect of assimilation between one vowel of a syllable and the vowel of the following syllable. The possibilities opened by the two vocalic harmony rules sum up as follow:

a and ɨ -------- can be followed by ---------- a and ɨ
o and ʊ ------- can be followed by ---------- a and ʊ
ɛ and ɪ -------- can be followed by ---------- ɛ and ɪ
œ and ʏ ------ can be followed by ---------- ɛ and ʏ

The only resulting oppositions are those between high and non-high vowels. For non-initial syllables the system is reduced to six vowels.

2.2.2. Combination with frequency bands

The four inter-syllabic relations created by harmony rules simplify the vowel identification of the four whistled statistical groups of vowel frequencies. Indeed, each frequency group is in relation with each of the other three through only one harmony rule. As a result, the nature of two consecutive vowels not whistled in the same frequency group will always be identified (a possibility that relies on the human ability of phonetic and auditory memory in vowel discrimination [9]). Very few opportunities for confusion exist; they concern only two-syllable words with identical consonants:

- 2 consecutive [ʏ] (resp. [ʊ]) might be confused with 2 consecutive [ɨ] (resp. [ɛ])
- [œ] followed by [ɛ] might be confused with [ɛ] followed by [ɛ]
- [a] followed by [a] might be confused with [o] followed by [a] or [o] followed by [o].

However the ambiguities that are not solved by the harmony system are sometimes overcome by the use of the extremes of the bands of frequencies. For example for the common words /kalaj/ and /kolaj/: /o/ and /a/ are phonetically distinct in /kolaj/ because /a/ bears a higher pitch despite the fact that its two vowels are usually whistled in the same way.

2.3. Other characteristics of vowel intervals

The farther the whistlers have to communicate the higher in frequencies is the whole scale of vocalic intervals, /i/ staying below 4 kHz and /o/ above 1 kHz. In a single sentence the limit of one octave between the lowest and the highest frequencies is systematically respected. This phenomenon, also observed in tonal whistled languages might be due to risks of octave ambiguities in human perception of pitch [10, 11]. On another hand, the freedom of variation of vowels inside their typical interval eases the rendering of stress by a frequency increase. Indeed, the stress doesn't change the level-distribution of the intervals because it acts as a secondary feature influencing the frequency: a frequency stressed vowel is often in the highest part of its interval. Finally, diphthongs present a continue modulation going from the first to the second vocal frequencies, with a significant frequency depth for different vowel types.

3. CONSONANTS

Whistled consonants are modulations in frequency and amplitude of the simple signal of a whistle. In an intervocalic position, a consonant begins by modulating the preceding vowel and ends by modulating the following vowel. When the amplitude modulation shuts off the whistle, consonants are also characterized by silent gaps. Generally speaking, both the simple whistled signal and the constraints of articulation due to whistling contribute to enhance the phonetic similarities of consonants already at play in the spoken form.

3.1. Frequency modulations

3.1.1. *Typical frequency shapes*

The articulation of consonants while whistling produces simple frequency shapes. Comparing them reveals similarities that sometimes underline categories, mostly confined to congeners, i.e. sounds formed at close articulatory loci. (figure 3). Some consonants are more difficult to classify because they bear intermediate positions between two of these categories, like [n], [b], [v] and [f]. Moreover, the whistled emulation of the spoken voice requires sometimes a slight change in the pronunciation: for example [n] is produced by lowering the soft palate without opening the nasal cavity. On another hand, the fixed lips modify the labial articulation of [m], [p] and [b] which all use in compensation a glottal occlusion to produce a stop (Figure 4). The occlusive [p] is expressed mainly with this process and is therefore very similar to [k] in whistles. The consonant [h] is whistled as a semi vowel, in a stable and continue frequency. The consonant clusters concatenate the shapes of each constituent by truncating them at their encounter.

Figure 3: Whistled articulation of the most common consonants and resulting frequency shapes of whistled speech.

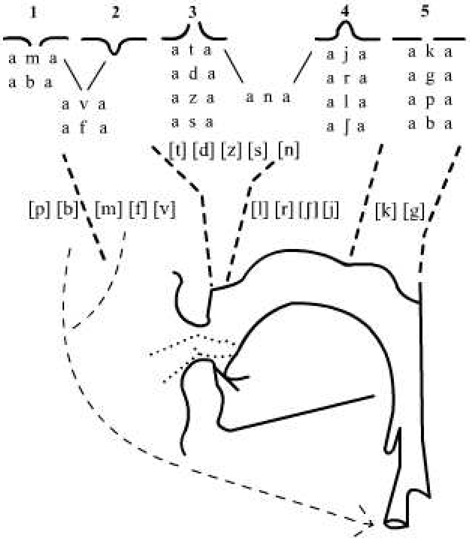
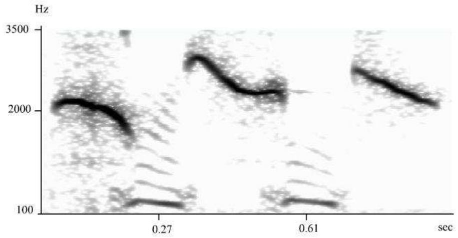


Figure 4: Turkish syllables /kom-jun-kop/ recorded near the whistler: the use of the glottal constriction for [m] and [k] is visible.



3.2. Amplitude envelope

The amplitude envelop of a whistled sentence reproduces the spoken speech units with a clearer syllable segmentation that underlines a slower speech rate (for example whistled sentences are on average 26% longer at middle distances). As the phrasing is the same in both whistled and spoken productions, the same speech groups are also delimited. Inside each speech group, the amplitude modulations of whistled consonants encode also several aspects of the spoken phonetics.

3.2.1. Consonantal cues carried by the amplitude modulation

The continuity or discontinuity of the sound during an inter-syllabic transition is the most obvious cue carried by amplitude modulations of consonants. But other cues are of clear interest. For example in discontinue whistled consonants a measure was made of the duration from the beginning of the inter-syllabic onset to the first amplitude peak (with the condition Apeak-Ao>10 dB). The results showed that the five consonants /t/, /d/ and /k/, /p/, /g/ bear systematically a very rapid and clear first peak amplitude onset (less than 20 ms). For other discontinue whistled consonants the results underlined that an abrupt amplitude modulation is not intrinsic to their onset attitude (although they sometimes behave so). For example, the consonants of the group 1 (figure 3) show in 87% of the cases a progressive amplitude increase that is expressed either by successive peaks or by an onset with no real peak until the vowel.

Finally, an interesting aspect was observed and measured for the first time: the consonants with rapidly modulated frequency shapes of groups 3 and 4 of figure 3 (transients) very often show an acoustic segmentation made thanks to a clear amplitude gap (on average 10 dB) between the vowel(s) and the consonant. During this event, there is a frequency jump of 100 Hz up to 250 Hz. In recordings made near the whistlers this event doesn’t appear as a discontinuity, but after propagation at long distance it is a very short discontinuity (approximately 10 ms at 750 m). This phenomenon also often occurs in the consonants of group 1 and 2. Acoustically, it indicates the beginning or the end of the consonant frequency slope.

3.2.2. Deduced frequency slopes

The mean onset slope of the frequency modulations for the consonants of the groups 1,2,3 and 4 (figure 3) was measured in CV onsets of VCV configurations. For [t, d, s, z] (group 3), the mean value of instant slopes is -14,30 Hz/ms (σ = 2,9), for [l, r, j, ʃ] (group 4) it is -10,8 Hz/ms (σ = 2,1), and 6,1 Hz/ms (σ = 2,8) for [m, v] (group 1 and 2), without significant difference for distinct consonants inside each group, or for distinct vowels following the consonants. These values reflect in the time-frequency domain the rapid articulatory movements of the consonants of groups 3 and 4 and the slower pace of the movements corresponding to group 1 and 2.

4. CONCLUSION

The distribution of whistled Turkish vowels in a frequency scale and the categories of consonants underlined by whistled modulations are representative of the whistled languages relying on articulation. The analysis of this study shows that the simplification at play in whistles is phonetic. It relies on an emulation of spoken speech and the segmental categories highlighted by this study are therefore also perceptually relevant in the spoken voice. As a consequence, whistled Turkish could be a good model to further analyze the perception of both the vowels and the modulations underlying in the complex formant distribution of the spoken voice. The present results would be a basis for such a study.

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