A sentence comprehension test with whistled Spanish experts

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Abstract

Whistled speech remains intelligible to trained listeners, despite a phonetic transformation of spoken utterances into whistled melodies. So far, very few studies have systematically tested the intelligibility of whistled sentences by expert whistlers, and the question remains about how long meaningful sentences with little context would be recognized. In the present study, we built an original experimental setting to test 22 highly trained whistlers on such long and unexpected sentences. We measured recognition rates at different levels of these sentences (words, syllables, vowels) and explored confusion patterns in relation to acoustic measures. Results show high recognition rates for the difficulty of the task and corroborate whistlers' observations.

Keywords: whistled language, speech, intelligibility, sentence comprehension, Silbo.

Introduction

Several populations all over the world have developed a natural whistled form of their local spoken language, used for long distance communication (Busnel, Classe 1976, Meyer 2015). For example, whistled Spanish in the Canary Islands (El Hierro, Gran Canaria, La Gomera, Tenerife) remains Spanish but transformed phonetically into whistles. Speakers of non-tonal languages such as Spanish transpose primarily linguistic segments into whistles: vowels are emitted at different whistled pitch levels depending on spoken vowel qualities, whereas consonants modulate the simple melodic line of vowels in amplitude and frequency (see figure 1). One of the most striking aspects of this natural whistled transformation is that it remains intelligible to trained speakers, despite a highly reduced acoustic channel to convey meaning. This lends alternative insights into how the phonetic expression of phonemes can be drastically reduced without hindering cognitive reconstruction. So far, only one perceptual study with systematic measures on intelligibility in whistled sentences has been published (Moles 1970) and the question remains about how meaningful sentences with little context are recognized. Nevertheless, this practice is hard to test with rare speakers of remote and endangered language communities.

To address these challenges we joined forces between actors of language revitalization in the Canary Islands and research on whistled language and built together an original experimental setting to test highly trained whistlers on long and unexpected sentences. Our main aims were the following: (i) to evaluate recognition rates at different levels of these sentences (words, syllables, vowels), (ii) to understand better confusion patterns at the light of acoustic measures from a high number of whistlers.

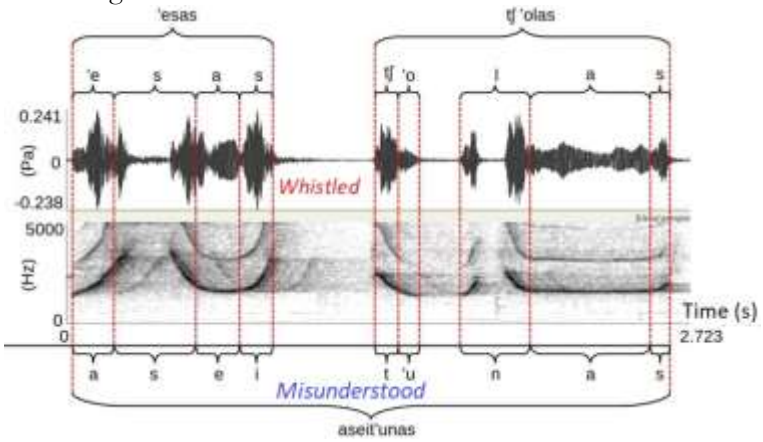

Figure 1: Waveform and spectrogram of whistled Spanish words "*esas cholas*" (meaning '*these slippers*', phonetic transcription above). The bottom line shows a confusion made once (Spanish word "*aceitunas*", meaning '*olives*')

Methods

The audio/video recorded behavioural experiment was included into the biggest annual whistled speech contest in Canary Islands (called *Concurso de Silbo* in the *Encuentro cultural con el Lenguaje Silbado 2022*). 39 sentences were built with the help of three whistled Spanish experts, all professors of *Silbo* (the local name for whistled Spanish in the Canary Island). They proposed sentences that were completely new to participants (never presented during previous contests nor during lessons) and judged as 'long, difficult, with minimum context' (for example: "*The gran mother will pay tonight the hat and the shirt.*"). 22 advanced whistlers took part in the contest (one emitted blurred whistles and was not analysed, one was not recorded). Each whistler had one minute to transmit a sentence selected by chance (among the ones that had not been whistled yet) to the partner situated 20m apart (the partner was also selected by chance) who raised his hand when he judged he had understood. Repetitions were allowed during up to one minute, as well as whistled feedback from the partner. Answers were finally written down by participants (*See a video of the experimental set up, a sentence transmission, and the list of sentences: https://vimeo.com/891992169*).

Results

Correct answers

23% of the participants (5 persons) fully understood their sentence. The general correct recognition rates were measured *for words (65,5%), syllables (69,1%), and vowels (78,9%)* on 20 participants. A Pearson correlation coefficient was computed to assess the linear relationship between the % of correct answers and the sentence repetitions nb. (20 recorded whistlers): *a negative correlation was found for words (r(19)=.45, p<0,001), syllables (r(19)=.37, p=.03), vowels (r(19)=.37, p=.03)*. Moreover, answers started to decrease after the second repetition.

Confusion patterns

Regular patterns of confusion clarify the picture. *Consonant-to-Vowel confusions* and *Consonant-to-Consonant confusions* occurred between frequency patterns with similar shapes (see examples in figure 1). Moreover, *the general confusion matrix of emitted vowels with any other phoneme* showed that /a/ and /e/ were the best recognized (resp. 83.06%, 83.12%), /u/ the worst (60.61%), with /i/ (72,34%) and /o/(75,9%) in between. *Vowel-to-consonant confusions* occurred only with consonants known to be often whistled as continuous or near-continuous (Díaz Reyes 2017, Meyer 2015): /i/ was taken for/g, l, ʎ, r/ (2,13% each of /i/ answers); or /e/ taken for /l, n/ (0.81% each). A confusion matrix with V*owel-to-Vowel confusions* only was derived (Table 1), showing that the 5 vowels were categorized differently [X2(16) = 1161, p<.001]. The agreement of the answers with the vowel categories was *'near perfect'* (*Cohen's Kappa*: k = 0.9, p<.001).

Table 1.Vocalic confusion matrix derived from answers (in %)

Played \ Answered	i	e	a	o	u
/i/	89,47	5,26	2,63	0	2,63
/e/	1,85	95,37	1,85	0,93	0
/a/	0	1,51	96,97	1,51	0
/o/	0	0	8,33	87,5	4,17
/u/	0	7,41	11,11	7,41	74,07

Measures in production

In parallel, the acoustic distribution of whistles corresponding to vowel production was analysed (2721 vowels, 20 participants, with repetitions). We ran a GLMM on whistled vowel frequencies, with Vowel (/i, e, a, u, o/) as a fixed factor and Participants as a random factor. Using nested modelling techniques and F-tests, we performed a backward selection and verified that Vowel had a significant effect on whistle frequencies. A significant main effect of Vowel (X2 (4, N=21) = 74.99, p <.001) was found and the post-hoc tests (*Tukey*) revealed significant differences in frequencies for different vowels across whistlers (p<.001), except for /o/ and /u/ (p=.27) (cf. figure 2); where freq(/i/)>freq(/e/)>freq(/a/)>freq(/o/)=freq(/u/).

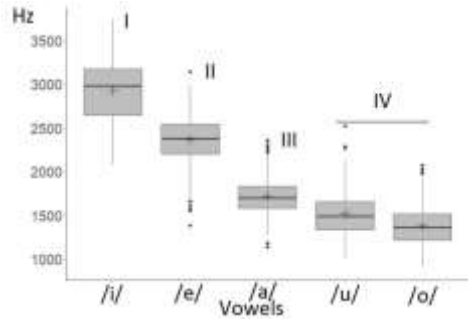

Figure 2. Whistled vowel frequencies as a function of vowel types (/i, e, a, u, o/) and significantly different groups (I, II, III, IV), across whistlers (n=20).

Discussion and conclusions

Results confirm that whistled speech enables highly trained specialists to understand unexpected long sentences without much context (with relatively high general rates of recognition, given the difficulty of the task). The results also explain why traditional whistlers generally limit repetitions to 2. The whistled vowel frequency distribution matches with previous studies (e.g., Meyer, 2015), but here mean frequencies of /u/ were slightly higher than /o/, although not significantly. /u/ was also the least stable in perception. Results also corroborate some whistled speech teachers' observations, such as that vowels with the highest mean frequencies (/i, e/) are the most often taken for consonants (Díaz Reyes, 2017) (mostly for voiced coronals rising towards high loci). Vowel recognition rates in sentences show a different pattern than when presented in isolation or in words (Tran Ngoc et al., 2023) as the most frequent Spanish vowels (/a, e/) were the best recognized here (vs. /i, o/ in isolation).

Acknowledgements

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