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## Duration as perceptual voicing cues in whisper

Yohann Meynadier, Sophie Dufour, Yulia Gaydina

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In modal speech segmental durations are secondary phonetic marks of the voicing feature in many languages. The voiced obstruents show shorter durations than unvoiced ones; while the pre-consonant vowels are shorter before unvoiced consonants than before voiced ones<sup>[1]</sup>.

In the one hand, auditory (Kluender et 1988), articulatory (Raphael 1975) and/or main phonatory-aerodynamic (Rothenberg 1968, Ohala 1983, 1997, 2011) constraints could provide a phonetic ground of these differences in C or V duration relative to voicing. In the other hand, the durational cues of voicing are largely seen as linguistically controlled (Lisker 1977, Ohala 2009). This can be supported by studies showing that perception of voicing is affected by the C and V durations<sup>[2-3]</sup> which enhance the possible phonological role of such phonetic details. But the particular share between physical and linguistic conditionings is still not well-known.

Because of the lack of voicing constraint, the **whisper could be a new paradigm** to assess the weight of physical vs phonological conditioning of segmental durations as function of voicing. No previous works had controlled C and V durations to assess the voicing perception in whisper, even if they showed that the voicing contrast is phonetically preserved in production and perception<sup>[4-7]</sup>. This study on French focuses on the **influence of voicing on segmental durations and of mismatched C and V durations on the perception of voicing in whispered speech**.

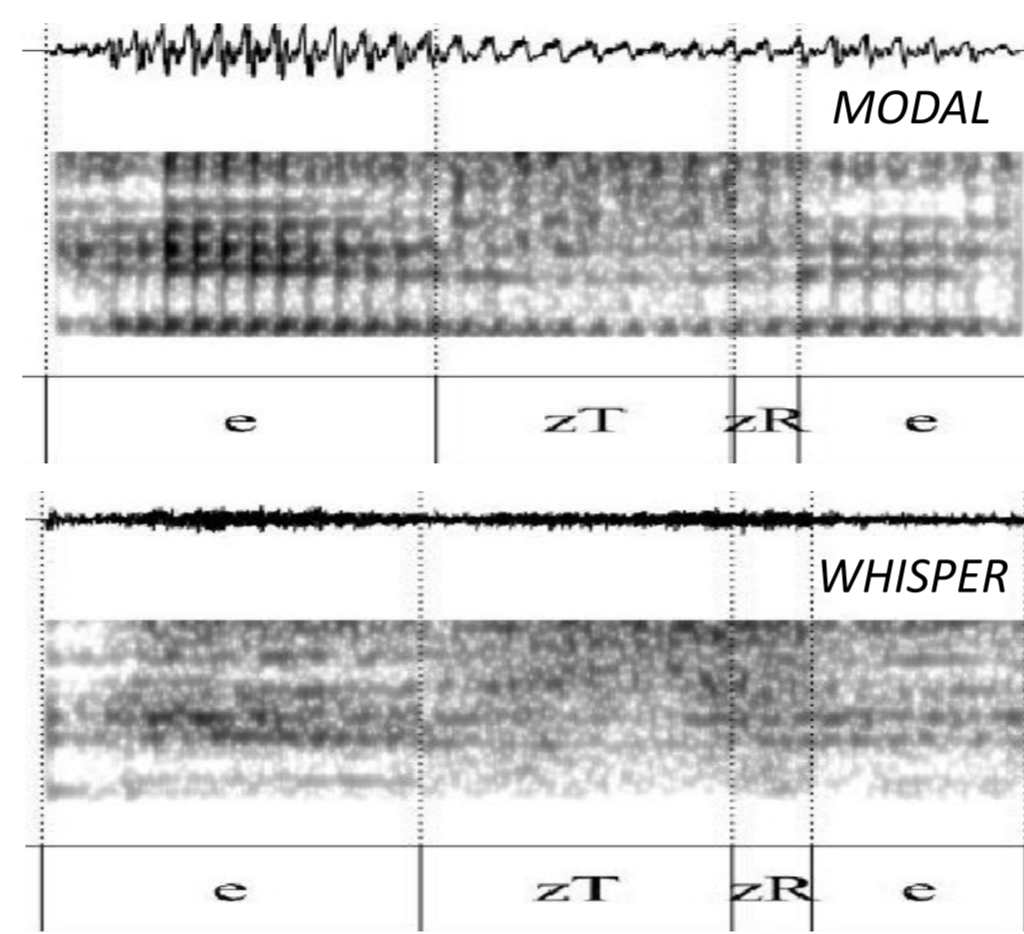
## Production

### Corpus

- Reading in **modal vs whispered** voice
- Lexical and non-sense isolated words
- **12 voiced vs unvoiced obstruents**: p-b, t-d, k-g, f-v, s-z, ʃ-ʒ in median unstressed position
- **4 French speakers** (2 M & 2 F)
- 5 repetitions

**NON-SENSE WORDS**  
eteve, ekeze, egepe

**LEXICAL WORDS**  
азыве / azyve  
debite / depite  
ekute / egute

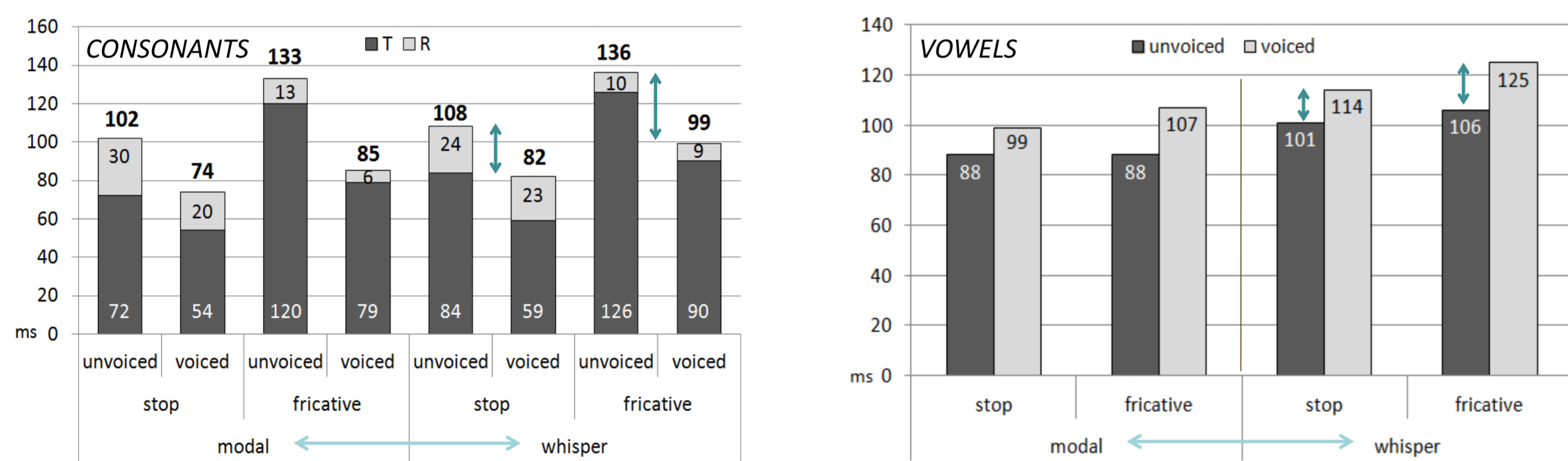


### Analysis

- **Acoustical durations** of C (steady-state  $T$ , offset  $R$ ) and of the pre-consonantal V
  - Repeated-measure Anovas on **duration** (ms)
  - **PHONATION**: modal vs whisper
  - **VOICING**: voiced vs unvoiced
- Non-sense and lexical words were pooled.

### Results

**PHONATION** modal < whisper → slower rate



### VOICING IN WHISPER (AS IN MODAL VOICE)

#### CONSONANTS

- $C_{[+vois]} < C_{[-vois]}$
- $\Delta_{[vois]}$  remains for stops
- $\Delta_{[vois]}$  slightly lower for fricatives

#### VOWELS

- before  $C_{[-vois]} < \text{before } C_{[+vois]}$
- $\Delta_{[vois]}$  remains for stops
- $\Delta_{[vois]}$  slightly larger for fricatives

On modal speech, it confirms previous studies in French<sup>[1]</sup>.

On whisper, it is in agreement with works on different languages<sup>[4]</sup> and with the only one study on French by Vercheran (2010).

The data show that the **phonological voicing contrast is also phonetically realized in whisper by segmental C and V durations**.

This study suggests that **duration differences as function of voicing are enough similar in modal and whispered speech**.

## Conclusions

**Contrastive durations of C and V are produced** as function of phonological voicing in French in modal and whispered speech.

Such **durational phonetic information play a role in voicing perception only in whisper and NOT IN MODAL VOICE**. This result confirms that listeners would use adaptative processes in the perception of phonological voicing.

As the whisper signal could be linkened to a spectrally altered speech, it meets studies showing that listeners switch from spectral to temporal cues in conditions of degraded or noisy speech (Winn et al. 2012).

Finally, the **perception of whisper supports a possible linguistic ground of durational correlates of voicing**. But some laryngeal investigations of the voicing feature in whisper also suggest a potential aerodynamical conditioning<sup>[9]</sup>.

**References** [1] for French: Chen 1970, O'Shaughnessy 1984, Bartkova & Sorin 1987, Lauefer 1992, Abdelli-Beruh 2004 – [2] Denes 1955, Lisker 1957, Wajskop & Sweerts 1973 (on French), Fledge & Hillenbrand 1986, Allen & Norwood 1988, Warren & Marslen 1989 – [3] Denes 1955, Raphael 1972, Hogan & Rozspypal 1980, Flege & Hillenbrand 1986, Allen & Norwood 1988, Crowther & Man 1992 – [4] Czech (Jovicic & Saric 2008), English (Sharf 1964, Parnel et al. 1977, Mills 2003, 2009, Kinsey 2005, Osfar 2011), Dutch (van der Velde & van Heuven 2011), Russian and Hungarian (Knyazev 1991), French (Vercheran 2010) – [5] Mills 2003, Vercheran 2010 – [6] Munro 1980, Higashikawa 1994 – [7] Fux 2012 – [8] Nittrouer 2004, 2005, Winn et al. 2012 – [9] Malécot & Peebles 1955, Weismer & Longstreth 1980, Higashikawa 1994, Mills 2009, Meynadier & Gaydina 2012, 2013.

## Perception

### Experimental design

- Auditory stimuli : **non-sense minimal pairs**
  - Binary visual choice : 'onabé' vs 'onapé'
  - **12 voiced vs unvoiced obstruents** (one M speaker)
  - **40 listeners** : 50% in modal vs 50% in whisper
- Neutralized factors: balanced order, dB normalization

### Stimuli

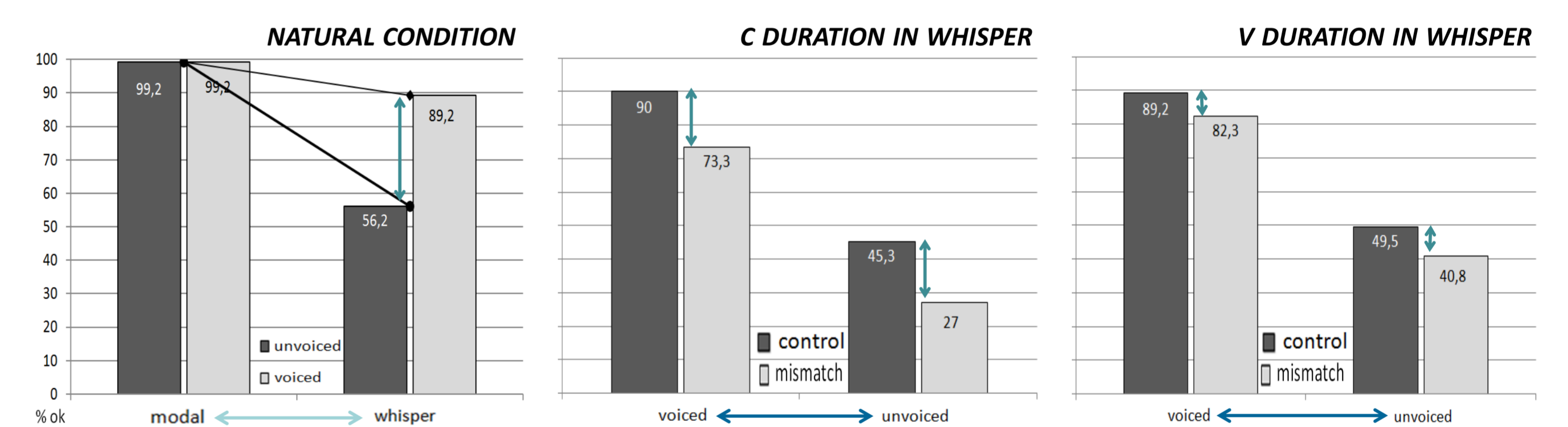
- **Natural** : no durational change, no acoustical modification
- **Control** : no durational change, signal inversion
- **Mismatch** : from the empirical  $\Delta_{[vois]}$  of observed durations in production
  - $C_{[-vois]}$  shortened to  $C_{[+vois]}$  duration (-30%)
  - $C_{[+vois]}$  lengthened to  $C_{[-vois]}$  duration (+40%)
  - pre- $C_{[+vois]}$  V shortened to pre- $C_{[-vois]}$  duration (-15%)
  - pre- $C_{[-vois]}$  V lengthened to pre- $C_{[+vois]}$  duration (+15%)

### Analysis

- Repeated-measure Anovas on **rate of correct responses (%)**
  - **PHONATION**: modal vs whisper (in natural condition)
  - **VOICING**: voiced vs unvoiced (in control and mismatch conditions)
  - **DURATION**: control (original duration) vs mismatch (opposite duration)
- Stops and fricatives were pooled.

### Results

**PHONATION** modal > whisper → lower recognition (loss of intelligibility)



**VOICING MODAL** ≈ 100 % of correct recognition → **no effect**

#### WHISPER

- $C_{[-vois]} < C_{[+vois]}$
- in all 3 conditions
- especially for non alveolar ( $\neq t-d, s-z$ )
- recognition of  $C_{[-vois]}$  at the chance level

equivocal in littérature  
(i) opposite direction<sup>[5]</sup>  
(ii) variability across speakers<sup>[6]</sup>  
(iii) variability across consonants<sup>[7]</sup> as here.

#### DURATION

##### MODAL

→ **no effect** of C<sup>[2]</sup> or V<sup>[3]</sup> duration  
 $\neq$  previous works

##### WHISPER

**mismatch duration < no change**

#### $C_{[-vois]}$ & $C_{[+vois]}$ recognition

- **decrease** for mismatch durations of C and V
- show **more effect of C** than V durations

#### $C_{[+vois]}$ recognition

- **remains at high level**: 90 % → 73-82 %
- no categorical switch of voicing perception

#### $C_{[-vois]}$ recognition

- **remains very low**: 45-50 % (chance) → 27-40 % (no chance)
- categorical switch to voiced percept

Two **unexpected results** are challenging for further works. First, the **unrecognized unvoiced C in whisper** is counter-intuitive: different investigations are needed (semantic priming?). Also, the **lack of duration effects in modal speech** could be due (i) to the uncontrolled spectral cues of voicing (laryngeal buzz, F1, noise intensity & freq.); (ii) to non-synthetic speech signal used here ( $\neq$  previous studies<sup>[8]</sup>).

However, the **C and V durations play a role in the perception of voicing in whisper**, i.e. even without any physical vibrations of the vocal folds.