Aerodynamic and durational cues of phonological voicing in whisper

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This study concerns the **phonologization process of fine phonetic details** in French, such as segmental durations used as a secondary phonetic information in obstruents voicing**. Phonologization is expected when phonetic properties are at least partly dissociated from their physical conditioning**. Due to a lack of a physical voicing constraint, the **whisper could provide a new paradigm to study this process**, by assessing the weight of physical *vs* linguistic conditioning of the segmental duration of obstruents as function of their phonological voicing.

In many languages, the voiced obstruents show shorter durations than unvoiced ones [1]. **On the one hand**, this phonetic durational difference is usually attributed to the ***Aerodynamic Voicing Constraint*** [2] in the vibration of the vocal folds during obstruents. However, this duration contrast due to voicing specification is also phonetically preserved in production in whispered phonation, i.e. without any physical voicing due to the open glottis [3]. **On the other hand**, it is **largely seen as linguistically controlled**, because of the important durational difference observed [4] and the role of C duration in the perception of voicing contrast in modal [5] or whispered [6] speech.

It is assumed that if the durational contrast of voicing in whisper is produced in absence of a physiological constraint, it would be the evidence of the phonologization of such fine phonetic details.

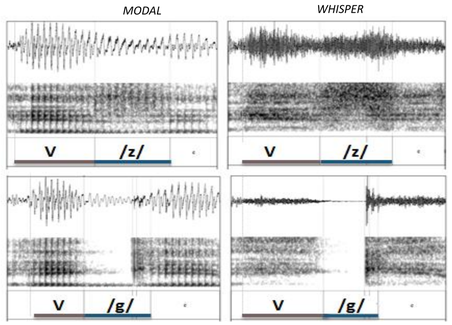
Duration

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
asyʁe / azyʁe
debite / depite
ekute / egute



Analysis

- **Acoustical durations** of **C** (and of the pre-consonantal V)
- Repeated-measure Anovas on **duration** (ms)
- PHONATION: modal *vs* whisper
- VOICING: voiced *vs* unvoiced

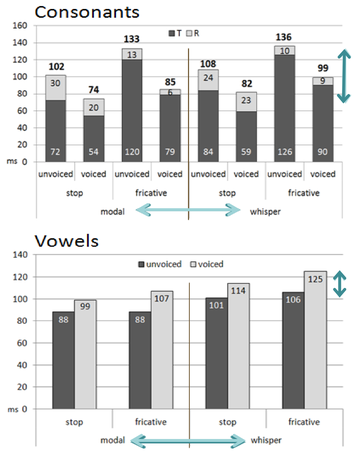
Non-sense and lexical words were pooled.

Results

Confirmation of previous works *on modal* [1] *and whispered* [3] *speech* in French *and* in different languages.

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

The duration differences as function of voicing are **enough similar in modal and whispered speech**.



PHONATION : modal < whisper
➲ slower speech rate in whisper

VOICING : **in modal as in whisper**
C ➲ +voicing < -voicing
V ➲ -voicing < +voicing

➲ *similar* $\Delta_{\pm voicing}$ *in modal as in whisper speech*

Δ ms		V	C
modal	stop	11	28
	fric	13	48
whisper	stop	13	26
	fric	19	37

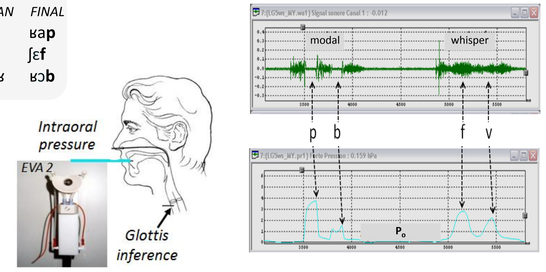
ratio		V	C
modal	stop	0.89	0.75
	fric	0.82	0.64
whisper	stop	0.89	0.70
	fric	0.85	0.73

Aerodynamics

Corpus

- Reading in **modal *vs* whispered** voice
- **Labial obstruents**: /p f/ *vs* /b v/ in **18** different lexical isolated words per C
- 8 French speakers *(2 M & 6 F)*

WORD-	INITIAL	MEDIAN	FINAL
(a)_a	vaʃ	savat	ʁap
(a)_ɛ	bɛʒ	afɛʁ	ʃɛf
(a)_ɔ	pɔm	ʁapɔʁ	ʁɔb



Analysis

- Maximum **intraoral pressure** during C *(P_o)*
  ➲ *inference of **Glottal Resistance** (decrease of opening)*
- Repeated-measure Anovas on **max P_o value** (hPa)
- PHONATION: modal *vs* whisper
- VOICING: voiced *vs* unvoiced

Word positions were pooled.

Aerodynamic Voicing Constraint on voiced obstruents [2]

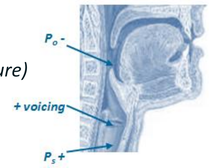
In MODAL VOICE

➲ adduction of vocal folds
➲ Glottal Resistance ↗
➲ P_o ↘

If P_o is less by 1-2 hPa than Ps (subglotttal pressure)
➲ vocal fold vibration stops
➲ **devoicing**

Longer is obstruent
➲ more P_o ↗
➲ greater risk of devoicing

So, shorter voiced obstruents prevent devoicing.



In WHISPER

Glottis Resistance = 0 (abduction)
but voiced obstruents shorter than unvoiced ones

Hypothesis 1 : no aerodynamic constraint
➲ duration constrast in obstruents is **phonologized**

Hypothesis 2 : aerodynamic constraint
➲ different P_o for voiced *vs* unvoiced obstruents
➲ difference in Glottal Resistance

A **physiological conditioning** on obstruent duration also exists in whisper

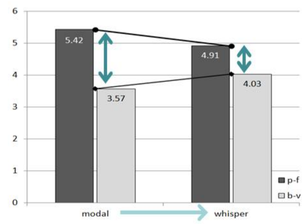
Results

Support for a glottal voicing contrast in whisper [7] in French, as in modal speech.

The **opposite behaviors** of voiced *(lower P_o increase)* and unvoiced *(higher P_o decrease)* obstruents could be due to **two different constraints**:

For voiced obstruents, an *Aerodynamic Whisper Constraint* is needed to produce the glottal noisy source.

For unvoiced obstruents, a *Perceptual Communicative Constraint* is needed to generate the lower acoustic energy of the supraglottal noise (as whisper is per se a low-intensity speech mode).



	/p/		/b/		/f/		/v/	
	Mod	*Whi*	Mod	*Whi*	Mod	*Whi*	Mod	*Whi*
F1	4.36	*5.02*	2.6	*4.46*	3.95	*4.35*	2.42	*3.27*
F2	5.27	*3.89*	2.72	*3.43*	4.47	*3.53*	1.96	*2.87*
F3	8,00	*6.08*	5.21	*5.56*	7.42	*6.92*	6.43	*5.23*
F4	6.26	*7.49*	3.94	*6.18*	6.4	*7.43*	4.73	*4.99*
F5	4.73	*4.11*	4.08	*3.34*	5.69	*4.68*	4.34	*3.85*
F6	4.59	*4.42*	3.05	*4.32*	4.59	*3.86*	2.25	*3.64*
M1	5.31	*4.46*	2.72	*3.58*	5.27	*4.21*	3.48	*3.26*
M2	5.29	*4.51*	2.74	*3.35*	5.13	*3.63*	4.41	*3.09*
mean	**5.48**	**5**	**3.38**	**4.28**	**5.37**	**4.83**	**3.75**	**3.78**

PHONATION not significant

VOICING as in modal
C ➲ +voicing < -voicing
but reduced by 50 % *(0,89 hPa)*

***VOICING*PHONATION* interaction**

P_o increase for /b v/
➲ *glottal opening* ↗

≠ P_o decrease for /p f/
➲ *glottal opening* ↘

Conclusion

As in modal voice, **contrastive durations of C** (and V) **are produced** as function of phonological voicing **in whisper** in French.

The ***Whisper Paradigm***, however, **does not seems to provide a clear evidence of the dissociation process between physical and linguistic control** of the phonetic durational details as function of voicing.

The phonologization of the obstruents duration contrast as function of their voicing specification does not find any convincing proof here , as **an phonatory-aerodynamic constraint also operate in whispered speech**.

This physiological constraint could explain the observed duration contrast of voiced *vs* unvoiced obstruents in whisper, as kind of an ***'Aerodynamic Whipser Constraint'***.

However, **perceptual constraints** in whisper seem to play an important role too, including the control of the intensity level of the supraglottal noise of unvoiced obstruents.

Also, some works on the **perception of obstruents in whisper could support to a phonologization process of the durational phonetic correlates of the voicing feature** (see Meynadier, Dufour & Gaydina 2013).

References [1] *for French:* Chen 1970, O'Shaughnessy 1984, Bartkova & Sorin 1987, Lauefer 1992, Abdelli-Beruh 2004 – [2] Rothenberg 1968, Scully 1974, Ohala 1983, 1997, 2011 – [3] *English:* Sharf 1964, Parnel, Amerman & Wells 1977, Mills 2003, Kinsey 2005, Osfar 2011, *Russian and Hungarian:* Knyazev 1991, *Serbian:* Jovicic & Saric 2008, *French:* Vercherand 2010, Meynadier& Gaydina 2012, *Dutch:* van der Velde & van Heuven 2011 – [4] Lisker 1977, Ohala 2009 – [5] Denes 1955, Lisker 1957, Wajskop et Sweerts 1973, Allen & Norwood 1988, Fledge &Hillenbrand 1986, Warren & Marslen 1989, etc. – [6] Meynadier, Dufour & Gaydina 2013 – [7] *Glottis:* Malécot & Peebles 1965, Hamlet 1972, Mills 2009 *vs* Zeroual et al. 2005; P_o: Weismer & Longstrenth 1980, Higashikawa 1994 *vs* Soda, Nishida & Suwoya 1967, Murry & Brown 1976.