Temporal vs. area-sum measurements of vowel nasality

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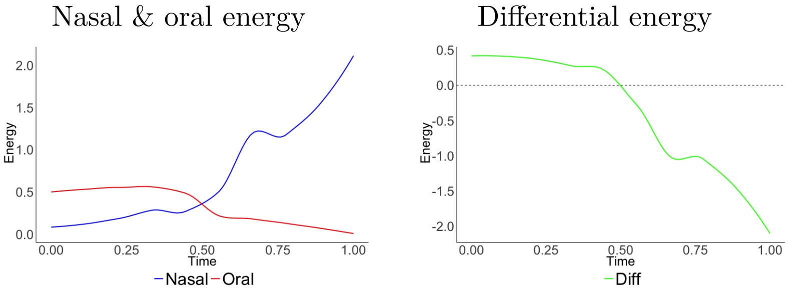
Introduction

Objectives

1. Propose a new formula for quantifying vowel nasality: Differential Energy Ratio (DER), based on relationship between oral & nasal energy curves.
2. Apply the DER on a (personally collected) nasometric corpus of French.
3. Offer phonetic explanation behind some effects.

Example: [i] in [in] sequence (French)



Background questions

1. **Q:** What kind of data?
   A: Mainly "split-level" (separate but simultaneous measures of orality & nasality)
2. **Q:** What's used now?
   A: Temporal formulae (proportion of *nasal phase* duration), using NAS as one example
3. **Q:** How does the DER compare in practice?
   A: Nasometric study of coarticulation in French: gives more nuanced scores, especially for vowels with rapid energy changes.
4. **Q:** Why?
   A: DER builds numbers directly into calculations.

Main points

1. DER & NAS **correlate** but **disagree** in certain key cases
2. DER inherently more precise than NAS: oral & nasal energies (E_o, E_n) not entirely interdependent – why?
    - **High vowels**: E_n can rise either slowly or most rapidly of all heights (*underestimated* by NAS)
    - **Non-high vowels**: E_o on average greater at start → sharp fall; E_n can either rise at similar rates or barely rise (*overestimated* by NAS)
3. The DER is more appropriate at quantifying vowel nasality than the NAS (at least concerning coarticulation).

Today: Focus on high vowels, esp. where NAS < DER.

Outline

Quantifying nasality

Phonetic correlates of nasality

Nasal vowels among most complex sounds of human language, several measurable phonetic correlates

- Articulatory: activation of *levator palatini* (e.g., Lubker 1968), lowering of velum (e.g., Henderson 1984)
- Aerodynamic: air pressure & area of velopharyngeal port opening (VPO; e.g., Warren et al. 1993)
- Acoustic: interaction between nasal cavity's pole-zero pairs and oral formants (Maeda 1993), weakening of F1 (e.g., Delattre 1954), etc. (cf. Baken & Orlikoff (2000) for review)

Instruments & data

- Articulatory (imaging, mechanical, EMA, electromyography): size of VPO, velic height or muscle activation over time, positioning of oral articulators
- Acoustic (non-instrumental): formant tracking, amplitude differences (*à la* Chen 1997) or p0 prominence (Styler & Scarborough 2014)
- **Split-level:** separate but simultaneous oral & nasal channels (aerodynamic or instrumental acoustic)

cf. Krakow & Huffman 1993, Delvaux 2012 for exhaustive surveys

Typical results

With example studies on French (so "e.g.," all around).

- Acoustic: average or point-by-point difference in dB (cross-categorical), measurement of distance between oral & nasal "formants" (Chen 1997)
- Formant tracking & split-level: global score ("V = x% nasal")
  - Formant tracking: onset of nasal band (Spears 2006)
  - Aerodynamic: onset of (sufficient) nasal airflow (Delvaux et al. 2008)
  - Nasometric: onset of (sufficient) nasal energy (Montagu 2007)

Caveats

- Several discrepancies on studies of coarticulation in French (% nasality vs. height)
- Different methods = different correlates = different stages of pronunciation:
  activation → movement → aerodynamics → acoustics
- Simultaneous multiple instruments impossible for most combinations, no way of directly comparing results (yet)

So let's use one data source – Dow (2014)

Methodology

Background & participants

- Nasometric (split-level acoustic) study of French (France)
- Objective: document nasal coarticulation patterns of French wrt vowel quality and duration
- Glottal Enterprises NAS-1 SEP Clinic hand-held nasometer: equally distant microphones (mouth, nose) separated by sound-attenuating plate
- 20 native speakers from Brittany, Picardy: 6 women, 14 men; average age = 57.4 (sd = 13.4); no significant differences between groups' French data

Stimuli

- Noun + adjective combinations of **vowel targets** and **environments** (e.g., *la partis*/an#s/*arcastique*)
  - V = oral vowels in oral contexts, /a, e, ø, o, i, y, u/
  - VN = oral vowels before noun-final nasal consonants
  - V^n = contrastive nasal vowels, /a^n, e^n, $ø^n$, o^n/
- Each list read 3 times by each speaker (self-directed pace)
- Recorded in Praat in stereo (separate channel for oral, nasal)
- Total of **3,240 vowels**

Measurements & treatment

- 10 equally-spaced measurements of vowel's energy in each channel (oral, nasal)
- Data re-centered around *sd* of each channel's readings within a speaker & repetition
- 2 measurements: nasalance-based (NAS) & Differential Energy Ratio (DER)
- Shared points:
  - p = arbitrary threshold (both measurements); here, where nasal energy overtakes oral energy.
  - C = end of vowel (orality $\rightarrow 0$).
- Vowel devoicing (occasional on word-final high vowels) caused some erroneous readings, but not enough to impact average 0% nasality on oral vowels

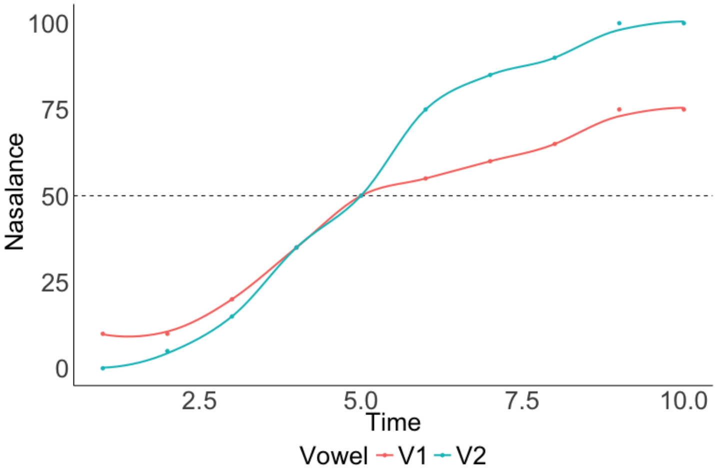
NAS calculations

Representative example of temporal measurements, along the lines of e.g., Rochet & Rochet 1991.

1. **Nasalance** (nasal energy over total energy) at each point, expressed as percentage
2. Nasal phase defined wrt arbitrary threshold: all points whose nasalance ≥ 50% (i.e., $E_n \geq E_o$)
3. NAS = # of points in nasal phase vs. total # of points

Simply put (specific to regressive nasalization): $\frac{C-p}{C}$

Hypothetical examples, NAS = 50%



DER calculations

Generalizing to where $E_o = f(x)$ and $E_n = g(x)$...

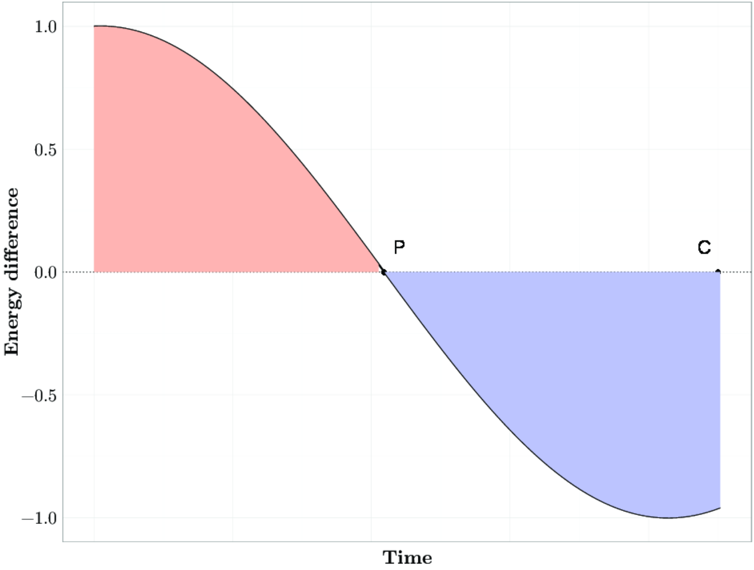
1. **Differential energy curve** (Δ): $f(x) - g(x)$
2. Phases separated around p, where $\Delta = 0$ (oral = positive values; nasal = negative)
3. Area-sum of each phase calculated

$$A_o = \sum_{x=0}^{p} [f(x) - g(x)]$$

$$A_n = \sum_{p}^{C} [|f(x) - g(x)|]$$

4. $$\text{DER} = \frac{A_n}{(A_n + A_o)}$$

DER crucial points, hypothetical Δ



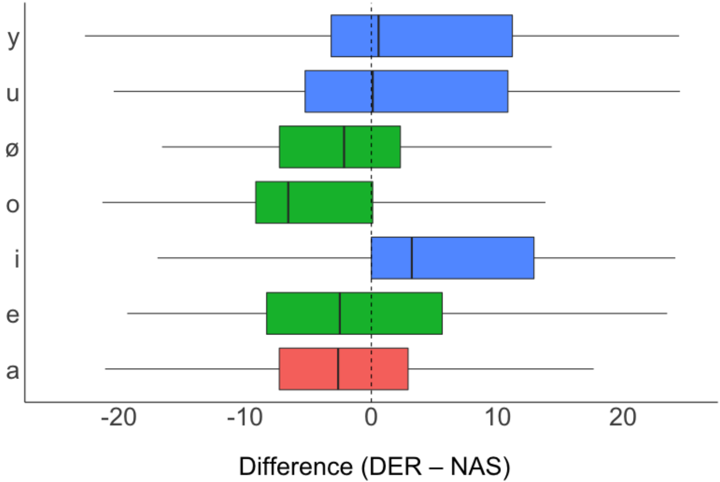
Results

Results by target, VN & V^n

Expressed in % nasal. V ≈ 0% ([V̥] aside)

Target	Context	NAS	DER	Diff
/a/	VN	21.3	20.5	-0.8
	V^n	86.2	89.0	2.8
/e/	VN	28.1	28.1	0
	V^n	86.2	89.4	3.2
/ø/	VN	22.3	20.5	-1.9
	V^n	66.2	66.8	0.6
/o/	VN	20.4	16.1	-4.4
	V^n	97.2	97.7	0.5
/i/	VN	61.2	69.6	8.3
/y/	VN	51.1	57.1	5.9
/u/	VN	34.8	39.2	4.4

Boxplot: difference by target (VN context)



NB: With a few exceptions, general trends hold for all speakers.

Correlation & paired t-test

All heights (VN context) correlate strongly (between r = 0.86 and 0.93).

Paired t-test (VN context) shows difference extremely significant for mid (negative direction) & high (positive) vowels

	low	mid	high
mean	-0.8	-2.09	6.67
t	-0.93	-4.19	13.8
p	0.36	< 0.001***	< 0.001***

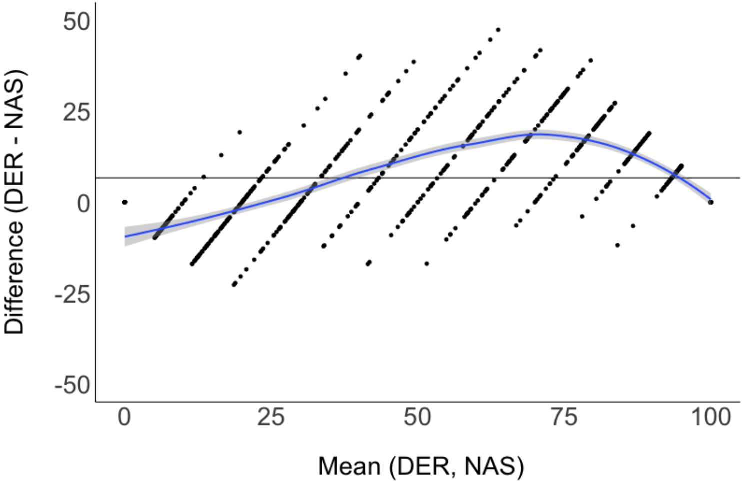
The two model & vary with nasality, but disagree somewhere.

Bland-Altman plot

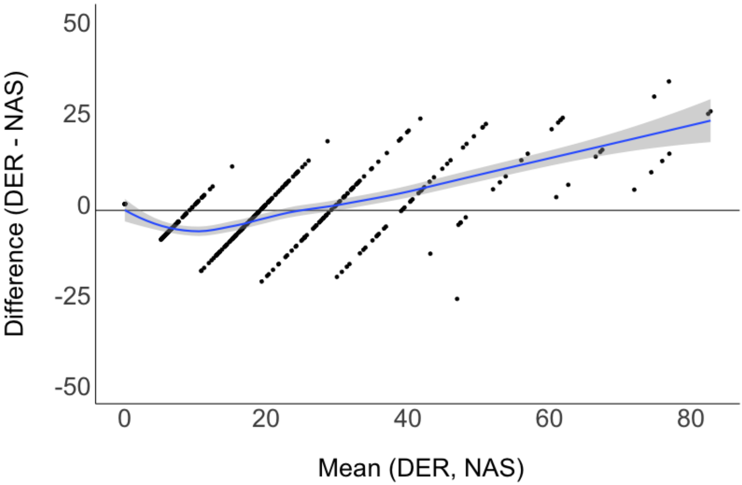
AKA Tukey mean-difference plot

- x-axis: mean % nasal (NAS + DER)/2
- y-axis: difference (DER – NAS)
- Used to test agreement between two measurements of the same phenomena

High vowels (VN context)



Mid vowels (VN context)



So?

- Simple averages mask the disagreement at rates of nasality where the difference is more evenly distributed
- Disagreement skewed towards NAS > DER at lower levels, NAS < DER at higher levels
- More pronounced (greater range of difference) on high vowels, esp. at higher end
- Degree of precision aside, how can we decide which is more appropriate?

Discussion

High vowels & nasalization

- **Aerodynamic**: High intraoral pressure on high vowels → greater nasal sound pressure levels on high vowels (Clark & Mackiewicz-Krassowska 1977)
- **Acoustic**: For VPO given, nasal coupling more likely to occur on high vowels (House & Stevens 1956) because of nasal pole-zero interactions (Maeda 1993)
- **Perception**: High vowels perceived as most nasal with least VPO size (e.g., Maeda 1982)

What about articulation?

Spoilers: Unclear.

- Velic height and vowel height long thought proportionate: among oral vowels, velum lowest on low vowels, etc. (e.g., Bell-Berti 1976), but called into question more recent studies (e.g., Rossato et al. 2003)
- Originally thought to signify low vowels easier to nasalize (esp. physiological motivation for development of French nasal vowels, e.g., Straka 1955)
- However, low vowels in experiments…
  - In nasal contexts: produced with much larger VPO than high vowels (Chen & Wang 1975)
  - In oral contexts: occasionally open velum & trace amounts of nasality (e.g., Ohala 1975, Clumeck 1976)
  - …but even these may not be universal (cf. Hajek & Maeda 2000)

Height & articulation

Are high vowels harder or easier to nasalize, from articulatory point of view? Probably irrelevant.

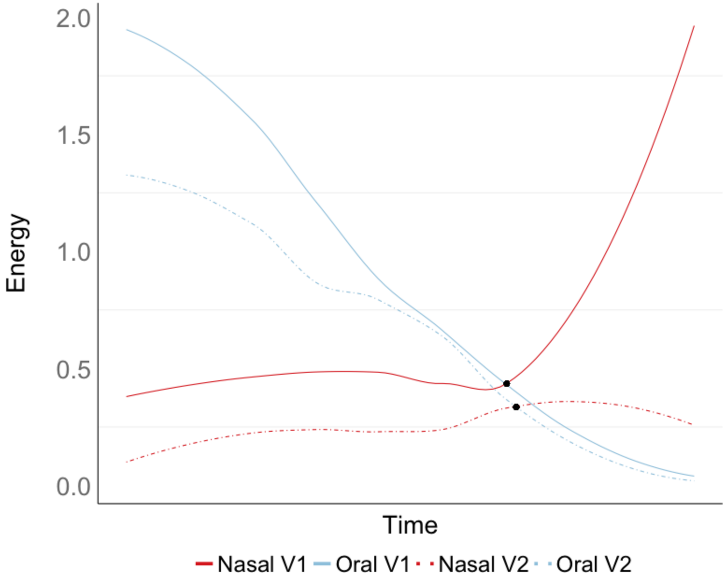
- If VPO size solely responsible: perhaps harder
- However, inherent velic height inconclusive
- More importantly, both aerodynamic and acoustic factors take precedence & likely make this question irrelevant

Back to the data

- Nasal energy rises twice as fast on high vowels (vs. on any other vowel type)
- Higher nasality $\neq$ greater difference (cf. contrastive nasal vowels; also low vowel VN in Picard: 87% (NAS) vs. 91% (DER))
- p being equal, a sharper change in one type of energy $\rightarrow$ greater difference between NAS & DER

Illustrations

- Representative examples: 2 productions of [y] in _N#s by same speaker
- Same crossover point but significantly different rates of nasal energy change
  - NAS (V1, V2) = 24.1%
  - DER (V1) = 39.3%
  - DER (V2) = 12.2%
- The DER reflects the difference between these 2 vowels, while the NAS conflates it, towards less nasal (V1) and more nasal (V2).


2.0
1.5
1.0
0.5
0.0
Energy
Time
Nasal V1
Oral V1
Nasal V2
Oral V2

Conclusion

Summary

- DER more reflective of nasality because of...
  - Its ability to differentiate rates of change
  - Its direct incorporation of energy readings
  - Its inherent nuance (not solely a function of crossover point)
- The difference between the NAS and DER is crucial on vowels where energy changes rapidly
- In French, this applies most strongly to high vowels' nasal energy – typically an underestimation by NAS, but not exclusively
- Possible explanation: Even if high vowels are harder to nasalize from an articulatory point of view, they are easier from an aerodynamic, acoustic and perceptual point of view

(A few) remaining questions

- Are these effects language-specific?
- Can this level of nuance be perceived? Can languages encode it in the grammar?
- What about mid vowels? Or more generally those cases where the NAS overestimates % nasal?
- How are we to account for speaker variation?
- Can a similar formula be applied to aerodynamic and/or non-instrumental acoustic data?

Potential implications

- In experimental phonological descriptions, vowel nasality may either be underreported or overreported.
- The DER may be a more accurate gauge of vowel nasality in clinical applications.

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References I

Baken, R. J. and Orlikoff, R. F. (2000). *Clinical measurement of Speech and Voice*. Singular.

Bell Berti, F. (1976). An electromyographic study of velopharyngeal function in speech. *Journal of Speech and Hearing Research*, 19:225–240.

Chen, M. Y. (1997). Acoustic correlates of English and French nasalized vowels. *Journal of the Acoustical Society of America*, 102(4):2360–2370.

Chen, M. Y. and Wang, W. S.-Y. (1975). Sound change: Actuation and Implementation. *Language*, 51:255–281.

Clark, W. M. and Mackiewicz Krassowska, H. (1977). Variation in the oral and nasal pressure levels of vowels in changing phonetic contexts. *Journal of Phonetics*, 5:195–203.

Clumeck, H. (1976). Patterns of soft palate movements in six languages. *Journal of Phonetics*, 4(4):337–351.

Delattre, P. (1954). Les attributs acoustiques de la nasalité vocalique et consonantique. *Studia Linguistica*, 7(2):103–109.

Delvaux, V. (2012). *Les voyelles nasales du français : aérodynamique, articulation, acoustique et perception*. Peter Lang, Bruxelles.

Delvaux, V., Demolin, D., J-Tarmegnies, B., and Soquet, A. (2008). The aerodynamics of nasalization in French. *Journal of Phonetics*, 36(4):578–606.

Dow, M. (2014). *Contrast and markedness among nasal (ized) vowels: A phonetic-phonological study of French and Vimeu Picard*. PhD thesis, Indiana University.

Hajek, J. and Maeda, S. (2000). Investigating universals of sound change: The effect of vowel height and duration on the development of distinctive nasalization. In Broe, M. and Pierrehumbert, J., editors, *Papers in Laboratory Phonology V*, pages 52–69. Cambridge University Press, Cambridge.

References II

Henderson, J. (1984). *Velopharyngeal function in oral and nasal vowels: A cross-language study.* PhD thesis, Universtiy of Connecticut.

House, A. S. and Stevens, K. N. (1956). Analog studies of the nasalization of vowels. *Journal of Speech and Hearing Disorders*, 21(2):218–232.

Krakow, R. A. and Huffman, M. K. (1993). Instruments and techniques for investigating nasalization and velopharyngeal function in the laboratory: An introduction. In Huffman, M. K. and Krakow, R. A., editors, *Phonetics and Phonology, vol. 5: Nasals, Nasalization and the Velum*, pages 147–167. Academic Press, New York.

Lubker, J. F. (1968). An electromyographic-cinefluorographic investigation of velar function during normal speech production. *Cleft Palate Journal*, 5:1–18.

Maeda, S. (1982). Acoustic cues for vowel nasalization: A simulation study. *Journal of the Acoustical Society of America*, 72, Suppl. 1:S102.

Maeda, S. (1993). Acoustics of vowel nasalization and articulatory shifts in French nasal vowels. In Huffman, M. K. and Krakow, R. A., editors, *Phonetics and Phonology, vol. 5: Nasals, Nasalization and the Velum*, pages 147–167. Academic Press, New York.

Montagu, J. (2007). *Etude acoustique et perceptive des voyelles nasales et nasalisées du français parisien*. PhD thesis, Université Paris 3.

Ohala, J. J. (1975). Phonetic explanations for nasal sound patterns. In Ferguson, C., Hyman, L., and Ohala, J. J., editors, *Nasálfest: Papers from a Symposium on Nasals and Nasalization*, pages 289–316. Stanford University, Department of Linguistics.

Rochet, A. P. and Rochet, B. L. (1991). The effect of vowel height on patterns of assimilation nasality in French and English. In *Proceedings of the 12th International Congress of Phonetic Sciences, vol. 3*, pages 54–57, Aix-en-Provence.

References III

Rossato, S., Badin, P., and Bouaouni, F. (2003). Velar movements in French: An articulatory and acoustical analysis of coarticulation. In *Proceedings of the 15th International Congress of Phonetic Sciences*, pages 3141–3144, Barcelona.

Spears, A. (2006). Nasal coarticulation in the French vowel /i/: A phonetic and phonological study. Master's thesis, University of North Carolina at Chapel Hill.

Straka, G. (1955). Remarques sur les voyelles nasales, leur origine et leur évolution en français. *Revue de Linguistique Romane*, 19:245–274.

Styler, W. and Scarborough, R. A. (2014). Surveying the nasal peak: A1 and P0 in nasal and nasalized vowels. *Journal of the Acoustical Society of America*, 136(4):2083.

Warren, D. W., Dalston, R. M., and Mayo, R. (1993). Aerodynamics of nasalization. In Huffman, M. K. and Krakow, R. A., editors, *Phonetics and Phonology, vol. 5: Nasals, Nasalization and the Velum*, pages 119–146. Academic Press, New York.

Appendix

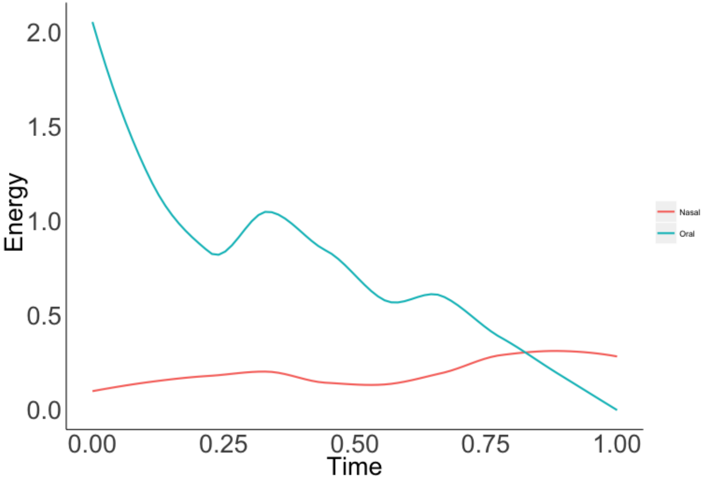
(A few) remaining questions, I

- **Q:** Are these effects language-specific?
  A: We can start by looking at Picard. Then...
- **Q:** Can this level of nuance be perceived? Can languages encode it in the grammar?
  A: Quite likely (cf. Maeda 1982), but link with DER needs to be established. Might be encodable in a more unidimensional interface/module.
- **Q:** What about mid vowels? Or those cases where the NAS overestimates % nasal?
  A: In all contexts (even V), E_o starts out much higher on non-high than on high vowels → sharper fall towards N. If E_n fails to rise at similar rates, this means $p \approx 70\%$ but negligible A_n.

(A few) remaining questions, II

- **Q:** How are we to account for speaker variation?
  A:
  - Anecdotes from the data: speakers seem to fall into groups according to rates of nasal energy rise, high vowel VN (small, middling and large rise)
  - Consistency within speakers may point to different status of phonologization of high vowel nasalization (needs to be teased apart with duration, as well)
  - More random variation may point to sloppy articulation (no contrastive high nasal vowels in French, ease of nasalization)
- **Q:** Can a similar formula be applied to aerodynamic and/or non-instrumental acoustic data?
  A: Quite likely again. Although difference between aerodynamic instruments and acoustic need to be worked out.

iN#N



NAS: 30%, DER: 7.8%

Low vowel, Bland-Altman plot