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Predicting Perceptual Similarity of French Vowels: The Influence of Phonology, Phonetics, and Frequency

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1. Background:

- Perceived similarity can be influenced by:
  1. inherent phonetic cues
  2. phonological relationships (Trubetzkoy 1969, Boomershine et al. 2008)
     a. lexical contrastiveness
     b. distribution uncertainty
  3. statistical patterns (Luce 1986; Pitt & McQueen 1998)
- **Current research question: What is the relative contribution of each of these factors on the perceptual confusability of French vowels?**

2. Methods:

Overview: Predict perceptual confusability measures using measures of acoustics, phonological relations, and frequency.

Part I: Perception Experiment

- Stimuli by a male native speaker of Continental French.
- Pseudo-words:[aC1VC2a], where C1, C2 = {b, d, g}, C1≠C2.
- Medial vowel: Null, or one of [i e ɛ y ø œ a u o ɔ ɛ̃ ɑ̃ ɔ̃], or French "schwa"/e-muet, which varies in pronunciation between [ø] and [œ] and is written orthographically as 'e', e.g. *le* 'the.'
- 6 consonantal contexts x 16 vowels = 96 tokens per listener.
- 25 native speakers of continental French listened to the pseudo-words, presented one at a time, and identified the vowel, if any, they heard between the consonants using key words.

Part II: Quantifying Predictors

- Acoustic measures of stimuli
  - Duration differences between vowel pairs (absolute value of the difference between the average percentages of word duration taken up by each vowel)
  - Euclidean formant distance between vowel pairs, using F1, F2, F3 (averaged over ⅓, ½, ⅔ measurement points)
- Phonological contrast from *Lexique* corpus (New et al. 2004)
  - Functional loads of pairs (# of minimal pairs and change in entropy; cf. Surendren & Niyogi 2006, Wedel et al. 2013)
  - Uncertainty of distribution of pairs (cf. Hall 2009, 2012)
- Frequency (also from *Lexique*)
  - Ratio of frequency of V1 to V2

PREDICTIONS:

- Symmetric predictors: LESS perceptual confusability due to greater acoustic difference between V1 and V2, greater functional load of V1 / V2, and greater uncertainty of distribution between V1 & V2.
- Asymmetric predictor: Greater frequency ratio of V1 / V2 should mean fewer misidentifications of V1 as V2.

3. Modeling:

Correct Response \ Given Response	'e'	[ø]	[œ]	[e]	[ɛ]	[o]	[ɔ]	[u]	[y]	[i]	[a]	[ɑ̃]	[ɔ̃]	[ɛ̃]	∅
'e'	**36.7**	38.0	24.7								0.7				
[ø]	26.7	**28.7**	44.7												
[œ]	31.3	40.7	**25.3**												2.0
[e]	0.7		1.3	**71.3**	26.7										
[ɛ]	0.7	0.7	1.3	22.7	**73.3**										0.7
[o]	2.0	1.3	2.7			**80.7**	11.3	1.3			0.7				
[ɔ]	5.3	3.3	4.0			32.0	**52.0**					2.0			0.7
[u]	2.7	2.0	2.0			0.7		**78.0**	13.3						1.3
[y]								0.7	**99.3**						
[i]										**100**					
[a]	0.7										**99.3**				
[ɑ̃]						0.7						**86.7**	12.0	0.7	
[ɔ̃]											0.7	4.7	**94.7**		
[ɛ̃]											0.7	8.0		**91.3**	

Table 1: Confusion data to be modeled: Percent accuracy of identification.

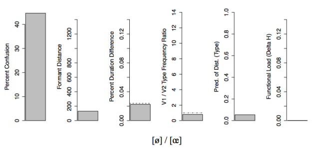
Table 2: Best-fit model, based on amount of variance accounted for:

Call: Confusability ~ Formant dist. + Type FR + Type UD + Delta-H FL + Formants: Type FR + Formants : Type UD + Formants : Delta-H FL + Type FR : Delta-H FL + Type UD : Delta-H FL + Formant dist. : Type UD : Delta-H FL + Formant dist. : Type FR : Delta-H FL

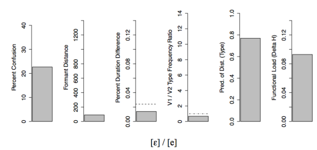
	Range of Measure (Unit)	Estimate	Std. Error	t-value	p-value
(Intercept)	--	68.000	5.786	11.754	<0.001
Formant dist.	47.74 – 651.62 (Hz)	-0.202	0.025	-8.060	<0.001
Type FR	0.13 – 14.0 (ratio)	-3.029	1.124	-2.694	0.012
Type UD	0.01 – 0.95 (bits)	-104.900	11.720	-8.955	<0.001
Delta-H FL	$1.5 * 10^{-7}$ – 0.09 (bits)	-1420.000	293.200	-4.842	<0.001
Formants : Type FR	--	0.011	0.003	3.799	0.001
Formants : Type UD	--	0.321	0.047	6.901	<0.001
Formants : Delta-H FL	--	4.914	1.288	3.816	0.001
Type FR : Delta-H FL	--	207.100	77.000	2.690	0.012
Type UD : Delta-H FL	--	2279.000	393.600	5.790	<0.001
Formant dist. : Type UD : Delta-H FL	--	-7.567	1.880	-4.025	<0.001
Formant dist. : Type FR : Delta-H FL	--	-0.841	0.297	-2.833	0.009

Residual standard error: 5.894 on 27 degrees of freedom
Multiple R-squared: 0.859
Adjusted R-squared: 0.8015
F-statistic: 14.95 on 11 and 27 DF, p-value: 9.216e-09

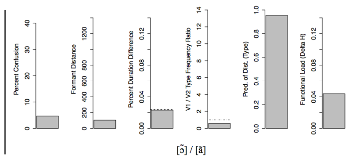
Figures: Examples of high confusability, mid confusability, and low confusability pairs. Each figure shows percent confusion and then the values of the predictors.



High confusability pairs: All predictor factors tend to work together to predict that the vowels will be confusable.



Mid confusability pairs: In this case, the relatively high values of UD and FL seem to mitigate the effects of very similar acoustic values.



Low confusability pairs: The even higher UD value, combined with a high-ish FL value seems to suppress confusability.

Overall patterns to note:

- Of a total of 196 pairs of vowels, 143 pairs had no confusability, and 12 had exactly one instance of a misidentification.
- Fifteen pairs had confusability between 1% and 10% of the time ("low" confusability).
- Four pairs had confusability between 10% and 25% of the time ("mid" confusability).
- Eight pairs had confusability more than 25% of the time ("high" confusability).
- The remaining 14 pairs are correct identifications.

Models:

- Linear regression models were created, using the predictor variables (formant distance, duration difference, functional load (FL), uncertainty of distribution (UD), and frequency ratio (FR)) to predict non-zero percent vowel confusions.
- For functional load, two different options were compared across models (# minimal pairs vs. change in entropy (ΔH)).
- For uncertainty of distribution and frequency ratio, both type and token frequency measures were compared across models.
- A total of 8 unique models with all possible combinations were compared (though no single model contained both FL, both UD, or both FR measure), with up to 3-way interactions.
- The maximum condition number, a measure of collinearity, was 7.5, which is typically thought to be low.
- Insignifcant effects (determined by F-test) were dropped stepwise, if they were not involved in a significant interaction.

4. Discussion:

- The confusability of French vowels is predicted by a range of interacting factors.
- A model that uses only acoustic factors (formant distance and durational difference) to predict confusability is statistically significant, but accounts for only 28% of the variance in the data – phonological and frequency factors are extremely important when vowels are in fact confusable.
- All vowel pairs that had a Euclidean distance in formant space of more than 652 Hz (n = 26) had zero confusability. But if vowels are close acoustically, other factors emerge as important in determining the extent of confusability.
- The predictor variables all had the expected effects: that is, a greater degree of formant distance, a greater frequency ratio, a greater degree of uncertainty of distribution, and a greater functional load each decrease the percentage of confusions.
- Duration differences were never found to be a significant predictor in any model.
- The effect of all three non-acoustic independent variables seems to be most strongly tied to their lexical function – i.e., it is change in entropy overall in the lexicon that matters for FL, and type-based measures of UD and frequency that emerge as most useful.
- When there is an asymmetry in vowel confusions (V1 is misidentified as V2 more than vice versa), V2 is always more frequent.
- The interactions indicate that these measures do indeed work together; an increase in one variable can lead to either an increase or a decrease in the predicted confusability of two vowels, depending on the values of the other variables.

5. References:

Adda-Decker, Martine, Philippe Boula de Mareuil, and Lori Lamel. 1999. "Pronunciation variants in French: Schwa and liaison." *Proceedings of ICPhS:* 2239-2242.
Blevins, Juliette. 2004. *Evolutionary Phonology: The Emergence of Sound Patterns.* Cambridge: Cambridge University Press.
Boomershine, Amanda, Kathleen Currie Hall, Elizabeth Hume, and Keith Johnson. 2008. "The influence of allophony vs. contrast on perception: the case of Spanish and English." In *Contrast in phonology: Perception and acquisition,* edited by Peter Avery, B. Elan Dresher and Keren Rice, 145-171. Berlin: Mouton.
Carton, Fernand. 1999. "L'épithèse vocalique et son développement en français parlé." *Faits de Langues* no. 13:35-45.
Féry, Caroline. 2003. "Markedness, faithfulness, vowel quality, and syllable structure in French." *Journal of French Language Studies* no. 13 (2):247-280.
Flemming, E. 1995. *Auditory representations in phonology.* Doctoral dissertation, Linguistics, UCLA, Los Angeles.
Fougeron, Cecile, Cedric Gendrot, and A. Bürki. 2007. On the phonetic identity of French schwa compared to /ø/ and /oe/. Paper read at 5emes Journees d'Etudes Linguistiques (JEL), at Nantes, France.
Goldsmith, John. 1995. "Phonological theory." In *The Handbook of Phonological Theory,* edited by John A. Goldsmith, 1-23. Cambridge, MA: Blackwell.
Hall, Kathleen Currie. 2009. *A probabilistic model of phonological relationships from contrast to allophony.* Doctoral dissertation, Linguistics, The Ohio State University, Columbus, OH.
Hall, Kathleen Currie. 2012. "Phonological relationships: A probabilistic model." *McGill Working Papers in Linguistics* no. 22 (1).
Hume, Elizabeth. 2003. "Language specific markedness: the case of place of articulation." *Studies in Phonetics, Phonology and Morphology* no. 9 (2):295-310.
Hume, Elizabeth. 2008. "Markedness and the Language User." *Phonological Studies* no. 11: 295-310.
Hume, Elizabeth, Kathleen Currie Hall, Andrew Wedel, Adam Ussishkin, Martine Adda-Decker, and Cédric Gendrot. 2013. "Anti-markedness patterns in French epenthesis: An information-theoretic approach." In *Proceedings of the Thirty-Seventh Annual Meeting of the Berkeley Linguistics Society,* edited by Chundra Cathcart, I-Hsuan Chen, Greg Finley, Shinae Kang, Clare S. Sandy and Elise Stickles, 104-123. Berkeley: Berkeley Linguistics Society.
Hume, Elizabeth, and Frédéric Mailhot. 2013. "The role of entropy and surprisal in phonologization and language change." In *Origins of sound patterns: Approaches to phonologization,* edited by Alan Yu, 29-50. Oxford: Oxford University Press.
Johnson, Keith, and Molly Babel. 2010. "On the perceptual basis of distinctive features: Evidence from the perception of fricatives by Dutch and English speakers." *Journal of Phonetics* no. 38:127-136.
Jun, Jongho. 1995. "Place assimilation as the result of conflicting perceptual and articulatory constraints." *Proceedings of West Coast Conference on Formal Linguistics* no. 14:221-237.
Kazanina, Nina, Colin Phillips, and William J. Idsardi. 2006. "The influence of meaning on the perception of speech sounds." *Proceedings of the National Academy of Sciences of the United States of America* no. 103 (30):11381-11386.
Ladd, D. Robert. 2006. "'Distinctive phones' in surface representation." In *Laboratory Phonology 8,* edited by Louis M. Goldstein, D. H. Whalen and Catherine T. Best, 3-26. Berlin: Mouton de Gruyter.
Landick, Marie. 1995. "The mid-vowels in figures: hard facts." *French Review* no. 68 (1):88-102.
Léon, Pierre, Parth Bhatt, and Renée Baligand. 1992. *Structure fu français moderne.* Toronto: Canadian Scholars' Press, Inc. Lindblom, Björn. 1986. "Phonetic universals in vowel systems." In *Experimental appoaches to linguistics,* edited by John J.
Luce, R. D. 1986. *Response times: Their role in inferring elementary mental organization.* New York: Oxford UP.
Lindblom, Björn. 1990. "Explaining phonetic variation: A sketch of the H&H theory." In *Speech production and speech modelling,* edited by William J. Hardcastle and Alain Marchal, 403-439. Dordrecht: Kluwer.
New, B., C. Pallier, M. Brysbaert & L. Ferrand. 2004. *Lexique 2:* A new French lexical database. *Behavior Research Methods, Instruments, and Computers* 36.516-24.
Noske, Roland. 1993. *A theory of syllabification and segmental alternation: With studies on the phonology of French, German, Tonkawa, and Yawelmani, Linguistische Arbeiten.* Germany: De Gruyter.
Ohala, John J. 1981. "The listener as a source of sound change." In *Papers from the parasession on language behavior,* edited by Carrie S. Masek, Robert A. Hendrick and Mary Frances Miller, 178-203. Chicago: Chicago Linguistic Society.
Pitt, M. A. & J. M. McQueen. 1998. Is compensation for coarticulation mediated by the lexicon? *JML* 39.347-70.
Steriade, Donca. 2001. "The phonology of perceptibility effects: the P-map and its consequences for constraint organization." In *The nature of the word: essays in honor of Paul Kiparsky,* edited by Sharon Inkelas and Kristin Hanson. Cambridge, MA: MIT Press.
Surendran, D. & P. Niyogi. 2003. Measuring the functional load of phonological contrasts. In *Tech.Rep No. TR-2003-12.* Chicago.
Trubetzkoy, Nikolai Sergeevich. 1969. *Principles of phonology.* Translated by Christiane A. M. Baltaxe. Berkeley: University of California Press. Original edition, 1939.
Wedel, A., A. Kaplan & S. Jackson. 2013. High functional load inhibits phonological contrast loss: A corpus study. *Cognition* 128.179-86.
Whalen, D. H., Catherine T. Best, and Julia R. Irwin. 1997. "Lexical effects in the perception and production of American English /p/ allophones." *Journal of Phonetics* no. 25 (4):501-528.