Acoustic and lexical effects on speech perception in Kaqchikel (Mayan)

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Our Project

Our project: the production-perception-lexicon interface in Kaqchikel (Mayan).

Methodological challenge: to model the production and perception of an under-resourced and under-studied language with small and noisy data collected in the field.

Outline

Goals of the talk:

- Report on:
  - Construction of spoken and written corpora.
  - An AX discrimination study on the perception of stop consonants.
- Examine:
  - The effect of acoustic and lexical factors on speech perception.
  - The time course of such effects.

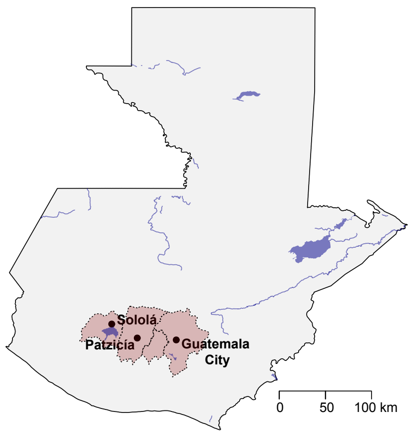
Outline

General findings:

- Both acoustic and lexical factors affect speech perception in Kaqchikel.
  - Indirect validation of small corpora for speech perception research.
- Both acoustic and lexical factors kick in early, and decay over time.
- Rich, experience-based factors influence perception even in low-level tasks which do not require lexical access.

Kaqchikel

Kaqchikel is a K'ichean-branch Mayan language spoken in the central highlands of Guatemala (over 500,000 speakers, Richards 2003, Fischer & R. M. Brown 1996: fn.3).



Phonemic consonants

	Bilabial	Dental/alveolar	Post-alveolar	Velar	Uvular	Glottal
Stop	p ɓ	t tˀ		k kˀ	q ʛ̥	ʔ
Affricate		t͡s t͡sˀ	t͡ʃ t͡ʃˀ			
Fricative		s	ʃ	x ~ χ		
Nasal	m	n				
Semivowel	w		j			
Liquid		l r				

(Campbell 1977, Chacach Cutzal 1990, Cojtí Macario & Lopez 1990, García Matzar et al. 1999, Majzul et al. 2000, R. M. Brown et al. 2010, Bennett 2016, etc.)

Perception study: procedure

Kaqchikel speakers heard pairs of [CV] (onset) or [VC] (coda) syllables.

- Vowels were always identical, but consonants could be different.
- Items embedded in speech-shaped noise generated from spoken corpus (0dB SNR, after amplitude normalization; LTAS over 4 hours of corpus).

Participants asked to respond SAME or DIFFERENT on a button box.

- **Assumption**: incorrect SAME responses indicate perceptual similarity between [C_1]~[C_2] pairs.

Perception study: stimuli

Item properties:

- V ∈ /a i u/
- C ∈ all consonants of Kaqchikel
  - Target pairs: C ∈ /p ɓ t tˀ k kˀ q qˀ (ʔ)/ (no affricates)
  - Filler pairs: any other consonant combination
- Syllables recorded by native speaker of Patzicía Kaqchikel (Ajsivinac).

Each participant heard 200 total trials (6000 pairs, in 30 randomized lists).

Perception study: presentation

Timing details:

- ISI = 800ms (250ms of noise padding before/after each syllable + 300ms silence between items)
- Inter-trial interval = 1500ms
- Up to 10 seconds to respond without receiving a warning.
  - Most responses under 1 sec. (mean RT = 854ms, median RT = 664ms)

Moderate ISI and response times may have favored a **linguistic mode of speech processing**.

(Pisoni 1973, 1975, Pisoni & Tash 1974, Fox 1984, Werker & Logan 1985, Kingston 2005, Babel & Johnson 2010, McGuire 2010, Kingston et al. 2016 and references there)

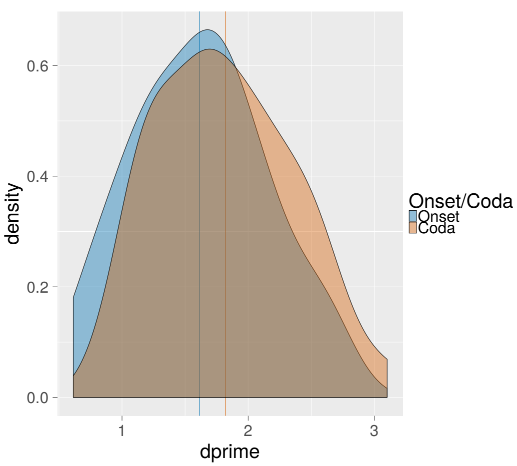
Perception study

45 participants (44 completed the study).

- All speakers of Patzicía Kaqchikel.
- Good mix of ages and genders.
  - 13 male, 31 female
  - Ages 18-50 (mean = 26, median = 25, SD = 6.2)

General findings

Relatively good discrimination: $\mathrm{d}'_{\mu} \approx 1.75$



General findings

Dorsals confusable with each other, apart from /kˀ/ (see also Shosted 2009).

- **Onset [TV] d'**: /k q qˀ/∼/k q qˀ/ 1.23 < all others 1.65
- **Coda [VT] d'**: /k q qˀ/∼/k q qˀ/ 1.50 < all others 1.85

/ɓ/ frequently confused with /p ʛ̥ ʔ/.

- **Onset [TV] d'**: /ɓ/∼/p qˀ ʔ/ 0.77 < /ɓ/∼all others 1.61; highest d' rank = 32/36
- **Coda [VT] d'**: /ɓ/∼/p qˀ ʔ/ 1.16 < /ɓ/∼all others 1.88; highest d' rank = 31/36

Corpus criticism

- Spontaneous speech is *naturalistic*, but...
- ...leads to data sparsity (cf. Xu 2010)
  - $/\mathrm{t}^{ʔ}/$ is rare (18, <1% of stops; England 2001, Bennett 2016)
  - Large skew toward prevocalic $[\mathrm{CV}]$ stops (>85%)
- Narratives, not dialogues (cf. CALLHOME, Switchboard)

Corpus construction

To test for an effect of lexical measures on speech perception, we compiled a text corpus of Kaqchikel:

- Corpus size: 1 million word tokens.
  - Constructed from existing religious texts, spoken transcripts, government documents, and educational books.
- Compare:
  - Kučera & Francis (1967): 1.014 million words of English
  - van Heuven et al. (2014): 201 million words of English

Corpus criticism

- Not huge — poor estimates of low frequency words (Brysbaert & New 2009)
- Not terrifically speech-like — too religious and governmental.
- Noisy — OCR errors, typos, new-line hyphens...
  - Applied various filters to clean up the corpus (see Appendix).

Acoustic similarity

Expectation: greater acoustic similarity predicts greater perceptual similarity.

Two kinds of acoustic similarity:

- STIMULUS SIMILARITY
- CATEGORY SIMILARITY: similarity of two phoneme categories based on *prior phonetic experience*.
  - Specifically: **category overlap**

Acoustic similarity

We used DYNAMIC TIME WARPING to estimate acoustic similarity (Sakoe & Chiba 1971, Mielke 2012)

- Stimulus similarity: over stimulus pairs.
- Category similarity:
  - Over all possible [CV] and [VC] pairings in the acoustic corpus
  - Pairs matched for stress and vowel quality.

DTW gives us a similarity metric for each pair of stimuli/sounds.

Lexical factors

Well-known that lexical factors interact with speech perception:

- Wordhood (e.g. Ganong 1980)
- Word frequency (e.g. C. R. Brown & Rubenstein 1961, Broadbent 1967, Vitevitch 2002, Felty et al. 2013, Tang & Nevins 2014, Tang 2015: Ch.4)
- Bigram frequency (e.g. Rice & Robinson 1975, Carreiras et al. 1993, Barber et al. 2004, Albright 2009, González-Alvarez & Palomar-García 2016)
- Segmental frequency (e.g. Kataoka & Johnson 2007, Tang 2015: Ch.4, Bundgaard-Nielsen et al. 2015)
- Neighborhood density (e.g. Luce 1986, Yarkoni et al. 2008, Bailey & Hahn 2001, Gahl & Strand 2016)
- Functional load/Presence of minimal pairs (e.g. Martinet 1952; Baese-Berk & Goldrick 2009, Graff 2012, Goldrick et al. 2013, Hall & Hume submitted)
- Etc.

Results

Analyzed participant accuracy with a mixed-effects logistic regression in R (R Development Core Team 2013, Bates et al. 2011)

Parameters:

- Fixed effects:
  - All acoustic and lexical factors mentioned above (no interactions).
  - Response time (z-scored by participant)
- Random effects:
  - Participant
  - By-participant slopes for lexical factors
  - Nuisance factors (item, list, stimulus order, onset/coda)

Full model reduced by step-down model selection.

Explanatory factors

	β	SE(β)	$\|t\|$	p-value
(Intercept)	0.8042	0.1621	4.963	6.95e-07***
Acoustic stimulus similarity	-1.0720	0.1151	9.316	2e-16***
Acoustic category similarity	-0.3876	0.1238	3.131	0.00174**
Functional load	0.4653	0.1649	2.822	0.00477**
Distributional overlap	-0.6320	0.1607	3.933	8.38e-05***
Word token frequency diff.	0.1848	0.1068	1.731	0.08353·

Stimulus similarity and category similarity

Both stimulus similarity and category similarity had an effect on discriminability in the perception study.

Possible interpretation:

- Discrimination is mediated by some representation of prior phonetic experience.
- These representations include rich acoustic detail for individual phoneme categories.
- Consistent with exemplar-type theories of lexical representation (e.g. Pierrehumbert 2001, 2016, Johnson 2005, Gahl & Yu 2006 and references there)

Lexical Factors – Contrastiveness

Both functional load and distributional overlap play a role in discrimination.

A possible interpretation:

- Discrimination is mediated by **how contrastive** two phonemes are
  - Importance for minimal contrasts.
  - Relative predictability.
- The perceptual space is warped by contrastiveness.
  - Consistent with Hall's (2012) Probabilistic Phonological Relationship Model.

Time course

Assumption: segment-level phonetic processing occurs prior to lexical activation in speech processing.
(e.g. Fox 1984, Norris et al. 2000, Kingston 2005, Babel & Johnson 2010, Kingston et al. 2016, etc.)

Predictions about the time-course of effects:

- Acoustic factors > Lexical factors
- Segment-level > Word-level

Time course effects

Responses binned according to by-participant RT terciles.

	Early ($\mu \approx$ 400ms)	Middle ($\mu \approx$ 650ms)	Late ($\mu \approx$ 1200ms)
Acoustic stimulus similarity	-1.4515***	-1.1651***	-0.74647***
Acoustic category similarity	-0.6544**	-0.3020$^{\cdot}$	-0.28756*
Functional load	0.9001**	0.4116$^{\cdot}$	0.28513$^{\cdot}$
Distributional overlap	-1.1437***	-0.8765***	-0.27972$^{\cdot}$
Word token frequency diff.	0.2671$^{n.s.}$	0.2314$^{n.s.}$	0.06068$^{n.s.}$

Time course effects

Predictions about the time-course of effects:

- Acoustic factors > Lexical factors
- Segment-level > Word-level

Not borne out!

- Acoustic measures active early, and weaken over time.
- Same pattern for lexical measures (functional load, distributional overlap).
- Includes an experience-based measure of acoustic similarity (acoustic category distance)

Conclusions

Our results suggest:

- Speech perception is mediated by phonetically rich memory traces associated with phonemic categories (exemplar theory).
- Lexical effects related to a graded notion of contrastiveness may affect speech perception.
- Lexical factors may have kicked earlier than predicted by 'modular' models of speech processing.
  - Did not find evidence that acoustic/phonetic processing precedes lexical activation.
  - Suggests co-activation of low-level and high-level factors. (McClelland & Elman 1986, McClelland et al. 1986, 2006)
  - Such activation appears to decay fairly quickly. (See too Kingston et al. 2016)

Conclusions

Three caveats:

- Classic findings of late time course for lexical effects involve LEXICAL ACCESS (e.g. Ganong effect, Ganong 1980, Fox 1984, etc.)
  - Not clear that our 'lexical' measures—functional load, distributional overlap—involve lexical access in the same sense.
- Our ISIs may have been too long to 'catch' a purely pre-lexical stage of processing, even for fast response times (ISI = 800ms)
- Gradual decay (rather than increase) in strength of lexical effects over time may be more consistent with autonomous, feed-forward models (e.g. MERGE) than richly interactive models (e.g. TRACE) (TRACE, McClelland & Elman 1986, McClelland et al. 2006; MERGE, Norris et al. 2000; see again Kingston et al. 2016).

Conclusions

Small, noisy corpora can make valuable contributions to speech perception research — provided they are carefully processed.

References

References available on request.

Slide download

Slides available for download at

http://tang-kevin.github.io/Files/Slides/Bennett_Tang_LSA2017.pdf