Synchronic knowledge of phonetically unnatural classes

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Phonological classes

Phonologists study the patterning of sound classes in language

- ‘voiced stops don’t occur word finally’

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Phonologists study the patterning of sound classes in language

- '**voiced stops** don't occur word finally'

We're interested in the distribution of groups of sounds, not individual sounds

- [ptk] as a class, compared to [bdg] as a class

Restrictions on individual sounds are often considered 'accidental gaps'

- They may be mentally represented, but they are outside of the core phonological system

Phonological classes

Phonological classes are defined by features, which refer to phonetic properties

- The phonetic definition may be complex and fairly abstract

The feature [voice] is a label for a collection of language dependent properties that distinguish /b d g/ from /p t k/

- vibration during closure, voice onset time, F0 & F1 at transition, vowel length, burst amplitude, closure duration, tongue root position, glottal height, etc.

In the 'normal' case, sound classes are both phonetically and phonologically supported

- The classes that emerge from phonetic analysis are those that are referenced by the phonology

Phonological classes

Phonetics-phonology isomorphy

- Phonological classes emerge from phonetic analysis (bottom up information)
- Phonological classes are used in stating abstract patterns (top down information)

But: substantial phonetic variability in the production of a category or class is also the norm

Today: phonetics-phonology mismatch

- In Bolivian Quechua, /q/ patterns as a stop but is frequently lenited [ʁ] (among other variants)

Structure of the talk

- Phonological description of Quechua
- Evidence that speakers have learned the distribution of /q/
- Phonetic study of /q/
- Some problems for learning phonetically diverse classes

Quechua

Quechua

Quechua is a language family with ~10 million speakers throughout the Andes (Colombia, Ecuador, Peru, Bolivia, Chile, Argentina)

South Bolivian Quechua: spoken by ~1.5 million in the central valleys and altiplano of Bolivia

Quechua

The consonantal inventory of Quechua includes lots of stops

	labial	dental	postalveolar	velar	uvular	glottal
plain	p	t	tʃ	k		
ejective	p’	t’	tʃ’	k’	q’	
aspirate	p^h	t^h	$tʃ^h$	k^h	q^h	
fricative		s	ʃ	x		h
nasal	m	n	ɲ			
approximant	w	l r	ʎ j			

Quechua

The consonantal inventory of Quechua includes lots of stops

	labial	dental	postalveolar	velar	uvular	glottal
plain	p	t	tʃ	k	/q/ = [ʁ]	
ejective	pʼ	tʼ	tʃʼ	kʼ	qʼ	
aspirate	p^h	t^h	$tʃ^h$	k^h	q^h	
fricative		s	ʃ	x		h
nasal	m	n	ɲ			
approximant	w	l r	ʎ j			

[ʁ] is a stop: syllable structure

Stops can’t occur before other consonants, or word-finally.

misk'i	'delicious'	t'anta	'bread'	waʌpa	'chicken’
ʌaxta	'town'	pampa	'plain'	mirk^{h}a	'freckle’

*mipk’i, *watʌa etc.

Like the other stops, [ʁ] cannot occur in pre-consonantal or final position.

ʁaymi	‘festival’	*yaʁmi
p’isʁo	‘bird’	*siʁp’o

[ʁ] is a stop: cooccurrence restrictions

Ejectives and aspirates occur word medially in words with initial fricatives or sonorants

ɾi**t'**i	'snow'	**m**os**q^{h}**oj	'to dream'
sa**ʧ'**a	'tree'	**ʌ**im**p^{h}**i	'color'

Ejectives and aspirates may not follow other stops in the word

*__t__an__t'__a	*__p__os__q^{h}__oj
*__k__a__ʧ'__a	*__ʧ__im__p^{h}__i

[ʁ] patterns with the stops – it cannot be followed by ejectives or aspirates later in the word

*__ʁ__a__p'__a	*__ʁ__a__t^{h}__a

Behavioral evidence for the status of [ʁ]

Evidence for phonological classes

Distributional patterns (syllable structure, cooccurrence restrictions) and inventory structure constitute phonological evidence for a class of stops that includes [ʁ] (= /q/)

We can also look for behavioral evidence that speakers make use of such a representation

General methodology: compare speakers' treatment of nonsense words

- control forms: phonotactically legal medial ejective: [map'i]
- unattested combinations with true phonetic stop: *[kap'i]
- unattested combinations with sonorant uvular 'stop': *[ʁap'i]

Two types of tasks

- Repetition: listen to a word and repeat it
- Forced choice wordlikeness judgment: listen to two words, pick which one sounds more 'natural'

Repetition: methods

19 balanced Quechua-Spanish bilinguals in Cochabamba, Bolivia

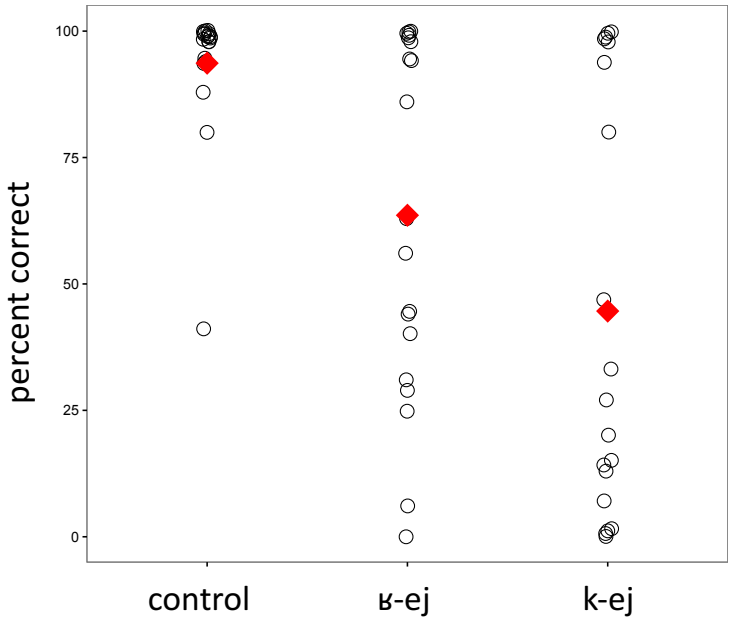
Instructions: listen to a word and repeat exactly what you hear

control *n* = 10	velar-ejective *n* = 10	uvular-ejective *n* = 10	filler *n* = 30
maʌʧ'i	*kaʌʧ'i	*ʁaʌʧ'i	ʧaxri
sit'u	*kit'u	*ʁet'u	ʌasku
wajk'i	*kap'a	*ʁap'a	santu

Repetition: results

Accuracy differs between the three categories

- control > uvular-ejective ($p < 0.001$)
  - more errors on *[ʁap'i] than on grammatical [map'i]
- uvular-ejective > velar-ejective ($p < 0.01$)
  - more errors on *[kap'i] than on *[ʁap'i]



Forced choice: methods

26 balanced Quechua-Spanish bilinguals in Cochabamba, Bolivia

Instructions: listen to a pair of nonsense words, choose which one is more 'natural'

control *n* = 12	velar-ejective *n* = 12	uvular-ejective *n* = 12	filler *n* = 24
maʌʧ'i - ʧ'aʌmi	*kaʌʧ'i - ʧ'aʌki	*ʁaʌʧ'i - ʧ'aʌʁe	ʧaxri - raxʧi
siɲʧ'u - ʧ'insu	*kiɲʧ'u - ʧ'iŋku	*ʁeɲʧ'u - ʧ'eɴʁo	ʌasku – kasʌu
wajʧ'i - ʧ'ajwa	*kap'a – p'aka	*ʁap'a – p'aʁa	santu - tansu

All pairs contrasted the positions of C_1 and C_2 in $C_1V(C)C_2V$ strings

- Control – what is the general preference for ejectives in initial or medial position?
- Velar-ejective/uvular-ejective – how does the positional preference change when medial is unattested?

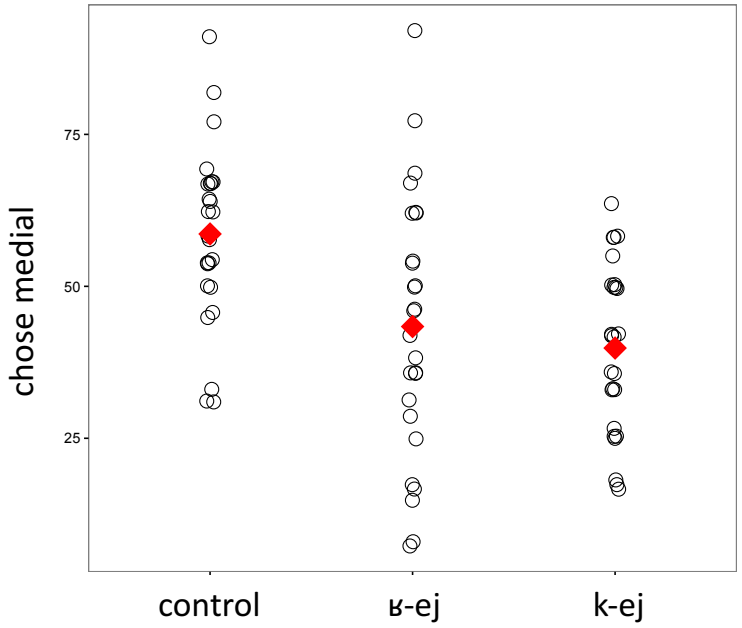
Forced choice: results

control: **prefer medial** ejective
- 57%, e.g. maʌʧ’i > ʧ’aʌmi

ʁ-ej: **disprefer medial** ejective
- 43%, e.g. *ʁaʌʧ'i > ʧ’aʌʁe

k-ej: **disprefer medial** ejective
- 40%, e.g. *kaʌʧ'i > ʧ’aʌki

- control > uvular-ejective, (p = 0.007)
- uvular-ejective ≈ velar-ejective, (p = 0.60)



Summary & interpretation

In both tasks, control stimuli differ from k-ejective and [ʁ]-ejective

- k-ejective and [ʁ]-ejective combinations are **systematically** absent
- the grammar penalizes forms with these combinations

*k-ejective has stronger effect than *[ʁ]-ejective in repetition; no difference in forced choice

- Could be a grammatical difference, where [ʁ]-ejective forms are penalized less
- Or [ʁ]-ejective forms are equally ungrammatical, but pose fewer difficulties in repetition task

There are two grammatical possibilities

- Option 1: Two separate restrictions, *stop-ejective and *[ʁ]-ejective
- Option 2: One grammatical restriction, *stop-ejective ([ʁ] is a 'stop', mapped to /q/)

The phonetics of stops and /q/

Phonetic classes

Phonological classes of sounds can often be defined based on shared phonetic properties

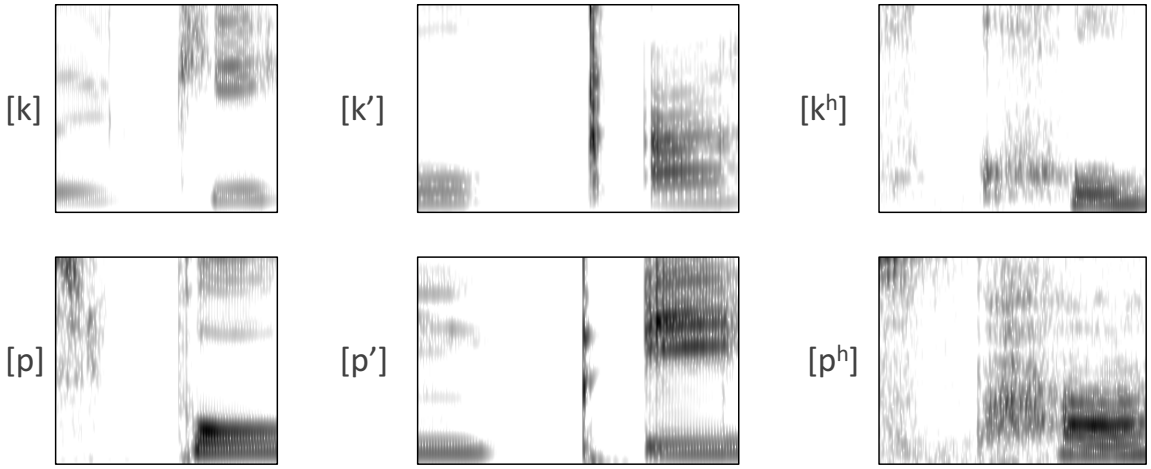
- Often this phonetic definition is multi-dimensional
- It always requires some analysis – all sounds are both similar and different from all other sounds

Unambiguous stops in Quechua have a silent closure, and a burst of some kind

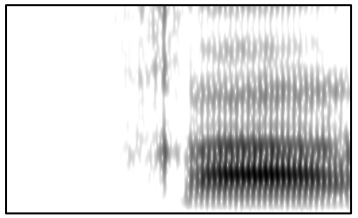
- The quality and length of the burst differ greatly, by place of articulation and laryngeal category

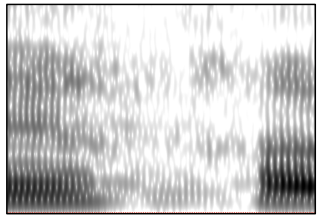
/q/ has many different realizations (at least [q χ ʁ ɢ]), many of which lack either a silent closure or a burst

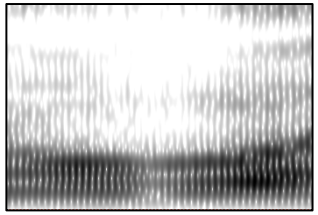
Some Quechua stops

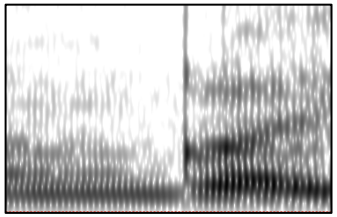


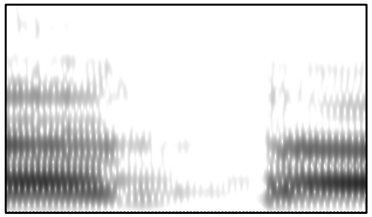
Acoustics of /q/

[q] 

[χ] 

[ʁ] 

[ɢ] 

closure, no burst 

Acoustics of /q/

Spontaneous speech collected via interview with 10 bilingual speakers

- Voiceless stop productions are attested, but lenition is more common

	q	no burst	χ	ʁ	ɢ	*n*
all contexts	25%	9%	13%	45%	19%	*582*

/q/ by context – running speech

Variation reflects familiar contextual preferences for voicing and manner.

	q	no burst	χ	ʁ	ɢ	*n*
V _ V	24%	6%	14%	55%	1%	*375*
s _	34%	29%	30%	7%	--	*70*
r _	13%	10%	34%	39%	3%	*97*
n _	37%	--	--	32%	32%	*19*
# _	56%	6%	11%	22%	6%	*18*

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Summary of acoustics

/q/ is most often intervocalic and produced as [ʁ]

There is phonetic evidence for /q/ as a stop

- [q] production is attested in all contexts (for almost all speakers)
- Some contexts favor stop production
- Some speakers produce more stops than others

Learning phonotactics with phonetic variation

Phonetic variation and learning

Behavioral and distributional evidence suggests that /q/-ejective combinations are systematically unattested.

Speakers may have mapped all realizations to /q/, and learned a single constraint against stop-ejective combinations

- Phonemic analysis: how do Quechua speakers learn that /q/ ([q ʁ χ ɢ…]) is a single category?
- Featural analysis: how do Quechua speakers learn that /q/ ([q ʁ χ ɢ…]) is a 'stop'?
  - Belongs to the same natural class as /p t ʧ k/, has the features [-continuant, -sonorant]

Or, speakers may have ad-hoc constraints against [ʁ]-ejective, [χ]-ejective, etc.

- Often, natural classes are used to distinguish systematic from accidental gaps, with the goal of avoiding ad hoc constraints of this type
- Is a phonotactic grammar of learnable from surface transcriptions?

Learning simulations

UCLA Phonotactic Learner (Hayes and Wilson 2008)

- Uses statistical techniques to induce constraints on systematically underattested patterns in a set of learning data
- Returns a weighted constraint set and assigns grammaticality scores to nonce forms

Learning data: list of 10k Quechua words from *Ñawpaqman*, a newspaper

- Onsets only (unrealistic, but easier to interpret for present purposes)

Representations

- Phonemic 'UR' features
- Surface features

Match results to behavioral data: control > velar-ejective, uvular-ejective

Phonemic representation

/q/ is transcribed as [q], given the manner features [-continuant, -sonorant] (voiceless stop)

/**q**un**q**aj**m**an/	given to learner as	q q m
/**q**un**q**u**r**i**k**ux**t**ij**k**u/		q q r k t k
/**q**un**q**uj**m**an/		q q m

The model learns constraint *[-continuant, -sonorant][+cg] (*stop…ejective)

The model distinguishes between systematic and accidental gaps, makes no other distinctions

	score
control	0 (perfect)
k-ej	-19
q-ej	-19

Surface features

/q/ is transcribed as [q ʁ χ ɢ] based on results from the interview data

- Transcription is proportional by context, e.g., initial /q/ is 62% [q], 22% [ʁ], 11% [χ], 6% [ɢ]

/**q**un**q**aj**m**an/	given to learner as	q ɢ m
/**q**un**q**uri**k**ux**t**ij**k**u/		q ʁ r k t k
/**q**un**q**uj**m**an/		ʁ q m

- Each variant is given surface phonetic features
  - [q] = [-continuant, -sonorant, -voice]
  - [ʁ] = [+continuant, +sonorant, +voice]
  - [χ] = [+continuant, -sonorant, -voice]
  - [ɢ] = [-continuant, -sonorant, +voice]

Surface features

The model learns

- *[-sonorant, -continuant][+cg] (no stop…ejective)
- *[+dorsal][+cg] (no [k kʼ k^h q qʼ q^h ʁ χ ɢ]…[ejective])

The model distinguishes control forms from illegal forms, but predicts substantial variation among illegal forms

Surface features

	score
control	0 (perfect)
k-ejective	-40
q-ejective	-40

	score
ʁ-ejective	-20
χ-ejective	-20
ɢ-ejective	-20
p-ejective	*-20*

k-ejective & q-ejective forms violate both constraints; other uvulars or stops violate just one

Prediction: [k]-ejective should be twice as bad as [ʁ]-ejective

- Behavioral results: [k]-ejective is the same or slightly worse than [ʁ]-ejective

Prediction: [k]-ejective should be twice as bad as [p]-ejective

- No differences found looking back through previous studies

Summary

Grammars learned from phonemic transcriptions and surface transcriptions differ

Surface transcriptions result in more constraints, with overlap, predicting too much variation among unattested forms

Transcribing [ʁ χ] doesn't prevent the model from learning the restriction on these sounds

- While these sounds aren't stops, they are uvular
- The model can learn the distribution of [ʁ χ] without also learning other constraints on accidental gaps
- The model doesn't actually need to find ad hoc constraints on individual segments, it can still learn general constraints on classes
- This is a happy accident in Quechua, might not generalize to other languages

Phonotactic learning from surface transcriptions may be possible, but the current model isn't perfect

Discussion

Overview of findings

Phonetic variation and sound change can easily lead to phonological patterns holding over phonetically unnatural classes on the surface

- Quechua /q/ patterns like a stop but is produced on the surface as [q χ ʁ ɢ]

Behavioral experiments show that Quechua speakers learn a phonotactic restriction of this type

- [ʁ]-ejective forms are treated as ungrammatical by speakers

Acoustic data shows that lenited forms are the majority

- [q] realizations likely help learners establish a "stop" label for this highly variable category

Learning simulations lightly favor the representation of a single stop category /q/

- With surface transcriptions, overlapping constraints predict excessive variation among absent forms

Outstanding questions

The repetition task supports a stronger restriction on [k]-ejective than [ʁ]-ejective forms

- This could be support for phonotactic constraints over surface representations.
- No difference is found on forced choice

Could a learning algorithm be tweaked to learn a better grammar from surface transcriptions?

- And how does surface transcription change the learning problem in other languages?

How would speakers learn a 'stop' representation from the highly variable phonetic signal?

- How is [q χ ʁ ɢ] mapped to /q/?
- How is distributional information integrated into the construction of phonological representations?

'Unnatural' classes come in many flavors

- The Quechua pattern is supported by two phonological patterns, as well as true [q] productions
- Is there behavioral evidence for unnatural classes in other languages with different types of support?

Thank you!

Repetition: results

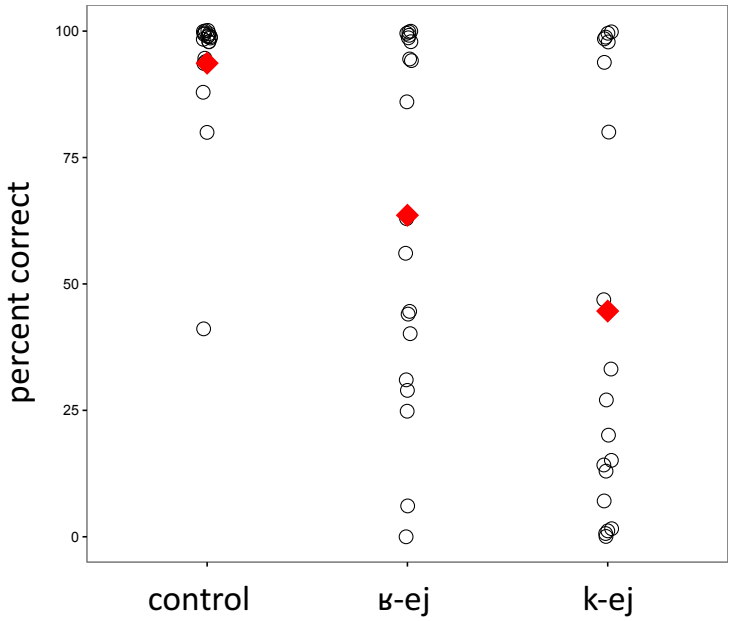
Accuracy differs between the three categories

- control > uvular-ejective ($p < 0.001$)
  - more errors on *[ʁap'i] than on grammatical [map'i]
- uvular-ejective > velar-ejective ($p < 0.01$)
  - more errors on *[kap'i] than on *[ʁap'i]

Errors

- *[kap'i] → [k'api], 32%
- *[kap'i] → [kapi], 18%

- *[ʁap'i] → [q'api], 4%
- *[ʁap'i] → [ʁapi], 32%



/q/ by context - isolation

Variation and lenition are both common in running speech, for all sounds in all languages

- Is there anything special about the Quechua case?

Word list data is perhaps informative of representations, a 'canonical' form

- 9 speakers produced 5 isolation words with /q/ in each context (45 tokens per cell)

	q	no burst	χ	ʁ	ɢ
# _	62%	2%	13%	18%	4%
V _ V	16%	24%	20%	40%	--
n _	18%	--	--	22%	60%