An ultrasound investigation of /l/-darkening in varieties of English

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/l/-darkening

- ▶ The process whereby /l/ is realised with a delayed and/or reduced tongue-tip gesture.
- ▶ Generally stated that light [l] is found in onsets, e.g. *light, love*, and dark [ɫ] is found in codas, e.g. *dull, fall*.
  - ▶ Controversy over whether such a categorical distinction is the right way of characterising this variation.
- ▶ Subject to morphosyntactic conditioning, varying from dialect to dialect.

Morphosyntactic conditioning of /l/-darkening

	light	*helium*	*heal-ing*	*heal it*	*heal*	
RP	[l]	[l]	[l]	[l]	[ł]	Cruttenden (2001)
Am. Eng. 1	[l]	[l]	[l]	[ł]	[ł]	Sproat & Fujimura (1993)
Am. Eng. 2	[l]	[l]	[ł]	[ł]	[ł]	Olive et al. (1993)
Am. Eng. 3	[l]	[ł]	[ł]	[ł]	[ł]	Hayes (2000)

Table 1: Adapted from Bermúdez-Otero (2007)

- Different dialects exhibit different types of morphosyntactic sensitivity.
- However, these claims are typically based on impressionistic transcription, judgement elicitation experiments, or acoustic evidence, all of which have proved difficult to interpret and may not be reliable (see Gick, 2006).
- Articulatory data are much more reliable, but are missing for many dialects (only available for American English 1 in this table).
- Dark [ł] in *helium* in Am. Eng 3 reflects an effect of stress, which isn't relevant to the varieties discussed for this presentation.

Research question

What determines the amount of darkening, as measured by articulatory criteria, that /l/ displays in different morphosyntactic environments in different dialects of English?

Two approaches in the existing literature:

1. Variability is purely gradient
2. Variability involves discrete allophones and is entirely down to category mixture.

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1. Variability is purely gradient
2. Variability involves discrete allophones and is entirely down to category mixture.

A gradient interpretation

- There is no categorical distinction between discrete light and dark allophones, i.e. [l] vs [ɫ], but only a gradient continuum of darkness.
- This claim has been argued for by, amongst others:
  - Sproat and Fujimura (1993), who argue that darkness depends on duration: the longer the pre-boundary rime, the darker the /l/.
  - Lee-Kim et al. (to appear), who say that the morphosyntactic parameter of boundary strength directly affects gestural coordination.

Gradient interpretation: Sproat and Fujimura (1993)

- Analysed /l/s in 9 contexts.
- Used X-ray microbeam technology which allowed them to monitor gestural phasing.
- They found that in light [l]s the coronal gesture precedes the dorsal gesture, and in dark [ɫ]s the dorsal gesture precedes the coronal.
- They argue that darkening is gradient, dependent on duration, and that gestures are aligned with adjacent segments.

Gradient interpretation: Lee-Kim et al. (to appear)

- Analysed /l/ in three phonological contexts: final (e.g. *cool*), intervocalic pre-boundary (e.g. *cool-est*) and intervocalic post-boundary (e.g. *flaw-less*)

- Used ultrasound, allowing for analysis of articulatory correlates of darkness such as tongue body lowering and tongue dorsum retraction.

- They found that /l/s were darkest in the final contexts, followed by pre-boundary, with post-boundary being the lightest: *cool* > *cool-est* > *flaw-less*
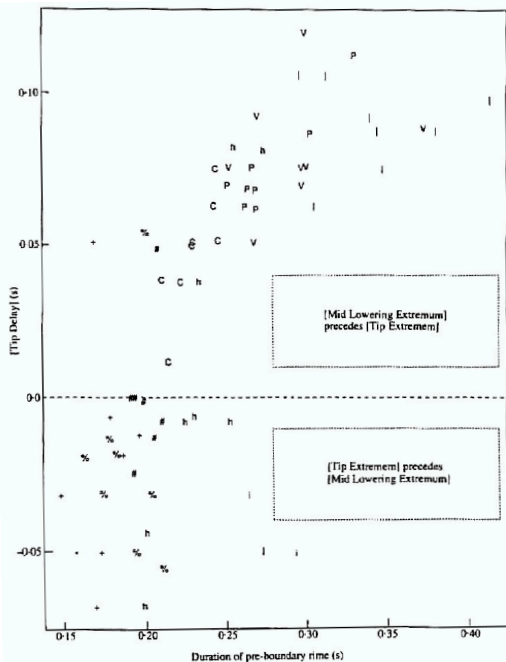
- They argue that this is evidence of a continuum.

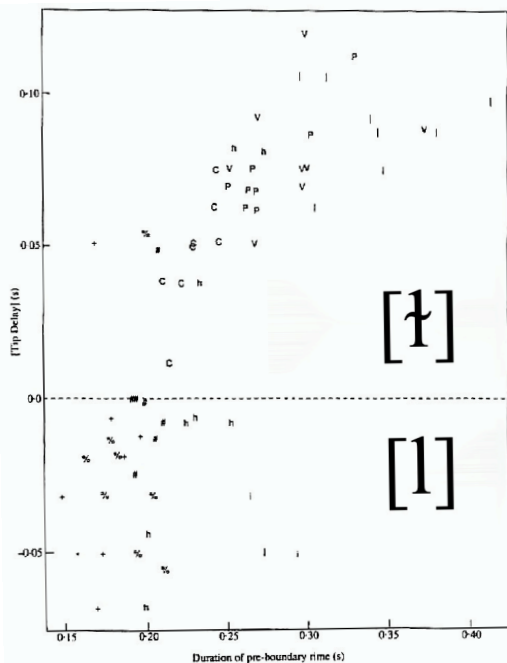# Categorical interpretation: category mixture (Hayes, 2000)

- There may be some low-level duration-driven effects, but the main distributional facts reflect the probabilistic application of variable, morphosyntactically sensitive, categorical phonological processes.

- Modelled with OO-correspondence and in Stochastic OT (Boersma and Hayes, 2001).

- Acceptability judgements for [ɫ] in a given environment directly reflect the probability of /l/ becoming categorically dark in production in that environment.
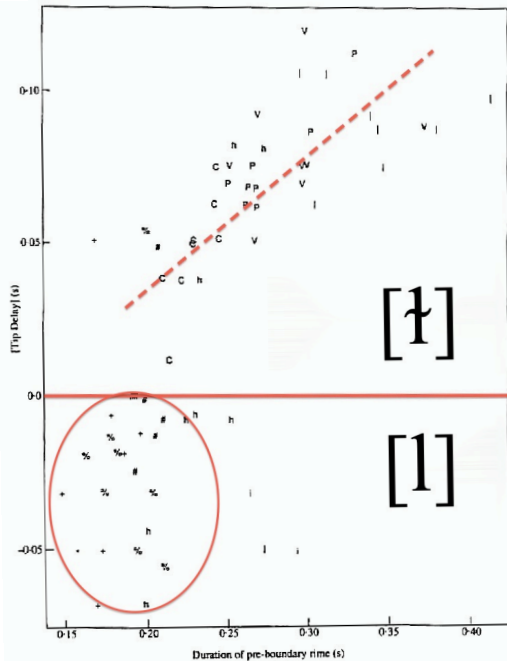
Problems with a purely gradient interpretation

A purely gradient approach underestimates the categorical effects.

- ▶ Sproat and Fujimura don't test for categoricity. They demonstrate that the articulatory degree of darkness is correlated with duration, but they fail to show that duration completely accounts for darkness.
    - ▶ Yuan and Liberman (2009, 2011) found that, in their corpus, only the darker /l/s in non-foot-initial position exhibited a significant effect of duration.

- ▶ Furthermore, Sproat and Fujimura's own diagram shows a correlation between duration and darkness for the "dark /l/s" only...

Problems with a purely gradient approach

In addition, Lee-Kim et al. underestimate
the possibility of categoricity.

- ▶ They only consider three phonological
  contexts (*cool, cool-est, flaw-less*)

- ▶ By sampling the distribution so
  coarsely, they don't have enough data
  to distinguish between categorical and
  gradient effects.

- ▶ They see differences between the
  three contexts as three categories,
  which they assume must be wrong.

Figure 2: Dorsum retraction extremum by
duration (Sproat and Fujimura, 1993:302)

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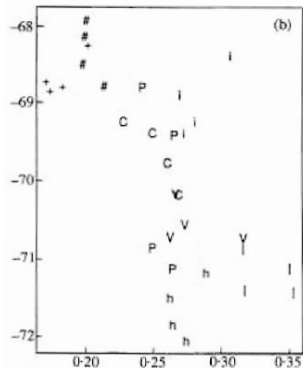 which they assume must be wrong.

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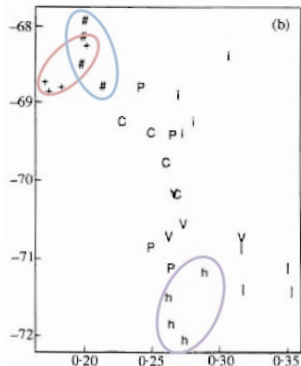 which they assume must be wrong.

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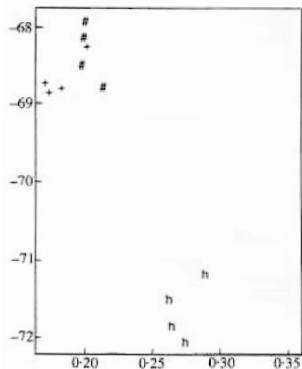 which they assume must be wrong.

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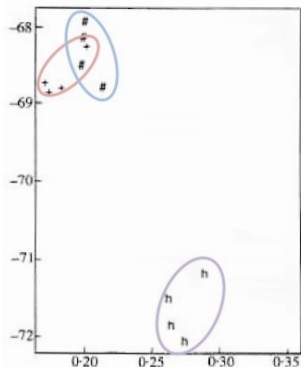- They see differences between the three contexts as three categories, which they assume must be wrong.

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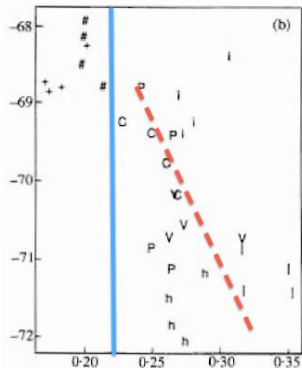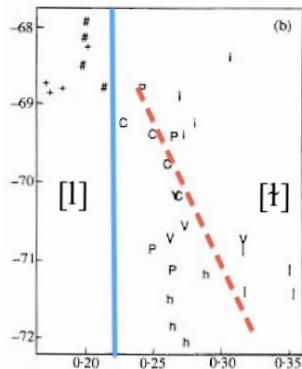 which they assume must be wrong.

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Gradient approach

- Lee-Kim et al. do question Sproat and Fujimura's claim that the degree of darkness of /l/-tokens is determined solely by duration.
- However, they argue that morphological boundaries can affect phonetic implementation.

Problems with a purely categorical approach

Hayes (2000) argues that acceptability judgements are determined by a variable grammar. However:

- ▶ The experiment design inherently elicits scalar responses in judgement.
- ▶ His experimental design makes it very difficult to distinguish between variability at the community level and variability at the individual level, particularly in production.
- ▶ This results in a vast overestimation of the role of categorical variation in the production of individuals.
- ▶ Hayes's design is also unable to control for the fact that duration variance is greater in some environments than others (e.g. phrase-finally).

Interim Summary

- In the existing literature, analyses tend toward one of two ways of looking at /l/-darkening with articulatory measures:
  - One underplays the role of categorical phonological variation.
  - The other overestimates it.
  - But there are compelling arguments for both sides.

- Is there a way of keeping the positive aspects of these analyses whilst overcoming their deficiencies?

A modular approach

- Categorical phonology feeding gradient phonetics.
- Phonology computes generalisations over discrete features; phonetics assigns targets to surface feature configurations.
- The phonology itself is stratified with three levels: stem level, word level, and phrase level.

The life cycle of phonological processes

- Phonetically driven innovations enter the grammar as gradient phonetic rules.
- Later, they may become stabilised as categorical phonological processes at the phrase level.
- Analogical change results in the new phonological process climbing up to higher levels.
- This narrows the domain of application of the process.

(Bermúdez-Otero, 2011)

The life cycle
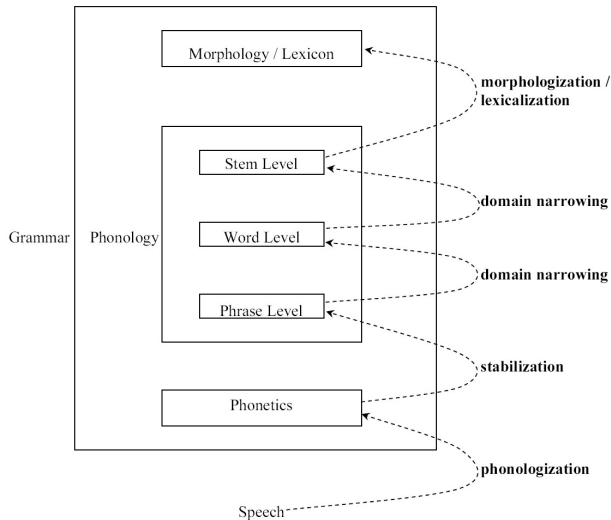
Figure 3: From Bermúdez-Otero and Trousdale (2012:700)

The life cycle of phonological processes

- Innovations enter grammar as gradient phonetic rules.

	elongate	*prolong-er*	*prolong it*	*prolong*
Stage 0	[ŋg]	[ŋg]	[ŋg]	[ŋg]

The life cycle of phonological processes

- Stabilise as categorical phonological processes at the phrase level.

	elongate	*prolong-er*	*prolong it*	*prolong*
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Stage 1	[ŋg]	[ŋg]	[ŋg]	[ŋ]

The life cycle of phonological processes

- Phonological processes climb up to higher levels.

	elongate	*prolong-er*	*prolong it*	*prolong*
Stage 0	[ŋg]	[ŋg]	[ŋg]	[ŋg]
Stage 1	[ŋg]	[ŋg]	[ŋg]	[ŋ]
Stage 2	[ŋg]	[ŋg]	[ŋ]	[ŋ]

The life cycle of phonological processes

- This narrows the domain of application of the process.

	elongate	*prolong-er*	*prolong it*	*prolong*
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Stage 1	[ŋg]	[ŋg]	[ŋg]	[ŋ]
Stage 2	[ŋg]	[ŋg]	[ŋ]	[ŋ]
Stage 3	[ŋg]	[ŋ]	[ŋ]	[ŋ]

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Table 2: Adapted from Bermúdez-Otero (2011)

Predictions of model

This predicts a typology of /l/-darkening systems:

	light	*heal-ing*	*heal it*	*heal*	
RP	[l]	[l]	[l]	[ɫ]	Cruttenden (2001)
Am. Eng. 1	[l]	[l]	[ɫ]	[ɫ]	Sproat and Fujimura (1993)
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Table 3: Adapted from Bermúdez-Otero (2007)

So far, there has been no articulatory corroboration of the existence of the systems labelled 'RP' and 'Am. Eng. 2'.

Rule scattering

- The life cycle also makes predictions about the relative position of diachronically related rules coexisting in the same synchronic system.
- A new rule enters a higher component of the grammar, but without ceasing to apply at the lower level.
- Innovative phonological rules do not replace the phonetic rules from which they emerge, but typically coexist with them: e.g. present-day English palatalisation (Zsiga, 1995):
    - Categorical palatalisation by featural change: *confess* [s]-*confession* [ʃ]
  coexists with
    - gradient palatalisation by gestural overlap: *press* [s]-*press you* [sĵ].

(Bermúdez-Otero, 2013)

Lenition trajectories

- ▶ Successive steps in a lenition trajectory give rise to a series of separate phonological rules entering the grammar one after the other.

- ▶ In the synchronic grammar, the older rules, effecting milder types of lenition, tend to have narrower cyclic domains (i.e. tend to apply at higher levels) than the younger rules, effecting more drastic types of lenition.

- ▶ **Example**: present-day British English /ɹ/
  - ▶ ɹ > reduction ɹ̝ > deletion ∅
  - ▶ Older, milder /ɹ/-reduction applies at the word-level: *the car appeared*
  - ▶ Younger, harsher lenition applies as the phrase level: *the car crashed*

(Bermúdez-Otero, 2011)

Prediction

The model that best fits the articulatory data for /l/ may require two (or more) diachronically related processes, overlaid one over the other in the manner predicted by the life cycle of phonological processes:

► either a phonological process manipulating discrete categories overlaid over a phonetic process effecting gradient adjustments.

► or an older, milder form of categorical darkening applying in relatively narrow domains feeding a younger, harsher form of categorical darkening applying in wider domains.

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Methodology

My pilot study:

- Speakers of various dialects of English were recorded producing /l/ in different phonological contexts (henceforth referred to by example token).

| Context	Environment	Example
initial	[$_{—word}$	*le*a*p*
stem-medial,V_V	[$_{stem}$V_V]	*he*l*ium*
stem-final,V_V	V$_{—stem}$][$_{suffix}$ V	*hea*l*-ing*
word-final,_V	V$_{—word}$][$_{word}$V	*hea*l *it*
word-final,_C	V$_{—word}$][$_{word}$C	*hea*l *beasts*
phrase-final	V$_{—phrase}$]	*hea*l

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word-final, _V	V$_{—word}$][$_{word}$V	*hea**l** it*
word-final, _C	V$_{—word}$][$_{word}$C	*hea**l** beasts*
phrase-final	V$_{—phrase}$]	*hea**l***

Methodology

- ▶ Subjects read lists of words and phrases containing the target stimuli interspersed with distracters.

- ▶ /l/s flanked by front high vowels in all contexts.

- ▶ Recorded five repetitions on a Mindray DP2200 ultrasound machine (frame rate 60fps deinterlaced).

- ▶ /l/s segmented acoustically and splines hand-drawn for all frames within /l/ boundaries in Articulate Assistant Advanced (AAA; Articulate Instruments, 2010).

- ▶ Spline coordinates of entire /l/ extracted for contextual comparison and mean midpoint values plotted in R's ggplot2 package (Wickham, 2009).

- ▶ T-tests carried out on phonological contexts in R for 42 fan points to determine whether two splines are significantly different ($p < 0.05$) from each another at that point.

  - ▶ For simplicity in reporting the results, the 42 points have been divided into tongue tip, body and root, following Davidson (2012).
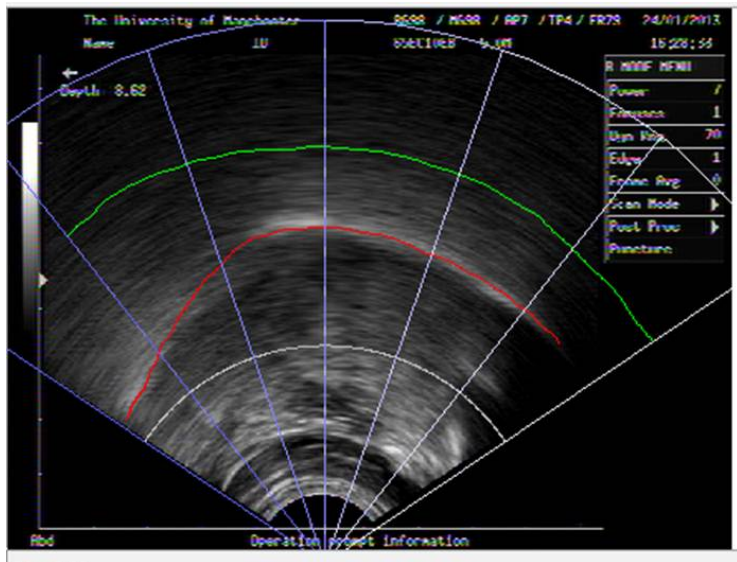
Ultrasound
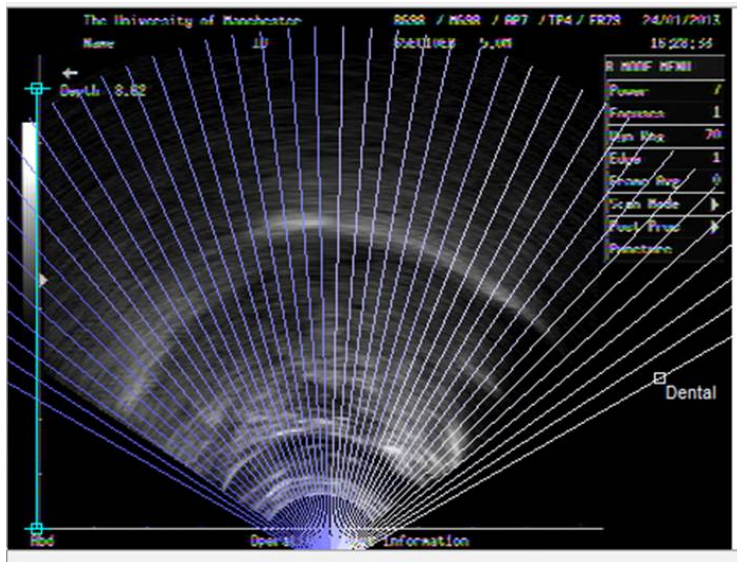
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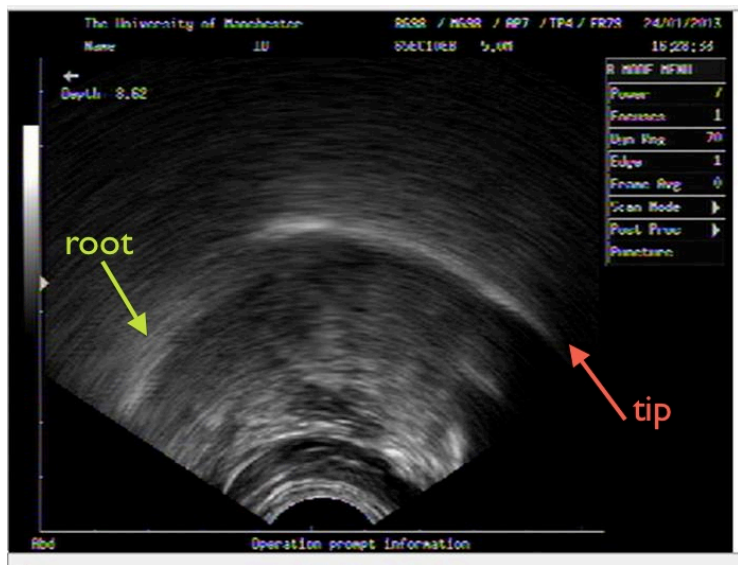
Ultrasound

Video

Results

Does this procedure find evidence for all of the different dialect types predicted by the life cycle?

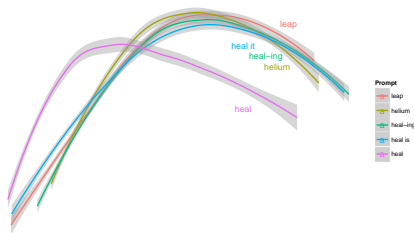|	*light*	*helium*	*heal-ing*	*heal it*	*heal*
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Am. Eng. 2	[l]	[l]	[ɫ]	[ɫ]	[ɫ]
Am. Eng. 3	[l]	[ɫ]	[ɫ]	[ɫ]	[ɫ]

- ► Speakers recorded so far include: RP, Manchester, Middlesbrough, Blackburn, and speakers from several regions of North America.
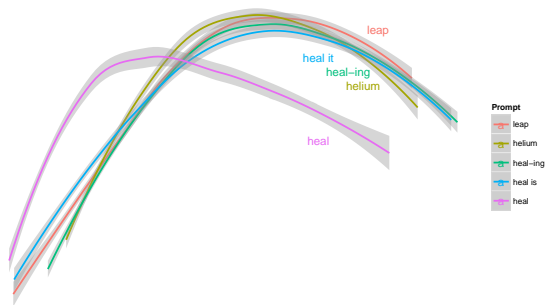- ► I'll be discussing a subset of these today.

RP

Cruttenden's (2001) description of RP is corroborated by articulatory
evidence from spline data: the backed tongue body, reduced tongue-tip
gesture, and retracted tongue root typical of [ɫ] is only found
non-prevocalically.

RP
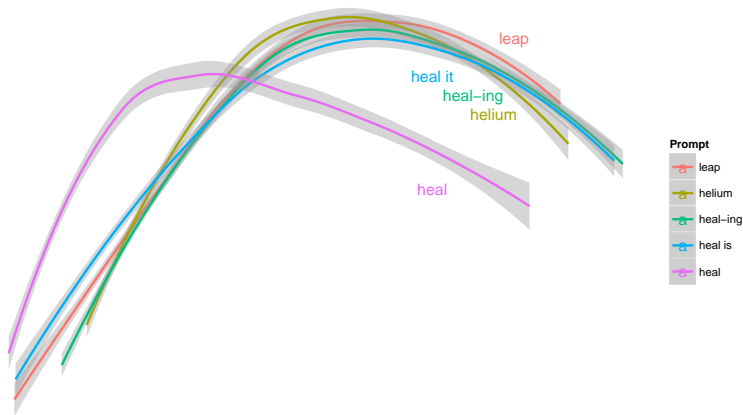
- Statistical tests confirm the observed pattern.

- There are consistent significant differences in tongue-root backing between *heal*-type tokens and the other four environments.

	leap	*helium*	*heal-ing*	*heal it*	*heal*
leap		not sig	not sig	not sig	sig
helium	not sig		not sig	not sig	sig
heal-ing	not sig	not sig		not sig	sig
heal it	not sig	not sig	not sig		sig
heal	sig	sig	sig	sig	

RP

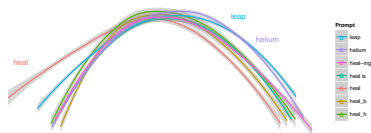|	*leap*	*helium*	*heal-ing*	*heal it*	*heal*
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Am. Eng. 2	[l]	[l]	[ł]	[ł]	[ł]
Am. Eng. 3	[l]	[ł]	[ł]	[ł]	[ł]

American English

At first glance, the splines do not seem to vary much from one another.
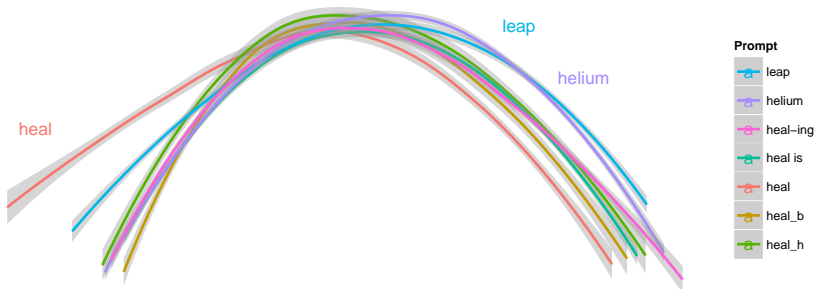
American English

However, statistical tests show that the *leap*-type and *helium*-type tokens are significantly different from *heal-ing* and *heal it* type tokens. These again are different from *heal*-type tokens.

	leap	*helium*	*heal-ing*	*heal it*	*heal*
leap		not sig	tip	tip/(body)	tip/root
helium	not sig		tip	tip	tip/root
heal-ing	tip	tip		not sig	root
heal it	tip/(body)	tip	not sig		root
heal	tip/root	tip/root	root	root	

	leap	*helium*	*heal-ing*	*heal it*	*heal*
Am. Eng. 2	[l]	[l]	[ɬ]	[ɬ]	[ɬ]

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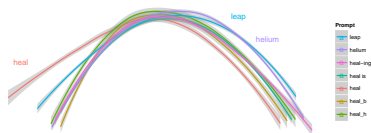

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helium	not sig		tip	tip	tip/root
heal-ing	tip	tip		not sig	root
heal it	tip	tip	not sig		root
heal	tip/root	tip/root	root	root	

	leap	*helium*	*heal-ing*	*heal it*	*heal*
Am. Eng. 2	[l]	[l]	[ɫ]	[ɫ]	[ɫ]

American English 2: rule scattering?

	leap	*helium*	*heal-ing*	*heal it*	*heal*
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Am. Eng. 1	[l]	[l]	[l]	[ɫ]	[ɫ]
Am. Eng. 2	[l]	[l]	[ɫ]	[ɫ]	[ɫ]
Am. Eng. 3	[l]	[ɫ]	[ɫ]	[ɫ]	[ɫ]

- These results fulfil one of the predictions of the life cycle: the existence of the dialect we labelled 'American English 2'.
- Light [l] in *leap*-like and *helium*-type tokens, dark [ɫ] elsewhere.
  - First articulatory evidence of such a dialect.
- But what accounts for the difference between *heal-ing* and *heal it*-tokens on one hand, and *heal*-type tokens on the other?
- Phrase final *heal*-type tokens may exhibit an added durational effect created by rule scattering: the duration-driven gradient effect that was the diachronic precursor of categorical /l/-darkening remains synchronically active in the phonetic module.

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Alternative analysis

- ▶ But we can't be sure from these results alone.
- ▶ This pilot study has the same problem as Lee-Kim et al.'s: I have sampled the distribution too coarsely to be able to distinguish between categorical and gradient effects reliably.
- ▶ It could be the case that there are three categories for my American speaker.
- ▶ Lee-Kim et al. see three categories as problematic, but there is evidence of dialects of English with three categorical realisations of /l/ e.g. South-East British English varieties with /l/-vocalisation (Scobbie and Wrench, 2007; Scobbie et al., 2010).
- ▶ These dialects have tongue-tip contact in *leap*, tip delay and contact in *heal it*, and no alveolar contact in *heal*.
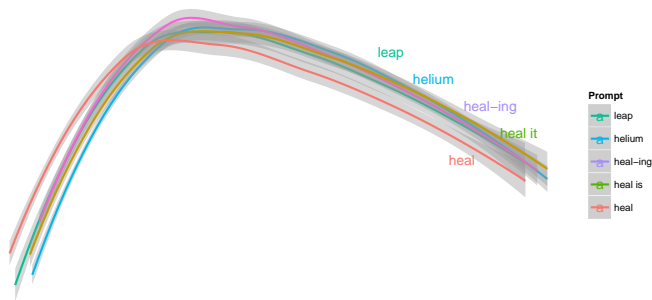- ▶ Three stages of lenition: l > ɫ > ʋ̈

American English 2

Reduced tongue tip	*leap*	*helium*	*heal-ing*	*heal it*	*heal*
Retracted tongue root	*leap*	*helium*	*heal-ing*	*heal it*	*heal*

- ▶ In both scenarios, we have two processes synchronically overlaid in the grammar.
- ▶ The first process causes reduction of the **tongue-tip** gesture in *heal-ing*, *heal it* and *heal* . Its domain is the stem level.
- ▶ The second process applies across the board, either in the phrase-level phonology, or in the phonetics.
- ▶ As predicted by the life cycle, the more advanced lenition applies in a wider domain.
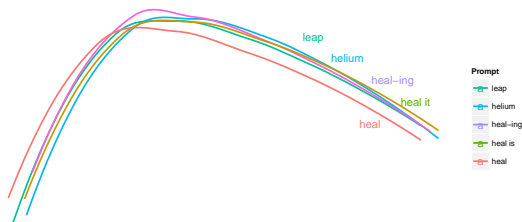
Manchester English

- Said to be dark in all positions (Cruttenden, 2001; Kelly and Local, 1986)
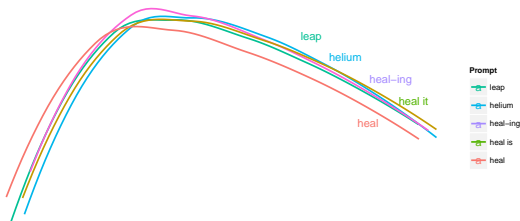- Midpoint tongue shapes and distribution looks much like the American English speaker.

Manchester

- However, statistical tests show that, although Manchester /l/ might seem like American English phonetically, it behaves the like RP /l/ phonologically.

- Differences in tongue-root backing between *heal*-type tokens and the other four environments are significantly different.

|	*leap*	*helium*	*heal-ing*	*heal it*	*heal*
leap		not sig	not sig	not sig	mostly sig
helium	not sig		not sig	not sig	mostly sig
heal-ing	not sig	not sig		not sig	mostly sig
heal it	not sig	not sig	not sig		mostly sig
heal	mostly sig	mostly sig	mostly sig	mostly sig	

Manchester

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- Differences in tongue-root backing between *heal*-type tokens and the other four environments are significantly different.

	leap	*helium*	*heal-ing*	*heal it*	*heal*
leap		not sig	not sig	not sig	mostly sig
helium	not sig		not sig	not sig	mostly sig
heal-ing	not sig	not sig		not sig	mostly sig
heal it	not sig	not sig	not sig		mostly sig
heal	mostly sig	mostly sig	mostly sig	mostly sig	

Variation in individual production

Individual speakers are largely consistent in their production within a phonological context, pace Hayes (2000).

Prompt
- leap
- helium
- heal–ing
- heal is
- heal
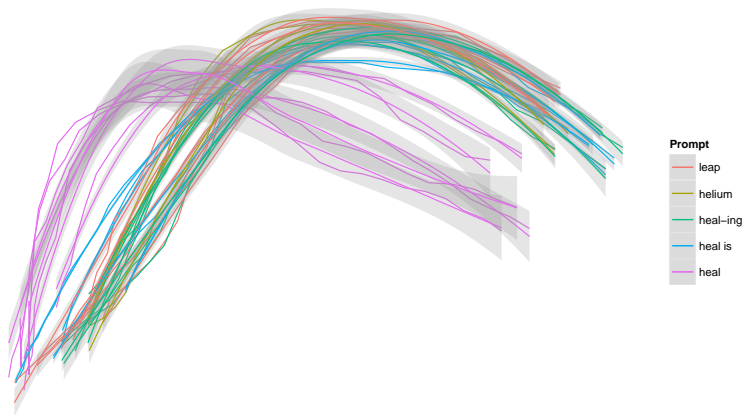
► More variance in phrase-final tokens, possibly reflecting greater durational range.

Further study

- Statistical analysis of articulatory correlates and duration may shed light on the differences between categorical and gradient processes.
- Recording speakers with a three-way distinction between light, dark and vocalised /l/.
- Comparison of articulatory and acoustic data.

Conclusion

- What determines the amount of /l/-darkening in particular varieties of English?
  - English /l/-darkening in English shows effects of synchronically overlaid processes, including both categorical phonology and gradient phonetics.
- A model which considers both of these factors can best account for this observed variation.
- A broad range of contexts is required in order to differentiate between categorical and gradient processes.
- The dialect typology of English /l/-darkening confirms the predictions of the life cycle of phonological processes.

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References I

Articulate Instruments. 2010. Articulate Assistant Advanced ultrasound module user manual, revision 2.14.

Bermúdez-Otero, Ricardo. 2007. Diachronic phonology. In *The Cambridge handbook of phonology*, ed. Paul de Lacy, 497--517. Cambridge: Cambridge University Press.

Bermúdez-Otero, Ricardo. 2011. Cyclicity. In *The Blackwell companion to phonology*, eds. Marc van Oostendorp, Colin J. Ewen, Elizabeth Hume, and Keren Rice, Vol. 4, 2019--2048. Malden, MA: Wiley-Blackwell.

Bermúdez-Otero, Ricardo. 2013. Amphichronic explanation and the life cycle of phonological processes. In *The Oxford handbook of historical phonology*, eds. Patrick Honeybone and Joseph C. Salmons. Oxford University Press.

Bermúdez-Otero, Ricardo, and Graeme Trousdale. 2012. Cycles and continua: on unidirectionality and gradualness in language change. In *The Oxford handbook of the history of English*, eds. Terttu Nevalainen and Elizabeth Closs Traugott, 691--720. Oxford: Oxford University Press.

Boersma, Paul, and Bruce Hayes. 2001. Empirical tests of the gradual learning algorithm. *Linguistic Inquiry* 32:45--86.

References II

Cruttenden, Alan, ed. 2001. *Gimson's pronunciation of English*. London: Arnold, 6th edition.

Davidson, Lisa. 2012. Ultrasound as a tool for speech research. In *The Oxford handbook of laboratory phonology*, eds. Abigail Cohn, Cecile Fougeron, and Marie K. Huffman. Oxford: Oxford University Press.

Gick, Bryan, Fiona Campbell, Sunyoung Oh, and Linda Tamburri-Watt. 2006. Toward universals in the gestural organization of syllables: A cross-linguistic study of liquids. *Journal of Phonetics* 34:49 -- 72.

Hayes, Bruce. 2000. Gradient well-formedness in Optimality Theory. In *Optimality Theory: phonology, syntax, and acquisition*, eds. Joost Dekkers, Frank van der Leeuw, and Jeroen van de Weijer, 88--120. Oxford: Oxford University Press.

Kelly, J., and J.L. Local. 1986. Long-domain resonance patterns in English. In *Institute of Electronic Engineers: Proceedings of the International Conference on Speech Input/Output*, 304--308.

Lee-Kim, Sang-Im, Lisa Davidson, and Sangjin Hwang. 2013. Morphological effects on the darkness of English intervocalic /l/. *Laboratory Phonology* .

References III

Olive, Joseph P., Alice Greenwood, and John Coleman. 1993. *Acoustics of American English speech: a dynamic approach*. New York: Springer Verlag.

Scobbie, James M., Marianne Pouplier, and Alan A. Wrench. 2007. Conditioning factors in external sandhi: an EPG study of English /l/ vocalisation. *16th International Congress of Phonetic Sciences, Monday 6th August - Friday 10th August, 2007, Saarland University, Saarbrücken* 441--444.

Scobbie, J.M., and M. Pouplier. 2010. The role of syllable structure in external sandhi: An EPG study of vocalisation and retraction in word-final English /l/. *Journal of Phonetics* 38:240--259.

Sproat, Richard, and Osamu Fujimura. 1993. Allophonic variation in English /l/ and its implications for phonetic implementation. *Journal of Phonetics* 21:291--311.

Wells, J. C. 1982. *Accents of English*. Cambridge: Cambridge University Press.

Wickham, Hadley. 2009. *ggplot2: elegant graphics for data analysis*. Springer Publishing Company, Incorporated.

References IV

Yuan, Jiahong, and Mark Liberman. 2009. Investigating /l/ variation in English through forced alignment. In *INTERSPEECH 2009: 10th Annual Conference of the International Speech Communication Association, Brighton, UK, 6-10 September 2009.*, 2215--2218.

Yuan, Jiahong, and Mark Liberman. 2011. /l/ variation in American English: A corpus approach. *Journal of Speech Sciences* 1:35--46.

Zsiga, Elizabeth C. 1995. An acoustic and electropalatographic study of lexical and postlexical palatalization in american english. In *Phonology and phonetic evidence: papers in laboratory phonology iv*, eds. Bruce Connell and Amalia Arvaniti, 282--302. Cambridge: Cambridge University Press.