Microvariation trajectories in children's nonword repetitions

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Outline

1. The problem: nonmonoticity in pronunciation learning
2. The study: nonword repetition
3. Factors contributing to variability and accuracy
4. Segment microtrajectories
5. Reflection on U-shapes in pronunciation learning

The problem: non-monotonic learning trajectories

- Learning null hypothesis: incorrect → correct
- U-shaped learning as a familiar deviation from this S-shaped trajectory (e.g., Becker & Tessier 2011)
- Is the U-shape a characteristic of individual words/ sounds, or is it more of a general statistical tendency over the entire lexicon?
- This study: examines nonword repetitions in close detail to elucidate learning trajectories

Hypotheses

- The pronunciation of a given word (or speech chunk) will exhibit an S-shape: monotonic improvement across repetitions over time
- The pronunciation of a given word (or speech chunk) will conform to U-shape: initial accuracy due to imitation, then inaccuracy due to grammar, then accuracy
- The pronunciation of a given word (or speech chunk) will show variability over time due to experimentation and exploration

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Study: nonword repetition task

- Nonword repetition paradigm (Gathercole & Baddeley 1989, applied to short-term phonological memory and phonetic variation by Edwards, Beckman and Munson, 2004)

Subjects

- 13 children enrolled in a preschool near the UC Berkeley campus; the preschool has an arrangement with UC Berkeley to allow researchers to run experimental studies, with parent permission in a quiet room
- Subjects were prescreened (via parent questionnaires) for language background and normal hearing
- Ages ranged from 3;10 to 5;4; group included boys and girls

Stimuli

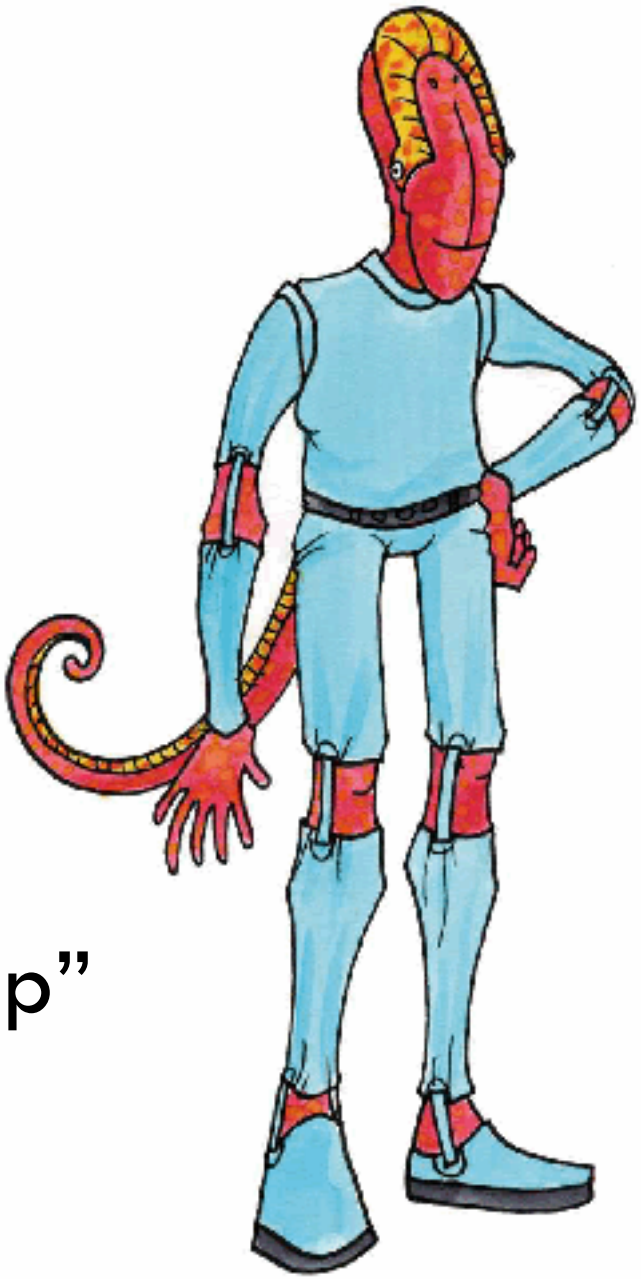
- 8 nonsense words
- 2-3 syllables
- Included a range of C's and V's
- Included phonotactically deviant speech chunks (unreduced segments in unstressed syllables)
- Included some segments that children often have difficulty with (liquids, fricatives)

Stimuli

		Phonotactic deviations	Potentially difficult sounds
nonono	[noˈnoːno]	—	—
baila	[ˈbaɪlə]	—	[l]
tebon	[tʰɛˈboːn]	[ɛ]	—
bikas	[ˈbɪkʰəs]	[kʰ]	—
tapeti	[ˈtʰæpɛtʰi]	[ɛ]	—
bubila	[ˈbuʷbɪlə]	[ɪ]	[l]
sitrup	[sɪˈtɹuʷp]	[ɪ]	[s], [tɹ]
saileft	[ˈsaɪləft]	—	[s], [l], [ft]

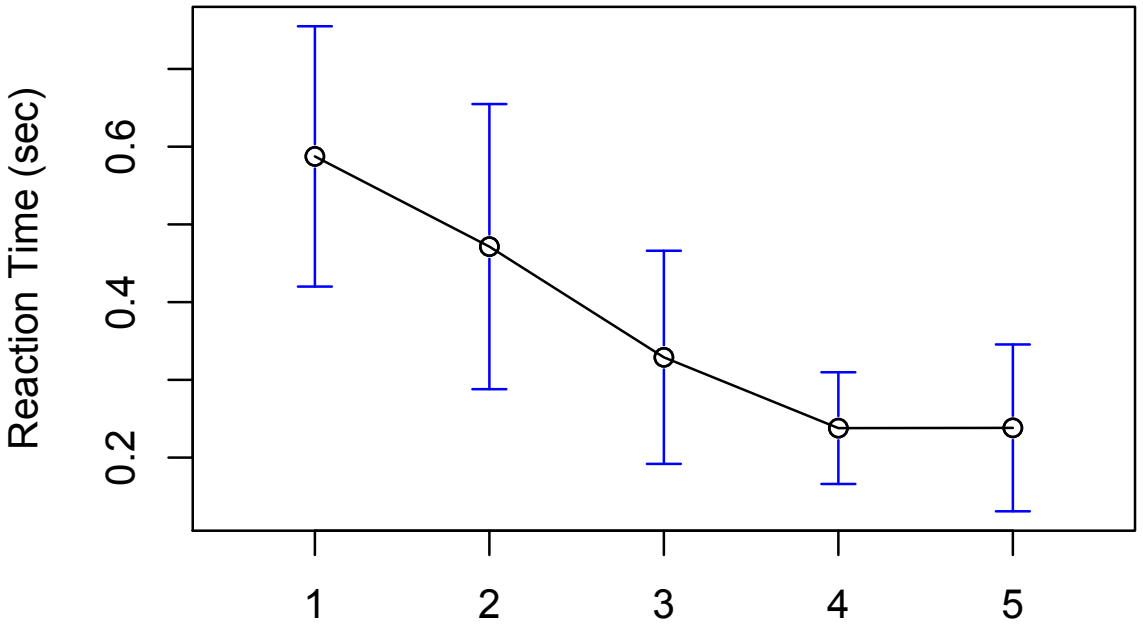
Stimuli

- Audio recordings produced by female adult native speaker of American English
- Each audio stimulus associated with an image, e.g.

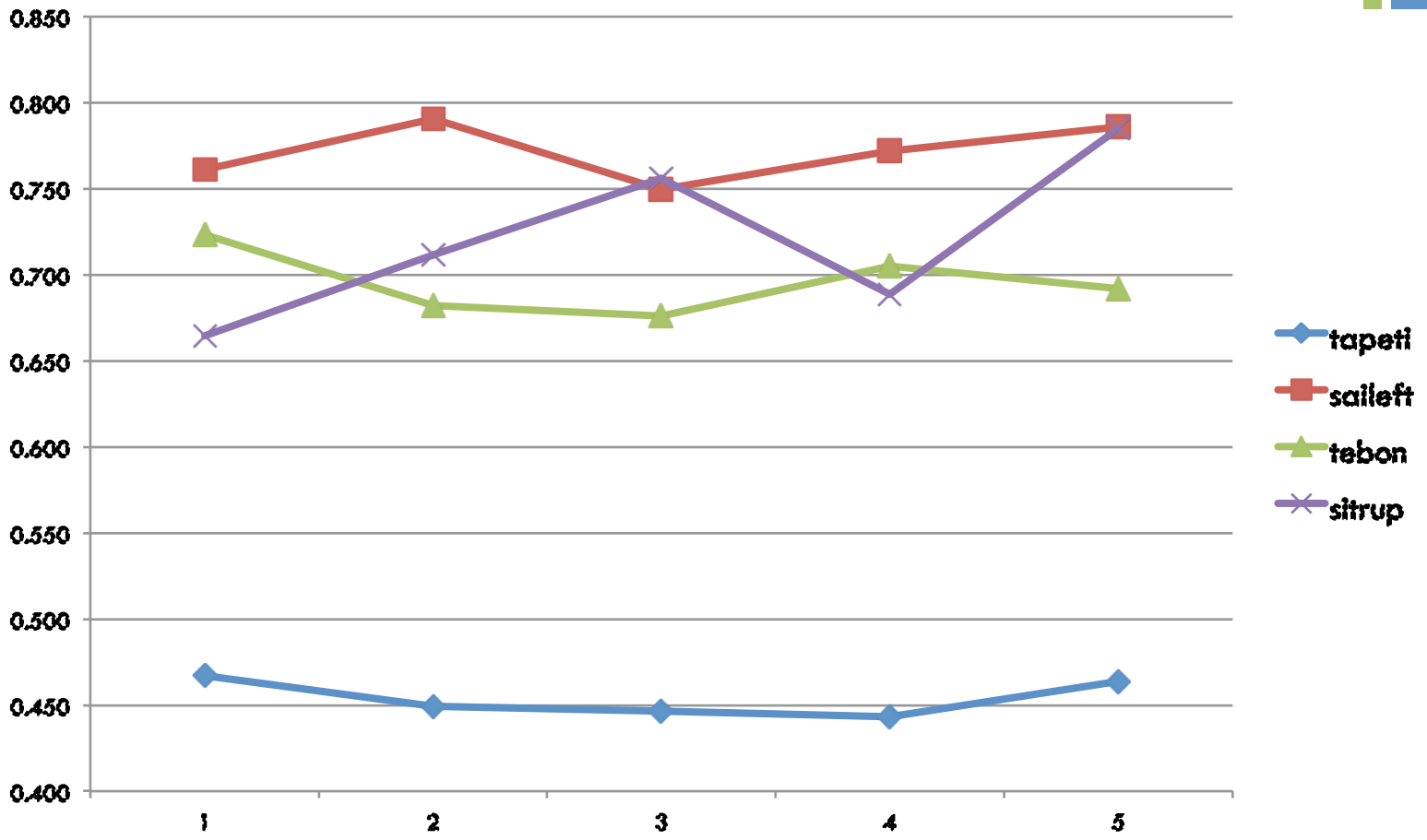


"sitrup"

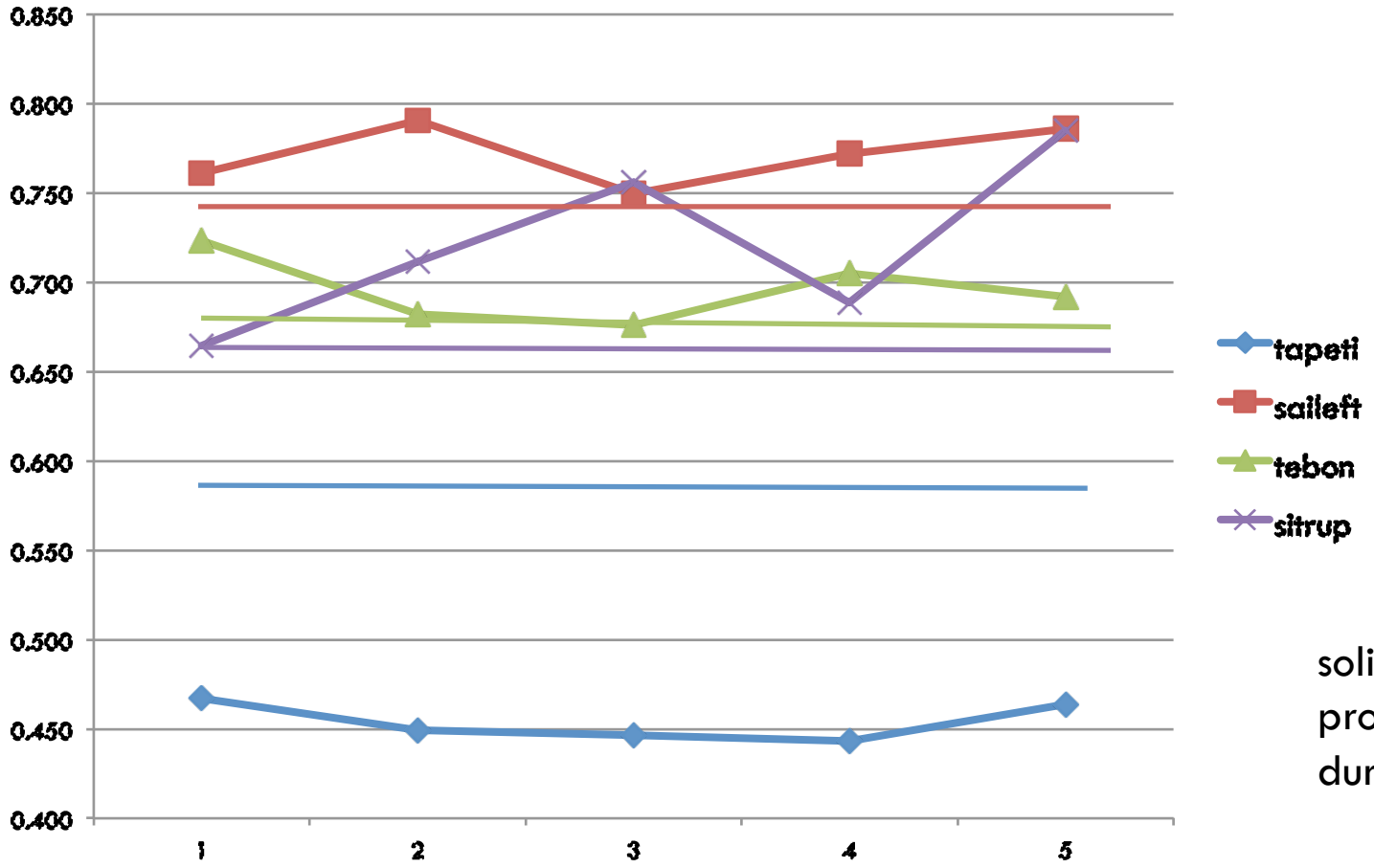
Reaction time



Durations


0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
1
2
3
4
5
tapeti
saileft
tebon
sitrup

Durations



solid line = prompt duration

Transcription data

- [nonono] not transcribed (too easy, not interesting)
- 455 repeated words (13 subjects x 7 transcribed words x 5 repetitions)
- 2,470 transcribed segments (38 segments, over the 7 words)

Transcription data

baila	tebon	bikas	tapeti	bubila	sitrup	saileft
[ˈbaɪlə]	[tʰɛˈboːn]	[ˈbɪkʰəs]	[ˈtʰæpɛtʰi]	[ˈbuʷbɪlə]	[sɪˈtɹuʷp]	[ˈsaɪləft]
[b]	[tʰ]	[b]	[tʰ]	[b]	[s]	[s]
[aɪ]	[ɛ]	[ɪ]	[æ]	[uʷ]	[ɪ]	[aɪ]
[l]	[b]	[kʰ]	[p]	[b]	[t]	[l]
[ə]	[oː]	[ə]	[ɛ]	[ɪ]	[ɹ]	[ə]
	[n]	[s]	[tʰ]	[l]	[uʷ]	[f]
			[i]	[ə]	[p]	[t]

Accuracy and variability

Accuracy

- Number of differences between stimulus and production (error count)
- Phonetic distance between stimulus and production (error magnitude)

Variability

- Amount of variation exhibited by each word
- Consistency across repetitions

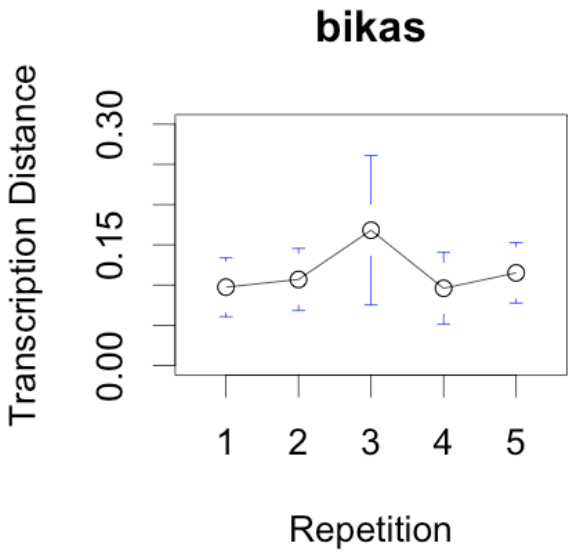
Accuracy

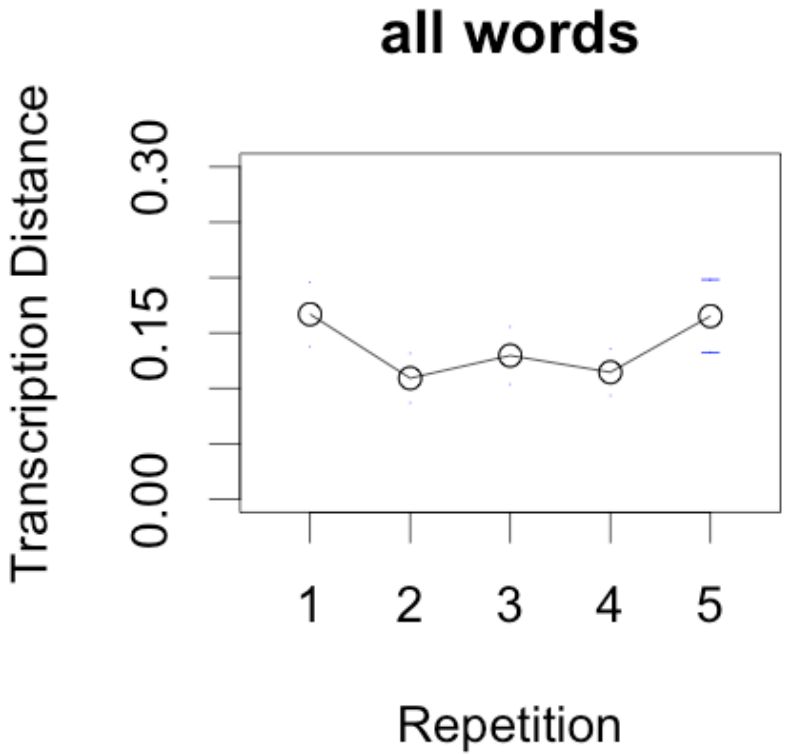
Differences between stimulus and production (error count), as % correct:

	Whole-Word accuracy	Segmental accuracy
baila	55.4%	85.1%
bubila	30.8%	76.9%
bikas	26.2%	82.5%
saileft	21.5%	75.4%
tebon	20.0%	79.4%
sitrup	18.5%	74.2%
tapeti	10.8%	80.0%

Accuracy

Perceptual distance between stimulus and production (error magnitude)





Accuracy and variability

Accuracy

- Number of differences between stimulus and production (error count)
- Phonetic distance between stimulus and production (error magnitude)

Variability

- Amount of variation exhibited by each word
- Consistency across repetitions

Variability

variant productions of each word

		Phonotactic deviation	Difficult speech chunks
bikas	12	x	x
baila	13		x
tapeti	15	x	
tebon	16	x	
bubila	25	x	x
saileft	26		xxxx
sitrup	26	x	xxx

Variability

- Consistency across repetitions

	Whole-Word consistency	Segmental consistency
bikas	38.5%	76.92%
bubila	30.8%	64.10%
tapeti	23.1%	79.49%
baila	23.1%	67.31%
tebon	15.4%	63.08%
sitrup	0%	57.69%
saileft	0%	55.13%

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Factors influencing errors

- Do errors tend to cluster around 'difficult' speech sounds? (no)
- Do errors cluster around phonotactically deviant speech chunks? (yes)
- Do errors tend to improve phonotactics? (yes)
- Did longer words have a higher likelihood of segment error? (yes)
- Does word position affect error rates (yes)

Speech chunk difficulty

Subjects performed slightly worse on the 'difficult' speech chunks (liquids, fricatives and the clusters containing those sounds) vs. others, but the difference is not significant

Speech chunk	% correct
Difficult (/l/, /s/, /ft/, /tr/) (n=390)	75.1%
Other (n=2080)	80.1%
Total	78.8%

Speech chunk difficulty

Subjects performed similarly on consonants and vowels

Speech chunk	% correct
Consonants (n=1,430)	80.0%
Vowels (n=1,040)	77.1%
Total (n=2,470)	78.8%

Phonotactic deviations

Subjects exhibited more errors for the (5) segments that are phonotactically deviant, i.e. unreduced vowels or aspirated intervocalic onset consonants in unstressed syllables, than for the (33) phonotactically conforming segments

Segment	% correct
Phonotactically deviant (n=325)	38.5%
Phonotactically conforming (n=2145)	84.9%
Total (n=2470)	78.8%

(Recall: Variability)

- Consistency across repetitions

	Whole-Word consistency	Segmental consistency
bikas	38.5%	76.92%
bubila	30.8%	64.10%
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Phonotactic deviations

Errors on the phonotactically odd segments tend to improve word phonotactics

word	phonotactically deviant segment	# errors overall	errors that improve phonotactics	# errors that improve phonotactics	% errors that improve phonotactics
tapeti	[ɛ]	58	[ɛ] → [ə]	49	84.5%
bikas	[k^h]	44	[k^h] → [g]	43	97.7%
bubila	[ɪ]	38	[ɪ] → [ə]	26	68.4%
tebon	[ɛ]	35	[ɛ] → [ə]	22	62.3%
sitrup	[ɪ]	25	[ɪ] → [ə]	10	40.0%

Phonotactic deviations

- Errors improving phonotactics: 150
  - (75% of errors on deviant segments)
  - (28.7% of all errors)
- Errors worsening phonotactics: 7
  - (1.3% of all errors)

Word length

- Segmental error rate increases with word length

Word length, in segments	# segments correct
4 (e.g., baila)	166 (85.0%)
5 (e.g., bikas)	422 (80.9%)
6 (e.g., tapeti)	972 (76.3%)

Word position

- Segmental error rate is greater word-medially than closer to word edges

Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6
0.94	0.83	0.68	0.50	0.84	0.85

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Segmental microtrajectories

- We are interested in the production trajectories of individual segments.

38 segments x 13 speakers = 494 trajectories

- Null hypothesis: segments will show either level or improving trajectories

Segmental microtrajectories

- Level (identical repetition) is majority pattern
- Improving is distinct *minority*, compared to other changing trajectories

Trajectory	n	%
Level	330	66.9%
Improving	39	7.9%
Other	124	25.2%

Segment microtrajectories

- Of the changing segment trajectories, only a minority were improving.
- Monotonic worsening is actually more common than monotonic improving.

Trajectory	n	%
Improving	39	23.8%
Worsening	45	27.4%
U shape improving	32	19.5%
U shape worsening	22	13.4%
Oscillating	26	18.9%

Tradeoff

- Monotonic improvement is accompanied by worsening of another segment in the same repetition set to a degree greater than chance

P(monotonic improvement) = .08

P(worsening of any kind) = .25

P(monotonic improvement accompanied by worsening in same repetition set) = .35

This is significantly higher than expected (binomial distribution test, $p < .001$)

Tradeoff

- The tradoff between improvement and worsening is strongest in more complex words
- Repetitions exhibiting both improvement in segment A and worsening in segment B:

6 segments	5 segments	4 segments	
24	5	3	Observed
12.07	6.03	2.51	Expected
bubila	bikas	baila	
saileft	tebon		
sitrup			
tapeti			

Summary of main points

- Influence of grammar: phonotactic deviations are 'repaired'
- Influence of performance considerations:
  - longer words are harder
  - word middles are harder than word edges
  - improvement in one segment often engenders errors in another

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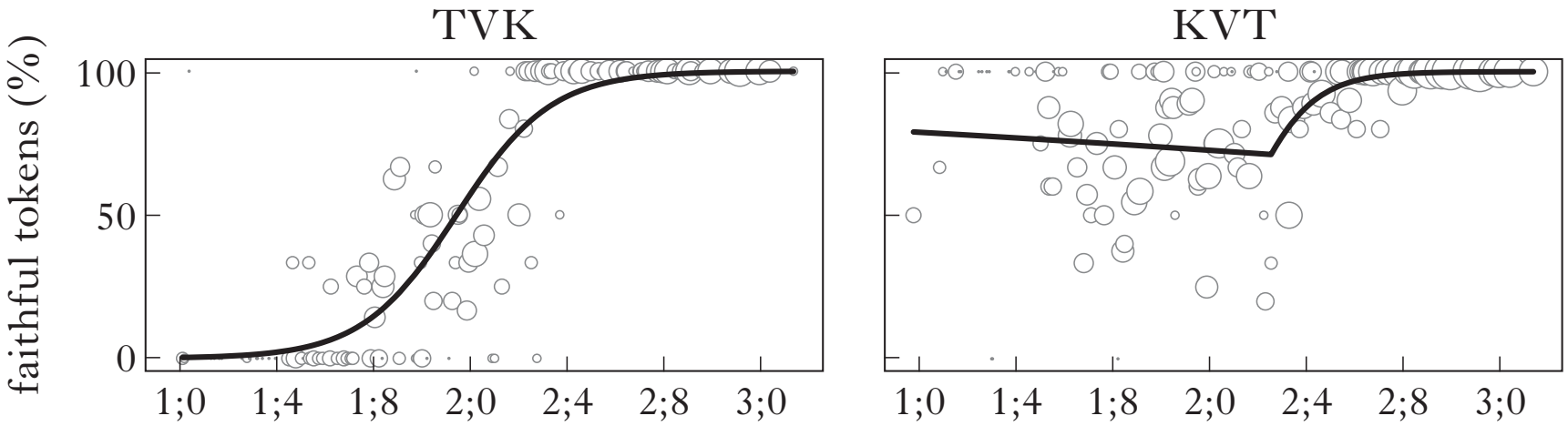
Reflections on U-shaped learning

- The improving U-shape did not occupy a place of special privilege in this data
- Compare to the evidence for U-shapes in phonological learning, e.g.

Reflections on U-shaped learning

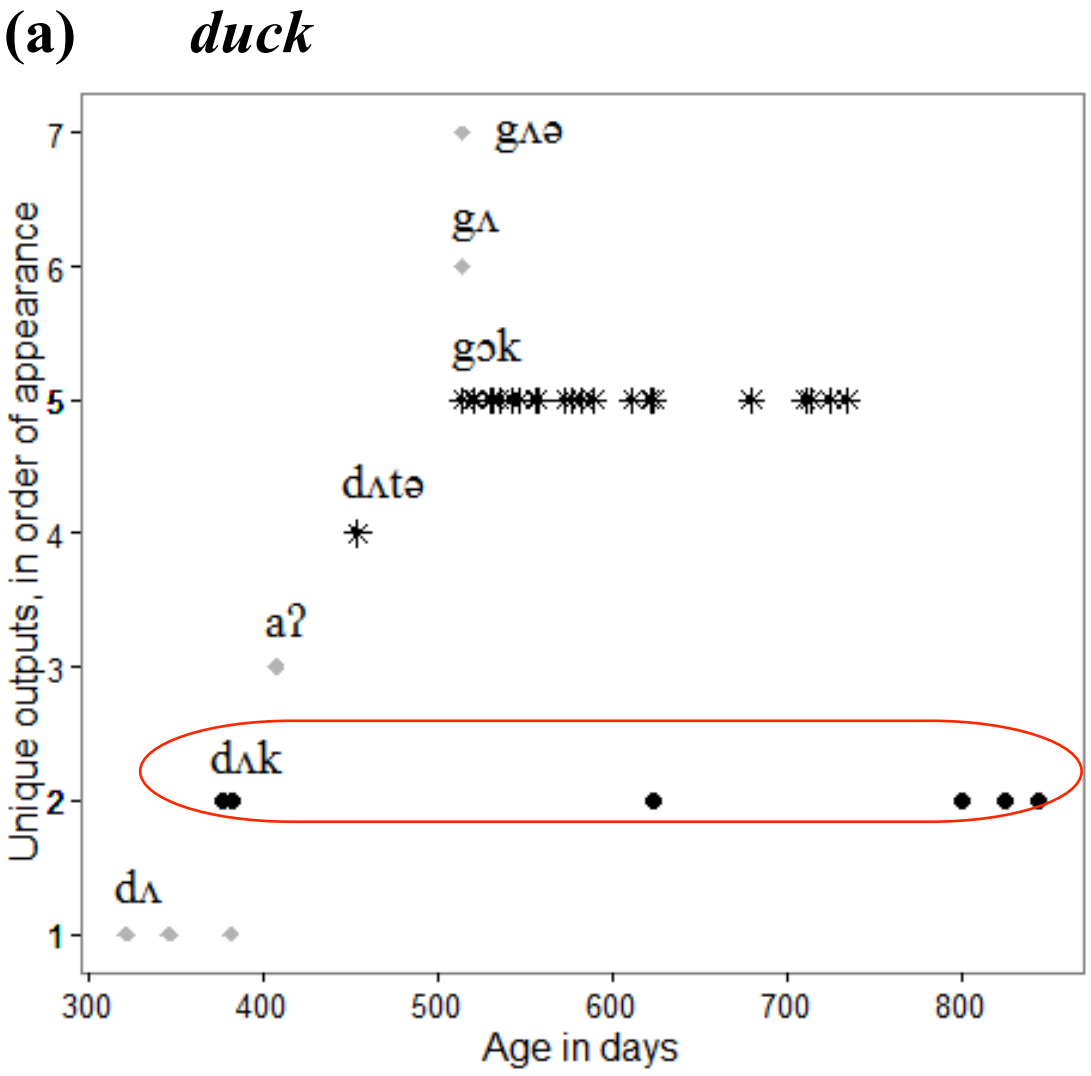
- Becker & Tessier 2011: S shapes and U shapes in the speech of Trevor (error: consonant harmony)
- TVK words (e.g. 'duck') showed S-shape
- KVT words (e.g. 'kiss') showed U-shape



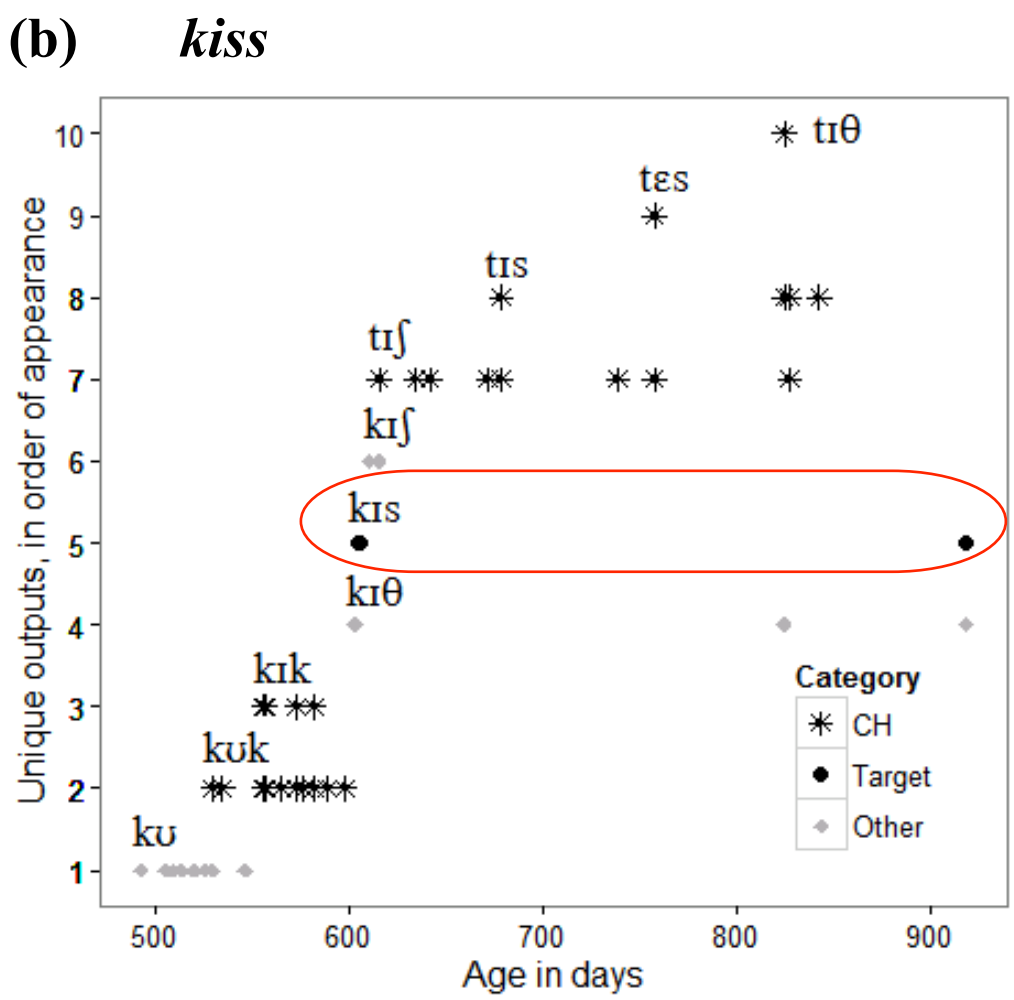
Reflections on U-shaped learning

- Becker & Tessier 2011: U shaped learning due to interaction between grammar and stored errors
- McAllister Byun & Inkelas 2014: individual words show more chaotic trajectories over time

Reflections on U-shaped learning

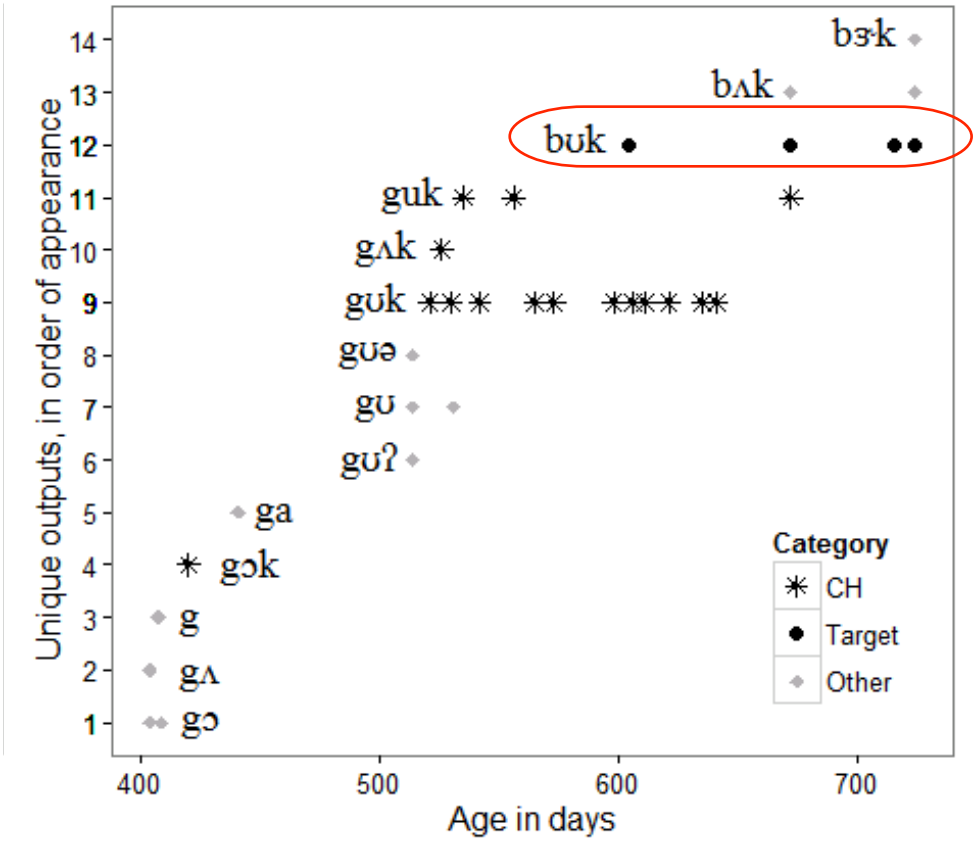


Reflections on U-shaped learning



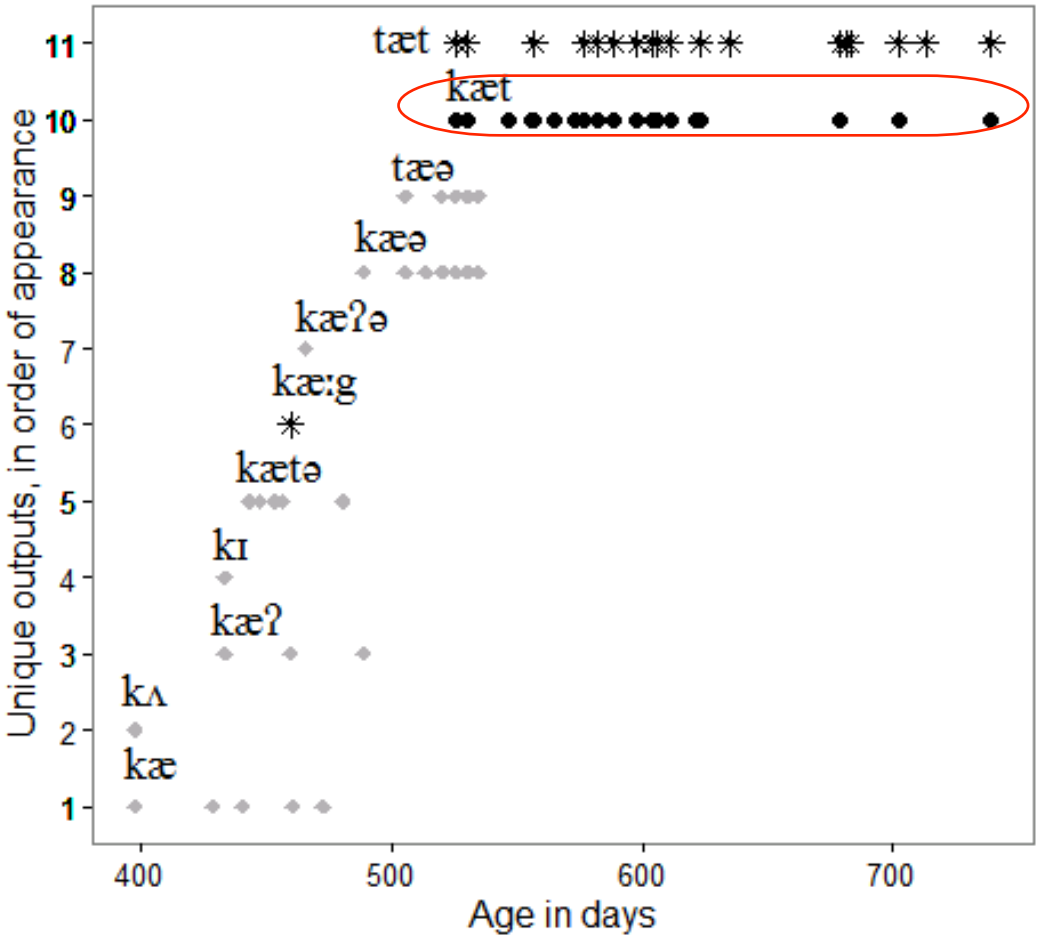
Reflections on U-shaped learning

(b) ***book***



Reflections on U-shaped learning

(a) ***cat***



Reflections on U-shaped learning

- Trevor's speech shows U-shaped (and S-shaped) curves in aggregate, but individual words show a space of variability around lexical items
- The contents of this space change over time

Conclusions

- The 5-word repetition sets in our study reveal exploration and experimentation
- This reflects the constant exploration and experimentation in phonological learning generally, seen even with familiar lexical items
- Experimentation, at the expense of accuracy, is useful in updating the child's articulatory-acoustic mappings (the A-map; McAllister Byun, Inkelas, Rose 2016)

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