The development of segment inventories

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TIN-dag 2007

Summary

- What do children learn when they are acquiring the sound structure of language?
- Three hypotheses:
  - Children acquire features;
  - Children acquire (unanalysed) segments;
  - Children acquire (unanalysed) words;
- We argue in favour of a traditional, Jakobsonian view (acquisition of features),
  - based on data from the CLPF database
  - and using a constraint-based framework

The issue

- A traditional phonological analysis of language acquisition invokes the notion of *features*
- In the ideal case, we see that children acquire features in a strict order
- Whenever they acquire a new feature, the whole natural class defined by this feature becomes available to them.
- E.g. (assuming place features)
  { p, t, k } → { p, t, k, b, d, g } → { p, t, k, b, d, g, f, s, x, v, z, ɣ }

(Roman Jakobson, *Kindersprache, Aphasie und allgemeine Lautgesetze)*

The challenge

- However, this view is too simplistic, and it has been recently questioned (e.g. by Edwards, Beckman and Munson 2004; Nicolaidis to appear)
- Their suggestion is that children acquire segments or even words first, without reference to internal structure

Empirical consequences

- Feature-based: children learn feature by feature; frequent and infrequent sounds are acquired around the same time if they are in the same natural class
- Segment-based: children learn more frequent sounds first; natural class behaviour is unexpected or epiphenomenal
- Word-based: children initially use all kinds of segments, provided they occur in frequent words; sounds spread through the lexicon

CLPF Database

- Data were based on a selection of the CLPF Database
- This selection concerns only one- and two-word utterances
- From this we automatically extracted the first segments (onset) and final segments (offset) which were produced, regardless of target sounds

Restrictions

- We did not (yet) consider the target sounds
- We disregarded the glides /j/ and /w/, since it is unclear whether to regard them as part of the consonantal system
- Similarly, we disregarded /ʃ/, /ʔ/ and /h/, of which the place in the segment inventory is unclear
- We ordered the remaining segments on Guttman scales

The data: Child 2 / onset

Ch	Dh	b	d	t	h	p	m	s	z	n	f	w	k	X	l	x	R	j		S	v
2	529	3	7	5	4	2															
2	540	3	6	7	2		2														
2	554	4	8	4	2				5												
2	567	5	15	7		2		3										2			
2	588	10	15	13		3	5	3	5					2							
2	602	5		9	2	12	2	4													
2	615	5	5	12		23	2	4		4	6	3									
2	629	19	10	11		9		3		2	5	2									
2	643	65	19	94	26	62	6	27	4	18	66	6	4	3			2				2
2	715	14	15	28	21	35	13	23	3	9	22	7	3								
2	766	34	16	32	10	32	12	12		10	20	8			2						
2	785	6	8	26	24	8	8	12		10	22	14	2							4	
2	817	28	10	12	12	8	16	20		4	12	8	18	4	4	2	2				
2	830	84	30	40	52	24	22	83	2	18	34	32	52	18	34			8		2	2

The data: Child 2 / coda

Ch	Dh	s	t	p	m	n	k	r	R	X	f	l	N	S
2	529	6	1	3										
2	540	3	1	4	1	2							1	
2	554	6	5	2	2	4	1							
2	567	7	6		2	7								
2	588	10	4	4	5	9								
2	602	8	6	1	1	4						1		
2	615	11	17	1	2	7								
2	629	6	16	2	1	11					1			
2	643	48	55	16	9	62	20	11	13	8	4	2	1	
2	715	19	19	4	6	20	12	9	7	4			1	
2	766	28	24	6	4	24	8	14			6			
2	785	20	12		2	30	10	2	4	6	4			
2	817	38	18		2	20	8	10	2	2	2	2	2	
2	830	82	62	27	12	104	24	20	12	15	14	8	4	4

The data: Child 10 / onset

Ch	Dh	m	p	t	k	h	d	n	j	b	s	w	l	X	f		N	g	r	
10	589	2																		
10	630	1																		
10	740	5																		
10	777	2	12	13	5	8						3								
10	797	7	3	7	4	1	2													
10	811	4	4	10	4	5														
10	827	8	10	2	6	8	2	3												
10	840	5	11	4	5	12	1	1	2											
10	854	3	17	4	7	9		2	1	1										
10	902	9	49	39	13	59		7	2	2										
10	915	10	30	17	12	32	3	5	1	4										
10	929	9	16	8	13	28	3	7												
10	942	13	34	24	12	53	2	13	1	4							2			
10	957	12	12	29	4	24	2	6	2						2					
10	971	20	32	32	2	30	3	11	1	6										
10	985	12	19	37	7	28	1	5	1		3									
10	998	13	10	42	4	27		11		3	4									
10	1002	4	11	21	6	7		2			3									
10	1012	8	11	19	12	25		9	1											
10	1026	11	14	26	9	27	10	6	1	10	11	2	1	2						
10	1065	12	9	13	12	21	8	20	8	7	5	5	2		2					

The segment-based approach (1)

- The following data (from the Joost van de Weijer Corpus) give an indication of the relative frequency of sounds in onset and offset in Dutch child directed speech

Onsets	Offsets
j = 10,6	n = 10,3
m = 10,6	t = 10,1
d = 9,6	r = 6,9
h = 7,2	m = 6,1
n = 6,9	s = 5,3
z = 5,6	k = 2,9
b = 5,4	x = 2,9
w = 4,4	p = 2,3
k = 4	l = 2,2
x = 3,6	nt = 1
v = 2,1	j = 0,5
l = 2	f = 0,4
p = 1,4	xt = 0,4
t = 1,3	st = 0,5

- We cannot find any correlation with the order in which sounds are acquired by the children in the corpus

The data: Child 2 / onset

Ch	Dh	b	d	t	h	p	m	s	z	n	f	w	k	X	l	x	R	j		S	v
2	529	3	7	5	4	2															
2	540	3	6	7	2		2														
2	554	4	8	4	2				5												
2	567	5	15	7		2		3										2			
2	588	10	15	13		3	5	3	5					2							
2	602	5		9	2	12	2	4													
2	615	5	5	12		23	2	4		4	6	3									
2	629	19	10	11		9		3		2	5	2									
2	643	65	19	94	26	62	6	27	4	18	66	6	4	3			2				2
2	715	14	15	28	21	35	13	23	3	9	22	7	3								
2	766	34	16	32	10	32	12	12		10	20	8			2						
2	785	6	8	26	24	8	8	12		10	22	14	2							4	
2	817	28	10	12	12	8	16	20		4	12	8	18	4	4	2	2				
2	830	84	30	40	52	24	22	83	2	18	34	32	52	18	34			8		2	2

The segment-based approach (2)

- Frequency would predict the following order:
  - j, m > d > h > n > z > b > w > k > x > v > l> p > t
- /t, p/ are usually the first to be acquired in spite of their relatively low frequency
- None of the children has /k/ before /t, p/
- None of the children has /z/ ([s]) before /p, t, b/

The word-based approach

- New sounds do not spread slowly through the vocabulary but are used instantaneously in all the words that require that sound.
- Example (child2):
  - Target onset /l/ is [h] or [s] up until 2;2.27. In subsequent recordings target words starting with /l/ are produced with onset [l] (100% correct): *leeuw, lift, lezen, lepel, lettertjes, lopen, lekker, luier, laarzen* etc.

More examples

- Target onset [m]. Is [m] only in three fossilized forms: *mamma, mij, meer*, [b] or [p] otherwise up until 1;11.20. In subsequent recording all target words starting with /m/ are produced with onset [m] (100% correct): *mag, mee, mooi, mannetje*.
- Target onset /f/ ([v]). Is produced [s] or [z] up until 1;8.10. In subsequent recording we find [f] onsets for all target words starting with /v/, like *vallen, vis, vogel*.
- Target onset /x/ is produced [s] and later [f] up until 2;1.25. In subsequent recording we find 100% [x] productions for target words with onset /x/: *grote, gegeten, ga, gek, glijbaan*.

Conclusion on frequency effect

- No evidence for the role of frequency in the acquisition path
- To the contrary, infrequent segments (such as /p/) seem to be acquired first
- Notice, however, that we have no data on the relative frequency of sounds or words in speech *directed to the children in our database*.

Problems with feature-based approaches

- An important reason why a feature-based analysis seems to fail, is that we find gaps: natural classes are not always learned as a whole.

Example: Beers (1996)

- inventory 1: { p, m, t, n, j }
  acquired features: [consonantal], [sonorant], [labial] [coronal]
  problem: how do we distinguish /j/ and /n/?
- inventory 2: { p, m, t, n, j, k }
  acquired feature: [dorsal]
  problem: no [ŋ] in inventory
- inventory 3: { p, m, t, n, j, k, s, x, h }
  acquired feature: [continuant]
  problem: no [f] in inventory

Feature-based approaches revisited

- Notice, however, that adult grammars also contain holes: e.g. adult Dutch does not have [g].
- These gaps are usually assumed to be the result of feature cooccurrence constraints (fcc): *[velar, voice]

Restricting fcc

- In order to describe the data, we need to have a restrictive theory of feature cooccurrence constraints
- We propose there are only two types (Itô, Mester and Padgett 1994):
  - *[F,G]: No segment has both F and G
  - [F]⊃[G]: If a segment has F, it also has G
- These constraints refer to only *two* features (never more)
- We will show that children actually use only a small subset of these

The theory

- We assume that acquisition involves two parallel paths:
  - Acquisition of features, e.g. [voice], [coronal], [velar]
  - Emergence of feature cooccurrence constraints

Acquisition of features

- We assume monovalent features: [voice], [coronal], [velar], [continuant], [nasal], [lateral], [rhotic]
- Since these features are monovalent, absence of a feature gives a default interpretation
- Thus, the representation of /t/ is {[coronal]}; that of /m/ is {[labial],[nasal]}
- These seem to be learned in a specific order (mostly the same for all children)
- We are neutral on the issue of feature geometry

Emergence of fcc

- Only the following constraints seem necessary:
  - **General:** *[nasal,velar],*[velar,voice], *[continuant,voice],[continuant]⊃[coronal],*[continuant,velar]
  - **Onset:** [continuant]⊃[labial], [nasal]⊃[labial], [labial]⊃[nasal]
  - **Coda:** [velar]⊃[continuant]

Features and fcc run in parallel

- The child can build *any* combination of features, except if she posits an fcc.
- Fcc's arise *exactly* at the moment when both features have been acquired, never later. (This is non-trivial.)
- However, they may be retracted later on in the acquisition process
- In terms of OT, this can be seen as an instance of constraint demotion

The data: Child 2 / onset

Ch	Dh	b	d	t	h	p	m	s	z	n	f	w	k	X	l	x	R	j		S	v
2	529	3	7	5	4	2															
2	540	3	6	7	2		2														
2	554	4	8	4	2				5												
2	567	5	15	7		2		3										2			
2	588	10	15	13		3	5	3	5					2							
2	602	5		9	2	12	2	4													
2	615	5	5	12		23	2	4		4	6	3									
2	629	19	10	11		9		3		2	5	2									
2	643	65	19	94	26	62	6	27	4	18	66	6	4	3			2				2
2	715	14	15	28	21	35	13	23	3	9	22	7	3								
2	766	34	16	32	10	32	12	12		10	20	8			2						
2	785	6	8	26	24	8	8	12		10	22	14	2							4	
2	817	28	10	12	12	8	16	20		4	12	8	18	4	4	2	2				
2	830	84	30	40	52	24	22	83	2	18	34	32	52	18	34			8		2	2

Example: Child 2 / Onset

	Features	**Constraints**	**Predicted inventory**	**Day**
1.	[voice] [labial], [coronal]	-	{ b, p, t, d }	529
2.	[nasal]	i. [nasal]⊃[labial]	{ b, p, t, d, m }	540
3.	[continuant]	ii. [continuant]⊃[coronal]	{ b, p, t, d, m, s, z }	554
4.	-	Revoke i. Revoke ii. (Assuming w=v)	{ b, p, t, d, m, n, s, z, f, v }	615
5.	[velar]	iii. *[voice,velar]	{ b, p, t, d, m, n, s, z, f, v, k, x }	643
6.	[lateral]	-	{ b, p, t, d, m, n, s, z, f, v, k, x, l }	766
7.	[rhotic]	-	{ b, p, t, d, m, n, s, z, f, v, k, x, l, r }	817

The data: Child 2 / coda

Ch	Dh	s	t	p	m	n	k	r	R	X	f	l	N	S
2	529	6	1	3										
2	540	3	1	4	1	2							1	
2	554	6	5	2	2	4	1							
2	567	7	6		2	7								
2	588	10	4	4	5	9								
2	602	8	6	1	1	4						1		
2	615	11	17	1	2	7								
2	629	6	16	2	1	11					1			
2	643	48	55	16	9	62	20	11	13	8	4	2	1	
2	715	19	19	4	6	20	12	9	7	4			1	
2	766	28	24	6	4	24	8	14			6			
2	785	20	12		2	30	10	2	4	6	4			
2	817	38	18		2	20	8	10	2	2	2	2	2	
2	830	82	62	27	12	104	24	20	12	15	14	8	4	4

Example: Child 2 / Coda

	Features	Constraints	Predicted inventory	Day
1.	[labial],[coronal] [continuant]	a. *[continuant, Place]	{ p, t, s }	529
2.	[nasal]	-	{ p, t, s, n, m }	540
3.	[velar] [rhotic]	Revoke a. b. *[nasal,velar]	{ p, t, s, n, m, x, f, k, r }	643
4.	[lateral]	Revoke b.	{ p, t, s, n, m, x, f, k, r, ŋ, l }	817

The data: Child 10 / onset

Ch	Dh	m	p	t	k	h	d	n	j	b	s	w	l	X	f		N	g	r	
10	589	2																		
10	630	1																		
10	740	5																		
10	777	2	12	13	5	8						3								
10	797	7	3	7	4	1	2													
10	811	4	4	10	4	5														
10	827	8	10	2	6	8	2	3												
10	840	5	11	4	5	12	1	1	2											
10	854	3	17	4	7	9		2	1	1										
10	902	9	49	39	13	59		7	2	2										
10	915	10	30	17	12	32	3	5	1	4										
10	929	9	16	8	13	28	3	7												
10	942	13	34	24	12	53	2	13	1	4							2			
10	957	12	12	29	4	24	2	6	2						2					
10	971	20	32	32	2	30	3	11	1	6										
10	985	12	19	37	7	28	1	5	1		3									
10	998	13	10	42	4	27		11		3	4									
10	1002	4	11	21	6	7		2			3									
10	1012	8	11	19	12	25		9	1											
10	1026	11	14	26	9	27	10	6	1	10	11	2	1	2						
10	1065	12	9	13	12	21	8	20	8	7	5	5	2		2					

Example: Child 10 / Onset

	Features	Constraints	Predicted inventory	Day
1.	[labial] [continuant]	a. *[continuant,Place]	{ p, s }	777
2.	[velar], [coronal] [nasal]	Revoke a.	{ p, s, k, t, f, x, n, m, ŋ }	915
3.	[lateral]	-	{ p, s, k, t, f, x, n, m, ŋ, l }	1065

Example: Child 4 / Onset

	Features	**Constraints**	**Predicted inventory**	**Day**
1.	[labial], [coronal], [velar] [continuant] [nasal]	a. [velar]⊃[continuant]	{ p, t, f, s, x, m, n }	497
2.	[rhotic]		{ p, t, f, s, x, m, n, r }	590
3.	-	Revoke a. b. *[nasal,velar]	{ p, t, f, s, x, m, n, r, k }	643
4.	-	Revoke b.	{ p, t, f, s, x, m, n, r, k, ŋ }	703

Example: Child 7 / Onset

	Features	Constraints	Predicted inventory	Day
1.	[coronal]	-	{ t }	392
2.	[labial] [nasal] [continuant]	 a. [nasal]⊃[labial] b. [labial]⊃[nasal]	{ t, m, s }	429
3.	-	Revoke b.	{ t, m, s, p, f }	460
4.	[velar]	Revoke a. c. (✘inexpressible constraint against /k/)	{ t, m, n, s, p, f, ŋ, x }	524
5.	[lateral]		{ t, m, n, s, p, f, ŋ, x, k, l }	537

Example: Child 8 / Onset

	Features	**Constraints**	**Predicted inventory**	**Day**
1.	[labial], [velar]	-	{ p, k }	517
2.	[continuant]	a. *[continuant,Place]	{ p, k, s }	572
3.	[coronal] [lateral]	-	{ p, k, s, t, l }	590
4.	[nasal]	b. [nasal]⊃[labial] -	{ p, k, s, t, l, m }	608
5.	-	Revoke a.	{ p, k, s, t, l, m, f, x }	636
6.	-	Revoke b.	{ p, k, s, t, l, m, f, x, n, ŋ }	649

Example: Child 9 / Onset

	Features	**Constraints**	**Predicted inventory**	**Day**
1.	[voice] [labial], [coronal]	-	{ p, b, t, d }	569
2.	[velar] [nasal]	i. *[velar,voice] ii. [nasal]⊃[labial]	{ p, b, t, d, k, m }	583
3.		Revoke ii. iii. *[nasal,velar]	{ p, b, t, d, k, m, n }	639
4.	[continuant]	iv. *[continuant,velar] vii. *[continuant,voice]	{ p, b, t, d, k, m, s, f }	691
5.	[lateral]	-	{ p, b, t, d, k, m, s, f, l }	741
6.	-	Revoke iv.	{ p, b, t, d, k, m, s, f, l, x }	846

Discussion / conclusion

- A feature-based analysis of acquisition of segment inventories seems feasible, if supplemented with a restrictive theory of fcc
- However, we still need to find out what determines the order in which features are acquired
- Variation might still be due to relative input frequency
- We also need to consider the relevance of the target words

Frequency of features

- Frequency of place features (Vd Weijer Corpus):
  labial: 22,9%
  coronal: 25,6% (excluding j)
  velar: 7,6%
- Order of acquisition of place could be due to frequency

Frequency of features

- Some plausibility for other features:

+continuant:	26,3%
+voice:	25%
+nas:	17,5%
+lat:	2%

- The fact that [continuant] is late in onsets is due to independent effects