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THE SOURCES OF PHONOLOGICAL KNOWLEDGE: A CROSS-LINGUISTIC PERSPECTIVE

ABSTRACT

Early word production profiles for children learning different languages reflect both similarities and differences. Experimental evidence of a link between speech perception and vocal production supports the idea that a match between the child's own babbling forms and input speech is the source of the constrained but relatively accurate first word forms, a point of similarity across language groups. Measurements of the duration of medial consonants in adult speech and in the early words of children exposed to languages differing in their phonetic and/or phonological treatment of consonantal length make it possible to distinguish between (1) direct learning of distributional frequencies and (2) lexical learning, which alone can account for the emergence of language-specific phonological contrasts and cross-linguistic differences in phonological patterning. It is argued that complementary implicit and explicit memory systems are sufficient to account for both of these kinds of learning, affecting the initial registering and later retrieval of phonological patterns and the establishment of lexical representations as well as the development of motoric routines and the matching of those routines to input speech. These learning mechanisms are thus able to account for the construction of phonological knowledge, given adequate exposure to an ambient language, with no need to posit innate linguistic knowledge or Universal Grammar.

KEYWORDS

Cross-linguistic studies, implicit and explicit learning (phonology *vs* lexicon), word templates.

1. Introduction

A central concern of the study of child language is to account for the developmental source of linguistic knowledge. In one influential approach to this problem innately given Universal Grammar (or UG) is assumed to provide the knowledge of linguistic structure that serves as the starting point for language acquisition, leading to the basic question, WHAT EXACTLY NEEDS TO BE LEARNED? (Peperkamp, 2003). This must then be followed by the question of the nature of the triggering process needed to establish the specifics of a given language: HOW DOES THE CHILD RECOGNIZE THE CRITICAL DATA THAT WILL MAKE IT POSSIBLE TO SET THE APPROPRIATE PARAMETERS, OR TO RERANK CONSTRAINTS IN THE APPROPRIATE WAY? For approaches that deny the existence of UG the questions are the converse: WITH WHAT KNOWLEDGE, IF ANY, DOES THE CHILD BEGIN?, followed by the complementary question, HOW CAN THE CHILD GAIN KNOWLEDGE OF LINGUISTIC STRUCTURE OR SYSTEM? The phonological side of this problem is often given short shrift by researchers interested in word learning (e.g., Bloom, 2000; Golinkoff, 2000). Yet before a child can begin to develop linguistic meaning he or she must first be able to represent and access word forms or phrases, which can then come to be associated with recurrent situations, objects or events.

The field of phonological development is presently able to draw on at least two different lines of empirical research: (1) production studies, based on diary entries and/or regular recordings of individual children or small groups, sometimes supplemented by acoustic analysis; (2) experimental studies of larger groups of infants' perceptual responses to speech. An important additional benefit of recent work in both perception and production has been the expansion from a heavily anglocentric field to the collection of data from a wider range of languages. This paper will draw on both of these sources of evidence, based on data from four languages, in attempting to provide answers to three broad questions:

(1) How similar is phonological development cross-linguistically and across individuals learning the same language? Early word production profiles for 11 children, each learning one of four different languages, will provide a basis for us to identify both similarities and differences.

(2) When does a link between speech perception and vocal production emerge, if it is not there to begin with? We will consider evidence for the formation of such a link toward the end of the first year, or in the period immediately preceding first word production.

(3) What learning mechanism(s) could account for both ambient language differences and individual differences among children acquiring the same language? The idea of complementary memory systems underlying implicit and explicit learning (McClelland *et al.*, 1995; Ellis, 2005) is now sufficiently well supported by both neuroscientific and modelling studies to suggest that (a) both memory systems must inform early word learning, and (b) these systems are sufficient to account for the construction of phonological knowledge, given adequate exposure to an ambient language.

2. Early words and templates

Despite Jakobson's well-known view (1941/68) to the effect that the babbling sounds produced in the prelinguistic period are wholly unrelated to the speech sounds found in early word forms, continuity between babbling and speech has been firmly established for many years now. Studies bringing clear empirical evidence to bear on the question have involved both the general patterning of babble in relation to early word production (Oller *et al.*, 1976) and the particular babbling of individual children in relation to their own first word forms (Vihman *et al.*, 1985); more recently, first signed words have also been found to be rooted in prelinguistic gesture (Cheek *et al.*, 2001).

Yet the implications of continuity have received relatively little attention: If the patterns found in first words are foreshadowed in babbling, then when and how does phonology begin? In recent work within the Optimality Theory (OT) framework "the initial state" virtually always receives some mention (e.g., in all but two of the chapers in Kager *et al.*, 2004), yet no definition of what the expression "the initial state" actually means in developmental or lexical terms is typically provided – although Menn (2004) notes that "even at the time they are producing their very first words, children cannot be said to be in an 'initial state' with respect to acquiring phonology" (p. 61). Menn bases her conclusion on the ample evidence of the influence of ambient language production values on infant production of vowels and accentual patterns already in the prelinguistic period (Boysson-Bardies *et al.*, 1989; Levitt & Wang, 1991); experience of the ambient language distributional frequency of within-repertoire consonants (labials and alveolars, stops and nasals) also affects infant production within the first year (Boysson-Bardies & Vihman, 1991).

In the OT framework universal markedness and faithfulness constraints are together taken to constitute a phonological system, with a particular ranking being required by each language. Given the logic of OT, current formalist approaches to phonological development assume with some consistency that learning can only be accounted for by assuming that markedness constraints are all ranked above faithfulness constraints "in the initial state"; additionally, the course of development can only be modelled by positing that markedness constraints are gradually reranked below faithfulness constraints if and only if exposure to the input language provides evidence for such a ranking. This developmental sequence will necessarily result in a relatively linear progression, much as Stampe (1968, 1971) and Smith (1973) proposed many years ago.

The difficulty is that longitudinal study of one or more individual children generally fails to reveal such a linear course of development or learning. Instead, as observed thirty years ago in an analysis of the early words of three children acquiring English (Ferguson & Farwell, 1975), such studies consistently show that relatively accurate first word forms are followed, in a period of more prolific production, by an overall regression in accuracy accompanied by an increase in systematicity or inner coherence among the child's own forms.

Table 1 provides some examples of such non-linear developmental sequences, drawing on the first recorded words of three children each learning English, Finnish and French and two learning Welsh as well as a subset of the later words of each of those children, drawn from the point at which each of them had a cumulative lexicon of some 50 words or more [1]. Under "early words" are listed ALL of the words recorded in the first one or two sessions in which the child spontaneously produced 3 to 4 identifiable words (excluding onomatopoeia, which were included in the count establishing the 4-WORD-POINT (4wp), however). In the columns to the right of the early words are presented a subset of the words produced a few months later, at the 25-WORD-POINT session, divided into those that were "selected", meaning that the target word attempted roughly matches the pattern that the child produces, and those that were "adapted", meaning that the target word has been adapted to fit the child's pattern. The pattern itself can be seen as a TEMPLATE that emerges as the product of word learning and which may differ for each child; we schematize the template, which applies to both selected and adapted later words, in angle brackets. A brief characterisation of the adaptation observed for each of the word forms is noted in the last column on the right.

	Early words			Selected		Adapted		Adaptation
English								
Molly				**< CVC’ >**	(see Vihman & Velleman, 1989)			
(10-11)	*baby* [beɪbi]	[papə]	(15)	*diaper* [daɪpəɹ]	[tæpə]	*down* [daʊn]	[ta:nə]	Add final V.
	cracker [krækəɹ]	[kwa]		*Hooper* [hupəɹ]	[hʌp:ə]	*gran’ma* [granma]	[nam:ə]	Replace onset by coda /n/.
	night(-night) [naɪt]	[hʌnʌ]						
Sean				**< CVC >**				
(12)	*allgone* [ɔlgɔn]	[ʔɔdæ:]	(16)	*bird(s)* [bəɹdz]	[bɤ:s:]	*cracker* [krækəɹ]	[dʒak]	Omit second syllable.
	boo [bu:]	[pʊ]		*book* [bʊk]	[bɪk]	*rabbit(s)* [ɹæbɪts]	[pæts]	Exchange segments, omit syl.
	dog [dag]	[ta:k]		*horse* [hɔɹs]	[hɪ:ʃ]			
	tick [tɪk]	[tɪ]		*duck* [dʌk]	[tʌk]			
				fish [fɪʃ]	[fø:tʃ]			
Timmy				**< (ə)Ca >**	(see Vihman, Velleman & McCune, 1994)			
(10-11)	*ball* [bɔl]	[bæ]	(15)	*(a) box* [əbaks]	[ʔəpa]	*book* [bʊk]	[pa]	Substitute [Ca/æ].
	block [blak]	[pæ]		*ball* [bɔ]	[pa]	*(a) brush* [əbɹʌrʃ]	[əba]	Substitute [Ca/æ].
	car [kaɹ]	[ka:ə]		*car* [kaɹ]	[ka]	*(your) nose* [jəɹnoʊz]	[ʔən:æ]	Substitute [Ca/æ].
	kitty [kɪtʰi]	[kaka]				*(your) eye(s)* [jəɹaɪ], [jəɹaɪz]	[ʔʌjæ]	Vɪ > jV [V = a/æ].

Finnish					(see Kunnari, 2000 ; Vihman & Velleman, 2000)			
				< VCCV >				
(17)	*anna* [ɑn:ɑ] "give"	[nɑ]	(20)	*äiti* [æiti] "mother"	[æiti]	*kala* [kɑlɑ] "fish"	[ɑlɑ]	Omit onset.
	hauva [hɑuʋɑ] "doggy"	[vɑ], [hɑ:vɑ]		*ankka* [ɑŋk:ɑ] "duck"	[ɑk:ɑ]	*loppu* [lop:u] "end"	[op:u]	Omit onset.
	heppa [hep:ɑ] "horse"	[pɑ], [ɑp:ɑ]		*auto* [ɑuto] "car"	[ɑt:o]	*nalle* [nɑl:e] "teddy"	[ɑl:e]	Omit onset.
	mummo [mum:o] "grandmom"	[mo], [ɑm:o]		*isi* [isi] "daddy"	[içi]	*pallo* [pɑl:o] "ball"	[ɑl:o]	Omit onset.
	pappa [pap:a] "grandpa"	[pɑ], [pɑp:ɑ]		*ukko* [uk:o] "old man"	[uk:o]	*sammui* [sɑm:ui] "died (said of car motor)"	[am:u]	Omit onset.
Eliisa				**< $C_1VC_1(C_1)V$ >**				
(10-11)	*katso* [kɑtso] "look"	[tɑto]	(15)	*kiikkuu* [ki:k:u:] "swings"	[ki:k:u]	*lintu* [lintu] "bird"	[titu]	Harmonize Cs.
	tyttö [tyt:ø] "girl"	[tito]		*kukka* [kuk:ɑ] "flowers"	[kuk:ɑ]	*nukke* [nuk:e] "doll"	[kuk:e]	Harmonize Cs.
				pappa [pɑp:ɑ] "grandpa"	[pɑp:ɑ]	*pallo* [pɑl:o] "ball"	[pɑp:u]	Harmonize Cs.
				pupu [pupo] "bunny"	[pupo]	*rikki* [rik:i] "broken"	[kik:i]	Harmonize Cs.
				tyttö [tyt:ø] "girl"	[tyt:ö]	*tippui* [tip:ui] "dropped"	[pip:u]	Harmonize Cs.
						vettä [vet:æ] "water"	[tit:æ]	Harmonize Cs.

Venla				**< $C_1VC_1(C_1)V$ >**				
(10-11)	*äiti* [æiti] “mother”	[æt:i]	(13)	*mamma* [mɑm:ɑ] “milk”	[mɑm:ɑ]	*nalle* [nɑl:e] “teddy”	[nɑn:e]	Harmonize Cs.
	an:a [ɑn:ɑ] “give”	[nan˘a]		*Viivi* [vi:vi] (name)	[vi:vi]	*pallo* [pɑl:o] “ball”	[pɑp:ɑ]	Harmonize Cs.
	kenkä [keŋkæ] “shoe”	[kek:æ]		*vauva* [vauʊa] “baby”	[vɑʊvɑ]	*possu* [pos:u] “pig”	[pɑp:u:]	Harmonize Cs.
						rillit [ril:it] “glasses”	[lil:i]	Harmonize Cs.
						setä [setæ] “uncle”	[tetæ]	Harmonize Cs.
French								
Carole				**< $C_1V(C_1V)$ >**				
(11)	*balle* “ball” [bal]	[ba], [baba]	(14)	*Babar* [babaʀ]	[baba]	*canard* “duck” [kanaʀ]	[kaka]	Harmonize C_2.
	bébé “baby” [bebe]	[bebe]		*bébé* “baby” [bebe]	[bebe]	*chapeau* “hat” [ʃapo]	[papo]	Harmonize C_1.
	nounours “teddy” [nunuʀs]	[ne], [nene]				*p’tite voiture* [ptitvwatyʀ]	[tity]	Omit second syllable.
	Mickey [mike]	[kə]				*sac* “bag” [sak]	[ka]	Vk -> kV ; omit coda.
	papa [papa]	[papa]						

Charles				**< VCV >**	(see Vihman, 1996)			
(11)	*au revoir* “goodbye” [ɔʀvwaʀ]	[awa]	(15)	*au revoir* “goodbye” [ɔʀvwaʀ]	[avwa]	*chapeau* “hat” [ʃapo]	[apo]	Omit onset.
	boum “boom” [bum]	[bœm]				*lapin* “rabbit” [lapɛ̃)]	[apa]	Omit onset.
	beau “nice” [bo]	[bo]				*va pas* “doesn’t fit” [vapa]	[apa]	Omit onset.
	donne/tiens “give/ here” [dɔn], [tjẽ)]	[dæ]						
	maman [mamã)]	[mama]						
	non “no” [nɔ̃)]	[nɛ]						
Laurent				**< CVlV >**	(see Vihman, 1993)			
(10)	*allo* “hello” [alo]	[hailo], [ailo]	(15)	*allo* “hello” [alo]	[alo]	*canard* “duck” [kanaʀ]	[kɔla]	C_2 > /l/.
	donne (le) “give (it)” [dɔnlø]	[də], [dlə]		*de l’eau* “some water” [dəlo]	[dəlo]	*chapeau* “hat” [ʃapo]	[bɔlo]	C_1 exchange with C_2; C_2 > /l/.
	l’eau-l’eau “bottle” [lolo]	[ljoljo]		*ballon* “big ball” [balɔ̃)]	[palc]	*la brosse* “the brush” [labrɔs]	[bəla]	C_1 exchange with C_2; C_2 > /l/.
	non “no” [nɔ̃)]	[ne]		*pas là* “not there” [pala]	[pala]	*la cuillère* “the spoon” [lakɥijɛ’ʀ]	[kola]	C_1 exchange with C_2; C_2 > /l/.
	tiens “here” [tjɛ̃)]	[ta]				*voilà* “there you are”	[lala]	Harmonize C_1.

Welsh						(See Vihman, 2000)		
Fflur				**< VCV >**				
(13)	*gwgwg* "bird/duck" [guguk]	[gaga], [gagak]	(21)	*eto* "again" [ɛtɔ]	[ʔəθa]	*bwni* "bunny" [buni]	[hʊni]	Omit onset.
	na "no" [na]	[na]		*hwnna* "this" [huna]	[ʔɔna]	*fyna* "there" [vɨna]	[ʔənæ]	Omit onset.
	sannau "socks" [sana]	[daða]				*moron* "carrot" [mɔʀɔn]	[ʔawan]	Omit onset.
						syrthio "fall" [sɨʀθjɔ]	[ʔʌsa]	Move onset to 2d syl.
Gwyn				**< (C_1V)C_1VU >**				
(12)	*babi* "baby" [babi]	[bab:i]	(14)	*ball/pêl* [bɔl], [pe:l]	[baʊ]	*cacen* "cake" [kakɛn]	[gogɛʊ]	Final syl > Vv.
	ball/pêl [bɔl], [peˇl]	[bə:u]		*dau* "two" [daɪ]	[daɪ]	*pobl* "people" [pɔbl]	[boboʊ]	Final syl > Vv.
	dau "two" [daɪ]	[da:i]		*miaw* "meow" [mjaʊ]	[maʊ]	*panda* [panda]	[bapaʊ]	Final syl > Vv; harmonize Cs.
						uh-oh [ʔʌʔəʊ]	[aʔaʊ]	Final syl > Vv.

(Age in months.)
<template patterns>

Table 1. First words and templates.

2.1. Early word forms

The difference between the early and the later word forms is that, in general, the early word forms of a given child show little if any "inner coherence"; they typically reflect attempts at a range of different adult words, with no readily discernible pattern across the words targetted or across the forms produced by the child. At the same time, the children's forms shown in Table 1 exemplify the kind of relative "accuracy" found in first words (as first noted by Ferguson & Farwell, 1975): Of the 11 children represented, one or two from each language group have at least one form that constitutes a near-perfect match to the target[2] (Sean *boo* and Timmy *dog*, *car*; Atte *pappa*; Carole *bébé* and Charles *papa*, *beau*; Fflur *na*, *babi* and Gwyn *dau*). In the early words we find no reorderings of adult segments and few segmental additions (exceptions are the onset [n] in Finnish *anna* (Venla) and the reduplication of French *balle* [baba] (Carole)).

Where the first words differ from their targets it is often due to omission of whole syllables (the second syllable in English *cracker* [kwa], the first in French *donne-le* [dlə] and in all of Atte's first words, alternating with a fuller form) or of coda consonants (English *night*, *tick*, *ball*, *block*; French *balle*, *nounours*, *au revoir*). Few non-geminate clusters are attempted (two in English word-initial position, one in French; one medial in English, two in Finnish); of these, only one is produced as a child cluster (Molly [kwa] for *cracker*). Of the five diphthongs attempted (two in English, two in Finnish, one in Welsh), only one retains both vocalic elements in the child form (Gwyn [daːɪ] for *dau* [daɪ] "two"). We can also observe palatalization of [l] in French *l'eau-l'eau* [ljoljo] [Louis]) and some vowel changes, in most cases a low and/or central vowel replacing a higher vowel (*baby* [papə], *allgone* [ʔɔdæː], *au revoir* [awa], *donne* [dæ], *tiens* [ta], and *gwgwg* [gagak]). Additional vowel changes involve a shift from front rounded to front unrounded or back rounded vowel (both in the same token of Finnish *tyttö*), in accord with markedness theory for vowels, and from a back rounded to a front unrounded vowel after [n], in accord with the CV-associations posited by Davis & MacNeilage (1990, 1994): *nounours* [nene], *non* [nɛ], [ne] (two different children).

To anticipate, these early word froms look very much like the basic (motoric) patterns typically found in babbling. The target words themselves have in common likely high token frequency in the speech addressed to the children (*cf.* the occurrence of "ball" and "baby" in three language groups, "dog" and "mother" in two, and both "give" and "no" in the first words of three of the 11 children). More strikingly, these first words drawn from four different languages also share their relatively simple structure – one or two syllables at most, few clusters or diphthongs, and a predominance of stops and nasals in the word forms for all four (the [ʋ] of Finnish *hauva* and the [l] of *allo* and *l'eau-l'eau*, both attempted by the same French child, are the sole exceptions; there is only one fricative onset (in Welsh *sannau*) in any of the 43 target words). In addition, no more than one supraglottal consonant is typically found per word (the exceptions are Sean *dog*, Eliisa *katso* and Charles *boum*, which vary place or manner across the two consonantal positions, but not both).

2.2. Later word forms: "selected"

The later word forms shown as "selected" generally show one or more unifying phonological characteristics – enough to suggest an (unconscious, or implicit) organizing principle at work in the time between the first words (age range here 10 to 13 months, with Atte an outlier at 17 months) and the end of the single-word period (age range here 14 to 16 months, with both Atte and Fflur as outliers at 20 and 21 months, respectively). The phonological pattern schematized in angle brackets for each child's later words generally characterizes the adult form of the selected target words as well as the child's own word forms, if we disregard the occasional reduction of consonant clusters (three cases) or diphthongs (one case) and the omission of word-final consonants (five cases, three by Timmy, who targets CVC words but produces only CV syllables).

2.3. Later word forms: "adapted"

The most interesting forms for our purposes are those labelled "adapted". Here the children have attempted words which are less closely related to the schematized patterns or templates and have produced forms that show various types of adaptation of the adult target, resulting in good agreement with the template but a regression in accuracy in comparison with what we saw in the earlier words. The final column indicates some of the changes required to arrive at the child's form from the targetted word. For several of the children a single adaptation can be identified for two or three different word targets (Atte, Charles and Fflur all omit onset consonants, for example, while Gwyn creates a diphthong in [aʊ] out of completely different adult second syllables and two Finnish children apply consonant harmony to all of the forms noted). For others we see a conspiracy of distinct changes to achieve a single output type (see Molly and Sean, for example). In several cases we see reordering of the vowels and/or the consonants of the adult form, apparently to achieve a sequence that is within the child's productive repertoire: Sean *rabbits* [pæts] (eliminate the [r], create a monosyllable, CV metathesis), Timmy *eye* or *(your) eyes* [ʔʌjæ] (CV metathesis, with the addition of an initial dummy syllable), Carole *sac* [ka] (CV metathesis), and three of Laurent's forms, which have a medial [l] where the likely adult model included the definite article as the first syllable.

2.4. Early words and templates revisited

The basic OT notion of a constrained output form as the motivation for rule-like relationships between presumed "underlying forms" (the adult models) and child surface forms fits here very well. On the other hand, there is little evidence to support the view that maximally unmarked output forms characterise the "initial state", if we take that to mean the children's first recognizable words. Of the 42 first word tokens provided here, 11 fit the Jakobsonian ideal of a maximally unmarked first word (in segmental terms), consisting only of the syllables [ba] (or [pa], [bæ], [pæ]) or [da] (and variants), either singly or reduplicated. At the same time these and other first word forms stand as exceptions to the minimal prosodic word, which is sometimes claimed to constitute an obligatory first stage for all children (the minimal word must consist of more than a one-mora syllable such as (C)V, meaning that it must include at a minimum a long vowel or diphthong, a coda consonant, or a second syllable: Demuth & Fee, 1995; Demuth, 1996): *cf.* English *cracker*, *boo*, *tick*, Finnish *anna*, *hauva*, *mummo*, and French *nounours*, *Mickey*, *beau*, *non* (twice) and *donne-le* (twice), and Welsh *na* in addition to the Jakobsonian forms: English *ball*, *block*, Finnish *heppa*, *pappa*, French *balle*, *donne* and *tiens*. Furthermore, the early words of various infants include such marked segments and structures as the velar stop [k], which occurs as an onset in all four languages and as a coda in two, the clusters [dl] and [kw], and both a front rounded vowel and a voiced interdental fricative, recorded in one form each.

From a functionalist perspective one can clearly see that the early words build on syllables commonly found in babbling. These early words, although reflecting no single pattern for most of the children, nevertheless appear to have been selected to fit the repertoire of segments, sequences, and syllable or word shapes developed through prelinguistic babbling practice. The later words show a wider range of sounds attempted and produced, but what can also be seen in those forms is the reuse of the same early-established motor routines for a wider range of target sounds and structures, resulting in adapted alongside selected forms. That is, the later words sacrifice accuracy to range, while continuing to reflect a relatively restricted set of output forms. This second step in the widely evidenced U-shaped developmental profile is commonly accompanied by relatively rapid increase in new word production, often identified as a "lexical spurt" (although Ganger & Brent, 2004, cast some doubt on the quantitative validity of the term).

The development of one or more templates can be seen to reflect a step towards phonological system (as argued also in Vihman & Velleman, 2000) and thus to constitute an advance over the early word forms despite the persistence of stringent output constraints and the regression in accuracy in the case of the adapted forms. In the adapted words, the number of child patterns is minimised, the range of adult forms attempted increases, and whole word phonological processes apply – e.g., consonant harmony to meet the challenge of differing consonants in a single target word, metathesis to achieve a particular (pre-established, familiar or "routine") vocalic or consonantal sequence or melody (for more extensive examples from a range of languages, see Vihman & Croft, in press). In general, the coherence of the later words for any given child, both selected and adapted, suggests implicit reference to an internal template as a phonological source as well as integration into the template of aspects of the external pattern provided in the target word itself.

We make the assumption that input frequency – including the child's own production patterns as well as the ambient speech to which the infant is exposed – must influence the development of routine or relatively automatized word patterns or templates. If that is true, then despite the commonality in patterning that results from the physiological or motoric limitations mentioned above, which can be expected to constrain all children to a certain extent, it is also to be expected that as each child becomes more experienced in word production, exposure to different ambient languages will result in differences in the formation of word templates. Evidence that this is the case can be found, for example, in the occurrence of <VCV> as a template (for some children) in languages with geminates (Finnish and also Hindi: see Bhaya-Nair, 1991) or with phonetically long medial consonants (Welsh) or iambic accent (French). For English, in contrast, <CVC> is a common template. Table 1 provides examples of all of these patterns; see also Vihman & Croft (in press).

3. The sources of phonological knowledge: Some experimental evidence

What is the source of the first words? And what is the mechanism behind selected pattern production? We know that individual children differ in their vocal patterns (e.g., Stoel-Gammon & Cooper, 1984; Vihman *et al.*, 1986; Vihman, 1993) and that, furthermore, differences in early word patterns can to some extent be traced to differences in individual vocal practice, or babbling (Vihman *et al.*, 1985). It has long been accepted that children "avoid" word patterns that do not fit their existing phonetic repertoire (*cf.* Schwartz & Leonard, 1982; Schwartz, 1988). Yet as Menn (1983) pointed out, it is difficult to see how children can be "aware" of the many sounds and prosodic structures that they cannot yet produce. A simple alternative is to turn the process around: Perhaps children are "selecting" what they DO know rather than avoiding what they do not. This can be readily explained as the product of the child's bimodal proprioceptive and auditory familiarity with his or her own frequent vocal production patterns and the implicit experience of a "match" when adult input includes phonetic patterns that resemble those well known own-output patterns (Elbers [1997, 2000], who coined the phrase "output as input" to express this phenomenon, relates it to the learning of grammar as well as phonology). Vihman (1993) proposed the term ARTICULATORY FILTER to characterize the hypothesized mechanism (*cf.* also Vihman & DePaolis, 2000). Two recent studies that provide evidence to support the idea are summarised below.

3.1. Early words and the emergence of a link between perception and production

3.1.1. An effect of vocal production on the perception of speech

Vihman & Nakai (2003) tested for an articulatory effect on perception by recording and transcribing the vocalisations of 27 monolingual English and 26 monolingual Welsh children on a bimonthly basis from 10 to 12 months. The infants were tested two weeks after the last recording on closely matching lists of nonword stimuli constructed to highlight one of two consonants of comparable input incidence (English /t/ *vs* /s/; Welsh /b/ *vs* /g/). Listening times were in inverse correlation with the children's frequency of use of the consonant, a novelty effect. That is, Welsh infants who frequently produced /b/ attended longer to the /g/-list and viceversa. For English, /t/ but not /s/ was commonly produced by many children, but attention to /t/ *vs* /s/ varied in inverse relation to the extent of the infant's vocal experience with it, based on the recorded data in the last session only. A later reanalysis revealed that the novelty effect pertained only to children with over 200 productions of the consonant tested, based on all four recordings, such that high producers of /b/ or /g/ (Welsh) or /t/ (English) looked significantly longer in response to the nonword list featuring the less produced consonant, while infants who produced fewer tokens of either of the tested consonants failed to show such a distinction. The findings clearly demonstrate an effect of motoric practice (together with the consequent auditory experience) on infant perception of input speech.

DePaolis (2006) tested further the question of production influence on perception. From 9 or 10 months on English-learning infants were recorded at home for 30 minutes, on a weekly or biweekly schedule, and the recordings immediately transcribed. Once the children showed stable production of one or more supraglottal consonants the headturn procedure was used to compare looking times to short narrative passages incorporating nonwords made up of one of three sets of consonants: (a) stable consonants used by the child being tested (OWN VOCAL MOTOR SCHEMES, or VMS), (b) comparable consonants used by other children (OTHER VMS), or (c) consonants which are uncommon in children's early productions (NON-VMS). Longer looking times to own VMS passages were recorded for children who were consistently producing only one consonant across two or more recording sessions, while longer looking times to the "other VMS" passages were recorded for children with two or more VMS consonants. The findings again support the hypothesis that the child's own output affects perception and suggest further that experience of self-produced input aids in the segmentation of the rapidly changing ambient speech stream, although the effect appears to be dynamic: For as long as only a single supraglottal consonant is being used regularly, its occurrence in running input speech holds the infant's attention, making words with that consonant salient to the child. Once the child has begun to make consistent use of two or more consonants, attention appears to turn to motorically accessible but as yet little practiced consonants ("other VMS"). Both effects support the idea of an "articulatory filter" mediating input speech to the child.

There is thus sufficient experimental evidence to support the idea, developed on the basis of the "circumstantial" evidence of early word "accuracy" or "selection", that the first words are the product of an implicit match experienced by the child when within-repertoire consonants are heard (e.g., the [b] of *baby, ball*, etc.). This leads to the child's production of roughly similar vocal forms in "priming situations", or situations in which that form has been often heard. This provides at least a partial answer to the question as to how and when a link between the child's perception and production begins to be established.

3.1.2. The role of phonetic practice in referential word production

However, primed or context-limited word use characterizes only the earliest stages of word learning. Rapid lexical advances are not seen until the child begins to produce words across a range of different, even novel contexts, giving evidence of referential or symbolic understanding of word use (Bates *et al.*, 1979; Vihman & Mc Cune, 1994). Based on a study of 20 children aged 9 to 16 months, McCune & Vihman (2001: 680f.) found that early production practice supported earlier onset of referential word learning, and concluded that "stable production control allows the child more readily to attend to and recall adult word forms and their associated meanings across different contexts". In a later longitudinal study of 12 British children those exhibiting early mastery of supraglottal consonants (or VMS) were again found to produce referential words earlier and to achieve a larger lexicon of referential words by 16 months (Keren-Portnoy *et al.*, 2005). Similarly, Storkel (2001) found in an experimental word learning procedure with three-year-old American children that CVC nonwords based on commonly occurring English diphones were better learned, with fewer errors of semantic category, than CVC nonwords based on rare English diphones. All of these findings can be interpreted to mean that stable phonetic representations (based on well practiced or highly familiar segments or segmental sequences) lead to greater automaticity in phonological processing and thus facilitate the efficient creation of new lexical representations. This evidence of the role of phonetic practice and consequent stable phonological representations provides an important insight into the role of phonology in the word learning process.

3.2. Later words and advances in knowledge the ambient language: The case of long consonants

In our discussion of the data presented in Table 1 we emphasized the similarities in the developmental profiles of children acquiring different languages. We saw these similarities as rooted not in the formal constraints posited for Universal Grammar but in the physiological limitations – or relative inexperience – of children just beginning to learn to use their rapidly maturing speech production capacities and to match that use to their better developed auditory capacities, which are exercised by the foetus in response to ambient speech already in the final weeks before birth. In this section we will consider the role of the ambient language in shaping the beginnings of a phonological system.

We have already noted that markedness is not a completely reliable predictor of the children's earliest word forms: Unmarked forms are predominant but marked forms occur as well. We have suggested that the source of relative markedness in first word forms is not UG but the biological constraints that shape children's vocalizations in the first year or two of life. Long consonants provide a useful test case for comparing these two sources of early word forms: Geminates are marked in phonological terms, since they are present only in a small minority of the world's languages (Maddieson, 1984, reports that only 18 out of his 317-language sample, or 6%, have even a single (phonologically) long consonant; 15 have several).

On the other hand, it is well established that children speak more slowly than adults and infants articulate more slowly than older children (*cf.*, e.g., Smith, 1978). In infants acquiring languages such as English and French, for example, which lack phonologically long consonants, the first words often give the impression that the child has become "stuck" on a medial consonant in a word like *baby*, producing a form we transcribe as [beɪb bi].

3.2.1. The duration of medial consonants in early words in languages with and without phonological geminates

Vihman & Velleman (2000) compared the length of medial consonants in five children each acquiring English, French and Finnish, including both babble and identifiable words, at the same two developmental points represented in Table 1: The first two half-hour recording sessions in which 3 to 4 identifiable words were produced spontaneously (4wp) and the session in which about 25 words were first produced ((25wp), corresponding to a cumulative vocabulary, by parental report, of approximately 10 and 50-75 words, respectively: Vihman & Miller, 1988). Table 2 shows the results: Whereas at the 4wp children acquiring all three languages produced relatively long medial consonants, ranging from 150ms for French to 208ms for English, by the 25wp the children exposed to languages lacking long medial consonants were producing considerably shorter consonants, with far less group variability, while the Finnish children showed the opposite trend of an increase both in mean length of medial consonants (to nearly 300ms) and in standard deviation, which is twice as large at the later word point. This suggests that intervocalic production of long consonants is well within infants' motoric capacity from the onset of regular word production, and that it is the "unmarked" singleton identified by phonological theory that must be mastered in response to exposure to the input language, not the "marked" geminate.

	4 WORD POINT		25 WORD POINT	
	Mean in ms.	Group s.d.	Mean in ms.	Group s.d.
English	207.97	82.51	121.87	28.81
French	149.56	43.68	139.98	8.18
Finnish	205.74	46.99	297.82	96.07

Table 2. Medial consonant length in three languages.

3.2.2. Phonetic vs *phonological consonant length: An acoustic study of early word production in Finnish and Welsh*

To what extent is the PHONOLOGICAL STATUS of long consonants in Finnish, which contrast phonologically with corresponding short consonants for virtually the entire inventory, the key factor in the difference documented in Table 2 between children exposed to English and French and children exposed to Finnish? What would be the effect on infant production of PHONETICALLY LONG BUT NON-CONTRASTIVE intervocalic consonants in the input? Welsh provides a useful point of comparison. In Welsh most disyllabic content words have what is considered a strong-weak or trochaic accent pattern, but the accent is expressed through the lengthening of the medial consonant and the final vowel; the vowel of the first syllable is short (contrastive vowel length occurs only in monosyllables). Figure 1 illustrates the phonetic expression of Welsh word accent by comparing English, French and Welsh with respect to the percentage of the VCV sequence taken up by these elements in elicited production by five adult female speakers each of the (American) English and French nonword /babi/ and the Welsh word *babi* "baby" (from Vihman *et al.*, 2006).

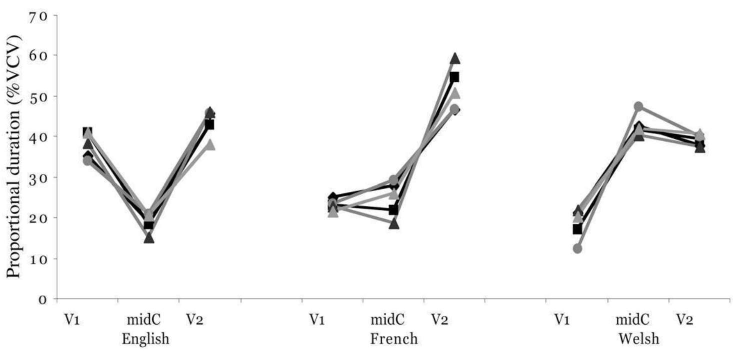

Figure 1. Proportional durations of V-C-V elements of adult disyllables: /babi/ Production (Individuals are plotted in different lines).

Vihman *et al.* (2002) analysed the acquisition of long consonants in Finnish and Welsh (see Kunnari *et al.*, 2001, for a preliminary report of the findings). Welsh disyllables are predominantly trochaic, Finnish disyllables exclusively so, with contrasting long and short vowels in both stressed and unstressed syllables and contrasting long and short intervocalic consonants permissible at any point in the word. Furthermore, Vihman & Velleman

(2000) reported that while in Finnish mothers' speech addressed to the infants 38% of all content words included a geminate, 43% of the words attempted by the children included one. This suggests that the geminate consonants – manifested as a within-word pause of a few milliseconds in the signal in the case of geminate stops – were perceptually salient to the children. In addition, 47% of the children's own word forms were perceived as including a long consonant. It is at least plausible that the children's tendency to produce relatively long medial consonants constitutes an additional element in the perceptual salience that leads to the disproportionate representation of geminates in the children's choice of words to say.

Kunnari (2000) recorded 10 children in Oulu, Finland, from 5 to 24 months while Vihman (2000) recorded 5 children acquiring Welsh in the home in North Wales, from 9 months to the 25-word point. For the purposes of the comparative study five children were sampled at the 4wp (mean age 1;1 in both languages) and 25wp (mean age 18 months for Finnish, 17 months for Welsh). Analyses were undertaken for both the mothers' speech to the children and the children's productions of both words and babble. For the mothers, two data sources were used: (1) the first 50 utterance-medial stops were extracted from child-directed speech only, at the 4wp, and digitized for acoustic analysis; (2) all of the mothers' disyllabic words with medial stops were extracted for direct comparison with the children's productions. For the children, all usable disyllables with medial stops were included.

Analysis of the mothers' first 50 utterances indicated that (1) in both languages more short (< 100ms) than long medial stops were recorded overall and (2) Finnish stops were significantly shorter than Welsh ($p < .0001$). Analysis of the mothers' disyllabic words showed that (1) Finnish durations had a bimodal distribution, reflecting the phonological contrast between singletons and geminates: the median value of short stops was 53ms while the median value of geminates was 169ms (overall mean 75ms). (2) In contrast, Welsh showed a single peak and the longer median value of 118ms (significantly different from Finnish, $p = .0001$).

Figure 2 shows the results for the children: At the 4wp Welsh stops were longer, on average, than Finnish stops, but by the 25wp the mean length of Finnish stops had become greater than the mean length of Welsh stops. Only Finnish stops showed a significant change over time ($p = .0003$ (babble), $p = .0001$ (words)). The Finnish children's production of medial stops was also more variable in duration.

It is worth observing in addition that the increase in medial consonant duration in Finnish is reflected in both babble, which is no longer so frequent at the 25wp, and in words, which are well represented. In general, the typical length of medial stops is roughly the same in words and babble in all four of the cases compared here.

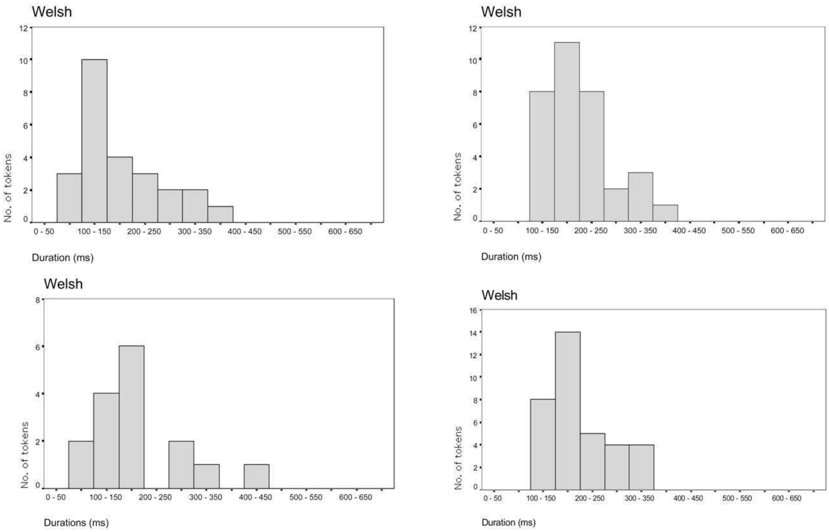

Figure 2a. Distribution (in milliseconds) of Welsh medial stops in disyllabic vocalizations at two developmental points. (1) 4wp (upper panels) and 25wp (lower panels); babble (left panels) and words (right panels).

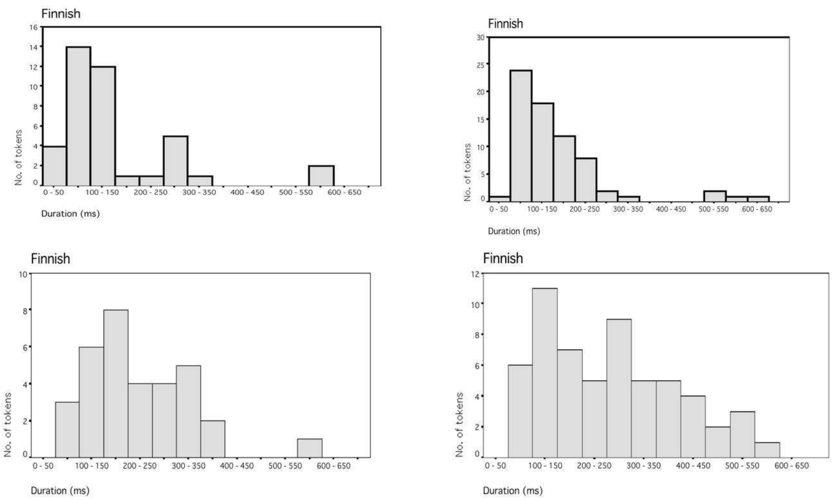

Figure 2b. Distribution of Finnish medial stops as measured in milliseconds at two developmental points. (1) 4wp (upper panels) and 25wp (lower panels); babble (left panels) and words (right panels).

The differences in the distribution of geminates in the mothers' input speech in the two languages constitute a plausible source for the differences in medial consonant duration seen in the children's production of both words and babble. Welsh input speech provides more frequent and more consistent exposure to (phonetically) long medial stops than does Finnish input, due to the fact that medial consonant lengthening is a concomitant of word accent in Welsh rather than reflecting a phonological contrast and is thus broadly represented across all disyllabic words (the actual extent of medial consonant lengthening in Welsh is dependent on sentence prosody, which must in turn reflect pragmatic emphasis and other variables). This results in earlier consistent production of long consonants in Welsh – but with no reason for the children to make further changes in medial consonant duration as word learning increases, since the effect is global and phonetic in Welsh rather than lexical and phonological as in Finnish. On the other hand, as the Finnish children learn more word patterns, with their bias to target and produce more words with geminates for the reasons offered above, they produce more long medial consonants overall and they show greater variability. The effect of increased length seen in the Finnish children's babble reflects the fact that words and babble are part of a common vocal system (Elbers & Ton, 1985; Vihman & Miller, 1988), with the targetted long medial consonants of Finnish words effectively "training" the child to lengthen medial consonants in babble as well[3].

4. The sources of phonological knowledge: A model of implicit and explicit learning and retrieval

There is empirical support for several distinct sources of phonological knowledge. First, the perceptual advances of the first year of life – e.g., progressive sensitivization to prosodic coherence in ever smaller units of input speech from 4 to 11 months (clauses, phrases, words: for a review, see Jusczyk, 1997); the limiting of consonant discrimination to phonological contrasts supported by the ambient language by 10-12 months (Werker & Tees, 1981); and growth in familiarity with the specific characteristics of ambient language prosodic and phonotactic patterning in the period 9 to 12 months (e.g., Jusczyk *et al.*, 1993; Jusczyk *et al.*, 1994) – are well documented. This profile of perceptual accommodation to the ambient language appears to reflect implicit learning of the distributional patterning of input speech, a kind of automatic "statistical" or "distributional" learning that has been convincingly demonstrated experimentally in studies of infant responses to briefly experienced nonword sequences (Saffran *et al.*, 1996; Johnson & Jusczyk, 2001) as well as to non-linguistic regularities (Kirkham *et al.*, 2002).

Secondly, we have argued here that a process of matching of the child's own well-practiced vocal patterns to frequent, situationally or prosodically salient adult words renders those words particularly familiar to the child. This provides a plausible basis for the first recognizable deployment of adult target words in routine or overlearned contexts, where a familiar situation can prime the production of a well-known vocal pattern (e.g., from Table 1, *baby* or *boo*). This would account for the relative accuracy of the first words (typically observed between about 10 to 18 months), which reflect the constraints on production that are also found in babbling. Figure 3 is a graphic representation of this hypothesized source of the first word forms.

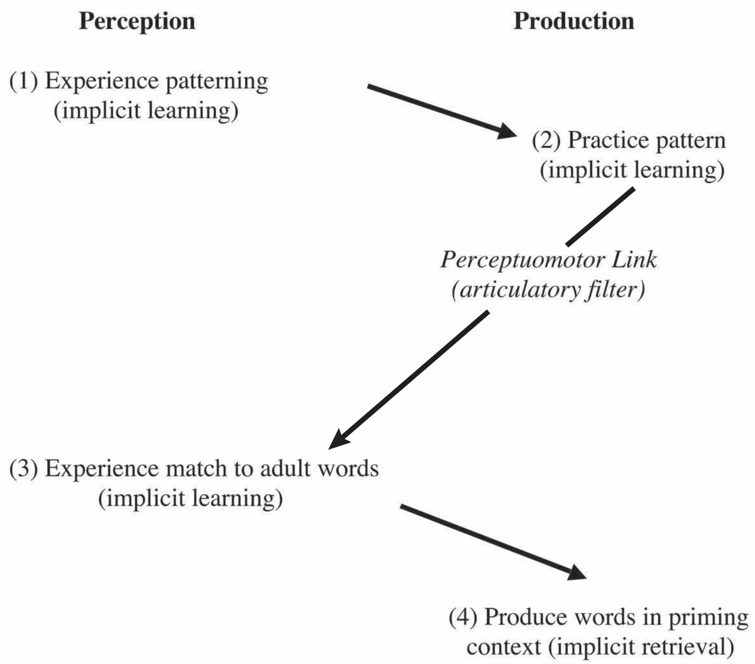

Figure 3. Model of learning (1): Sources of the first word forms.

But how can we account for the later word forms? As illustrated in Table 1, children's production patterns diversify only slowly, while the extension of existing child patterns to less similar target word forms occurs far more rapidly. We propose that the basis for the regression in accuracy seen in the adapted forms reflects yet another kind of implicit learning: Child-specific templates are abstracted from the production patterns of known lexical items. This own-word-based distributional learning necessarily incorporates (1) the physiologically grounded production constraints common to all children, (2) the attentional biases of the individual child, and (3) the structural characteristics of salient and motorically accessible adult words of the particular ambient language – leading to such language-specific characteristics of templates as the CVC of many English-learning children, VC_1C_1V of Finnish, VCV of French or Welsh, and so on. The patterns thus abstracted are then "projected" onto similar but less closely matched target word forms, yielding the less accurate but more phonologically systematic template-based words of the later period, both selected and adapted.

Implicit learning is a powerful mechanism that can account for (1) the automatic registration of the distributional patterns of the ambient language; (2) the gradual development of well-practiced production routines; (3) the matching of vocal production patterns to the input, resulting in primed first word production; (4) the induction of systematic patterns (templates) that support further learning (see also Pierrehumbert, 2003). But this is not sufficient to account for word learning. Although "explicit learning" is generally associated with conscious learning and meta-knowledge, as found in second-language learning in the classroom, for example (Ellis, 2005), it can plausibly be invoked in the context of word learning in one-year-olds as well. There is ample evidence of distinct memory systems in the human brain (McClelland *et al.*, 1995; Ullman, 2004; Ellis, 2005), sometimes distinguished as "procedural" (related to implicit, distributional, or statistical learning) and "declarative" (related to explicit retrieval). Declarative memory requires the involvement of both the hippocampus and the frontal lobes, which direct attention, while procedural memory continues to function even in the case of hippocampal damage, as in cases of amnesia (Squire, 1992)[4]. The product of the declarative memory system is item learning, the laying down of detailed exemplars, complete with rich contextual detail (including characteristics of the speaker's voice) whereas procedural memory requires the recurrence of a particular sequence; declarative memory is immediate, capturing the unique association of co-occurring events, whereas procedural memory is typically slow and cumulative. The hippocampus is required to lay down detailed, multimodal episodic memories, which are the basis of any one-off learning; this memory system alone is capable, in adults, of rapidly learning conjunctions of associated elements of experience (McClelland *et al.*, 1995). It is thus declarative memory that underlies the learning of the arbitrary links between form and meaning that result in a flexibly retrievable lexicon. A distinction can be drawn in other mammalian species between "inflexible" (implicit or procedural) learning, retrievable only through highly specific primes, and "flexible" (or explicit-like, declarative) learning, retrievable in novel situations, without priming (Squire & Kandel, 1999), just as we can distinguish between "primed" or context-bound (inflexible) early word production in infants in contrast with referential or symbolic (flexible) word use, which reflects the emergence of a deeper level of understanding of communication and linguistic expression in the child (Bates *et al.*, 1979).

It is useful for the purposes of understanding infant learning to define "declarative learning" and "explicit retrieval" as meaning "learning with both INTENTION and ATTENTION", although this will no longer be necessary once a lexicon has begun to be well established (as demonstrated by studies of "fast mapping", beginning with Carey, 1978). The beginnings of explicit word learning are accompanied by evidence of a "desire to know", as the child insistently points at different objects, for example, alternating pointing with turning to look at the adult interlocutor. The product of such learning is EXPLICIT LEXICAL RETRIEVAL, leading to spontaneous word use outside of a priming context (typically seen between the 4wp and the 25wp; this is "context-flexible" word use: Vihman & McCune, 1994; McCune & Vihman, 2001). Figure 4 illustrates this advance in word learning, which underlies further advances in phonological knowledge.

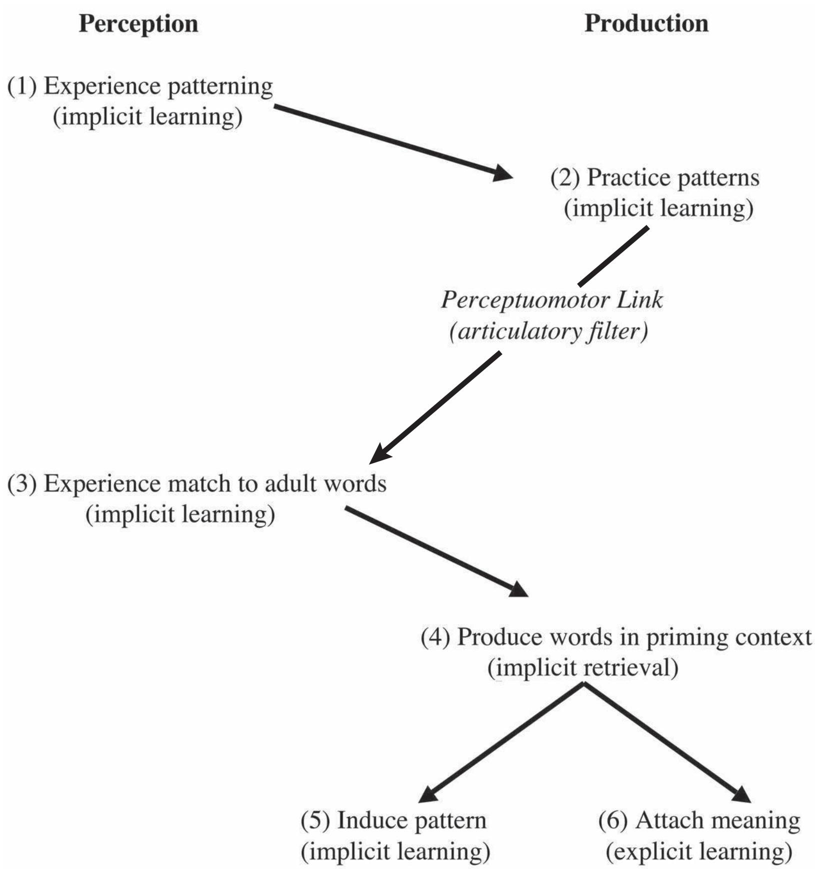

Figure 4. Model of learning (2): Implicit and explicit sources of phonological knowledge.

The first explicit learning and retrieval is evidenced, then, in the children's later word production, as the child begins to expect meanings to be arbitrarily associated with forms. Explicit learning is facilitated when the child has developed a repertoire of phonological representations, as we noted earlier (McCune & Vihman, 2001; Storkel, 2001; Keren-Portnoy *et al.*, 2005; *cf.* also Werker *et al.*, 2002, who found a difference in the ability to notice a minimal phonological shift in nonsense word labels for novel objects as early as 14 months only in the case of children with a reported production vocabulary of over 25 words). An additional source of phonological knowledge, then, is LEXICAL LEARNING. Once the child begins to retain novel form-meaning associations the "data base" on which (automatic, but gradual and cumulative) implicit or procedural learning can operate again expands, leading to the continued abstracting out of new phonological patterns. More rapid lexical learning is now made possible by the child's increasingly stable phonological representations, based on a growing repertoire of well-known words and their common underlying template.

5. Summary and conclusion

Our primary goal has been to suggest learning mechanisms that could account for the emergence of phonological knowledge. We began by presenting developmental profiles of early word production in four languages, noting both similarities and differences, and we observed in addition some differences in word templates that appear to reflect ambient language influence. We presented experimental evidence to suggest that the child's first words, which are typically produced in a priming situational context, are the product of an implicit match of the child's own production routines to input speech. We then described acoustic studies of medial consonant duration in languages that do or do not have long medial consonants and that do or do not contrast long and short consonants. These studies provided evidence that (1) children do not begin with what must be considered the "unmarked value" with respect to geminates, based on distribution in adult languages, but with the marked value of long consonants; (2) phonetic lengthening as a concomitant of the accentual system led to earlier production of long consonants in Welsh, while the phonological contrast of short and long consonants in Finnish appeared to depend on lexical learning, affecting children's medial consonant production only at the later word stage. We have argued, in conclusion, that several types of implicit learning – of distributional characteristics of input speech, the effects of motoric practice in production, the experience of a match on hearing adult forms resembling the child's own well-practiced motoric routines and, finally, the induction of distributional patterns from words the child produces – underlie word production, but that knowledge of phonological system depends, in addition, on lexical learning, which provides the basis for further pattern induction. To the extent that this account has been persuasive the question arises as to what aspects of the development of phonological knowledge remain to be explained by reference to Universal Grammar; we must leave the answer to that question to others.

NOTES

1. The English and French data are from the Stanford Child Phonology project; see Boysson-Bardies & Vihman (1991), Vihman (1993) and Vihman & McCune (1994) for details of data collection, transcription and reliability. The Welsh data were collected in North Wales, following the same procedures, with support from the Economic and Social Research Council; see Vihman (2000). The Finnish data were collected in Oulu, Finland, as part of Sari Kunnari's dissertation study of 10 children (Kunnari, 2000). All of these studies followed the word identification criteria laid out in Vihman & McCune (1994).
2. Differences in voicing between target and child form are disregarded, as children do not typically control voicing at this age; reliability in the transcription of voicing in infant production is also difficult to achieve.
3. Note that at this stage some babble may actually reflect unidentified attempts at word production.
4. For evidence that slow skill learning, based on practice (as seen in the development of vocal production routines), occurs without the involvement of the hippocampus, see Wilson, Maruff & Lum (2003).

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RÉSUMÉ

Les données experimentales, obtenues pour des enfants apprenant des langues cibles différentes, se caractérisent par des similitudes et des différences. Elles montrent également une continuité entre la perception de la parole et les premières vocalisations. Ceci invite à considérer que la mise en relation précoce entre les formes du babillage et les formes des mots entendus est à la base des premières unités produites qui au départ sont structurellement très limitées mais relativement correctes. C'est cette conception que nous retenons pour rendre compte aussi bien des similarités que des différences dans la forme des premiers mots produits pour des langues cibles différentes. Des mesures de la durée de consonnes médiales dans la parole adulte et dans les mots des enfants dans des langues où la longueur consonantique a une valeur phonologique *vs* phonétique différente permettent d'établir que la mise en place des représentations phonologiques repose sur (1) l'apprentissage direct de fréquences de distribution et (2) l'apprentissage du lexique, qui suffit à expliquer le développement des contrastes phonologiques pertinents pour chaque langue-cible. Selon nous, les systèmes complémentaires de mémoire implicite et explicite permettent de rendre compte des deux types d'apprentissage. Nous défendons donc le point de vue selon lequel une exposition régulière à l'environnement linguistique suffit pour expliquer la construction de la connaissance phonologique sans avoir recours à une connaissance linguistique innée ni de la Grammaire Universelle.

MOTS-CLÉS

Approche typologique, comparaison inter-langues, apprentissage implicite et explicite (phonologie *vs* lexique), gabarits lexicaux.