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Getting sound structures in mind. Acquisition bridging linguistics and psychology?

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Acquisition data have never prominently figured in linguistics despite the fact that the ultimate goal of linguistics is to understand what constitutes knowledge of language and how this knowledge is acquired.¹ In his recent GLOW lecture, Chomsky (2004) stressed that in order to answer these questions it is important to gain insight into how a lexicon is built up during acquisition, and what lexical representations look like. Here, I focus on representations of sound structures in the lexicon.

So far, child data have always been considered as external evidence in linguistics, just like results from psycholinguistics have been (Boland, *this volume*). Consequently, I know of no linguistic theory that has undergone changes based on new results in research on child phonology. At best, child language data have been used as additional evidence for particular linguistic claims. On the other hand, linguists take learnability very seriously, as any grammar, being it syntactic or phonological, should in principle be learnable on the basis of the primary language data that a child encounters. Although many researchers recognize that child language data would ultimately bear on the issue, the realistic study of child language acquisition has been considered “much too complex to be undertaken in a meaningful way” (Chomsky & Halle 1968: 331). Since

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1968, this view has not changed dramatically, although the rise of Optimality Theory (OT) (Prince & Smolensky 1993) has instigated a spurt of new research on acquisition of phonology.

Studies in acquisition of phonology have mostly been concerned with why children produce words differently from adults. Most researchers have explained the differences by assuming different phonological systems for children and adults. This is true for early generative studies on phonological acquisition (Smith 1973), as well as current studies on acquisition in OT (see papers in Kager *et al.* 2004). In a sense, phonological representations have not been central in generative studies of acquisition of phonology, even though they have been the major concern in 'adult' phonology, which aimed at providing the most elegant and economic descriptions of lexical representations, using universal phonological units only. Moreover, information that can be supplied by rules is often assumed not to be present in the representations, leading to abstract underspecified phonological representations of words (e.g., Chomsky & Halle 1968, Lahiri & Marslen-Wilson 1991, Steriade 1995).

In psychology, child language studies, in particular, infant speech perception studies, have recently given rise to a new view of language acquisition (Kuhl 2000). In the seventies and eighties researchers argued that children pick up salient parts of the input first (e.g., Ferguson & Garnica 1975, Waterson 1981), and have initially global representations of words that only become more detailed under pressure of the increasing lexicon. Changes in the lexical representations served an efficient organization of the lexicon. Today, most psychologists studying language acquisition assume that children have detailed phonetic representations from a very early stage. By simply listening to language infants acquire sophisticated information about what sounds and sound patterns occur in the language, which of those patterns are frequent and which are likely to co-occur. Moreover, they do so long before they utter their first word. If infants already know so much about their language before speaking it, any discrepancies between this knowledge of the sound patterns of words and the actual way in which they produce them must lie in production skills, either due to underdeveloped or untrained articulatory routines or by processing limitations, such as limited memory, weak entrenchment of forms, etc. Although it is often claimed that production plays a role in normal development, its role in understanding language acquisition is fairly limited in current views on acquisition. The usual assumption is that perception precedes production and production hardly influences perception of mental representations of words.

Thus, both psychologists and linguists are concerned with the manner in which the sound structure of words is represented in the mental

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lexicon. Psychologists are interested in the units that are used for speech recognition and speech processing. Linguists, in particular phonologists, are concerned with the form of phonological representations, the (universal) units of which they are composed and the phonological processes that relate different appearances of words. Linguists aim to discover which structures are universal and how much variation exists among the world's languages. Their ultimate goal is to define linguistic competence. Psycholinguists strive for understanding how knowledge of language is used in perception and production, i.e. their main interest lies in linguistic performance.

Yet, a number of great linguists have explicitly assumed that linguistic competence should have psychological reality, meaning that it should be reflected in performance. Halle (1985/2002), for example, states the following: "speakers find it difficult to memorize the stress contours of each word separately, but find it easy to compute the stress contours by means of rules". Hence, stress need not be part of each individual lexical item, but can be computed by stress rules. Similarly, Kaye (1989) has argued that processing considerations are the ultimate cause of phonological phenomena. Many phonological processes, such as vowel harmony, have a delimitative function and help detecting morpheme boundaries. Lahiri & Reetz (2002) go even further by arguing that speech perception highly benefits from abstract phonological representations in the mental lexicon: the less information is stored in the lexicon the less the change that it mismatches with the incoming acoustic signal or, put differently, the more likely a word is being recognized. However, despite the fact that phonologists have often (mostly implicitly) assumed psychological reality of phonological rules and representations, seldom have they gone out of their way to prove this in a way that has convinced psycholinguists. On the other hand, psychologists have largely ignored results from theoretical linguistics.

With the appearance of Optimality Theory (OT) in the early nineties the focus in generative phonology has been shifted from underlying representations (input) to surface representations (output). In OT phonology is viewed as a set of universal (innate) constraints that link input and output structures. Each language has ordered these constraints in a language particular way. The constraint order evaluates all possible output forms of words and selects one as the most optimal candidate. An important difference with the 'traditional' view of phonology is the focus on output structures. This is also reflected in the principle of 'Richness of the Base', which states that there are no restrictions on input representations. The constraint hierarchy contains different types of constraints. In the simplest model of OT the constraint set is composed of

markedness constraints, which ban marked structure, previously captured by rules or morpheme structure conditions, and *faithfulness constraints*, which formally link input and output structures and demand that output structures equal input structures. Thus, to evaluate output structures, the input representation still is important, as it determines the satisfaction of faithfulness constraints. However, abstractness of phonological input representations is not an issue that is investigated in OT and in practice, many phonologists working in OT have adopted a much more liberal notion of lexical representation than earlier generative phonologists, often allowing for considerable phonetic details in the lexical representation, such as information about prosodic structure.

In psychology, too, the current view seems to be that representations contain detailed information, based on a growing number of studies showing that both adult and child listeners use detailed and context-sensitive information of spoken words. It has therefore been questioned whether one can hold on to the sharp division between speech processing and phonological representations (Bybee 2001, Fisher, Church & Chambers 2004). However, so far, the existence of abstract phonological representations has not been completely denied, as listeners are able to recognize words despite of considerable variation across speakers and environments. Even though many researchers now seem to favor phonetically detailed stored representations, often they also assume a process of 'normalization', which ensures that only context-independent information is kept in the sound representation for words (Lively, Pisoni & Goldinger 1994; see Fitzpatrick & Wheeldon 2000 for a good overview).

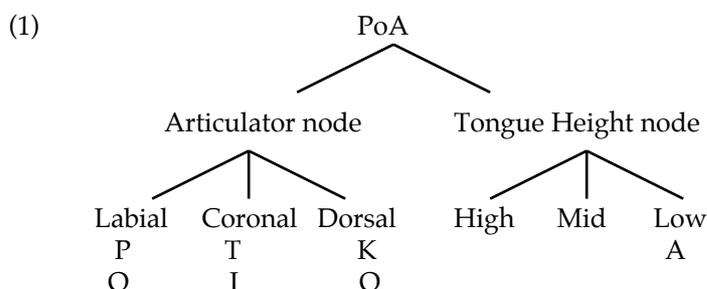
In this chapter I want to show that children's production forms provide evidence for the claim that children (1) build up abstract phonological representations of words and (2) make generalizations over their own productive lexicon resulting in phonological constraints which are part of children's developing phonological system. This view has serious consequences for OT, at least as a theory of acquisition. On the one hand markedness constraints emerge in the course of development instead of being innately present. On the other hand, representations also develop; hence, the interpretation of faithfulness constraints is not stable either. Moreover, I assume that there is a single abstract phonological representation mediating between word recognition and production. In the second part of the chapter I argue that these claims not only make it possible to understand the production patterns attested in spontaneous child language, but also provide a way of linking results from early word recognition and production studies. I can only provide a sketch of my ideas, as each subpart is in it self very complicated. My view is undoubtedly colored by my own background as a linguist.

EARLY SPEECH PRODUCTION

One of the first acquisition studies, which tried to link formal phonological theory and language acquisition is Jakobson's monumental 'Kindersprache' (1941/1968). Jakobson assumed that "phonology begins with the selection of sounds accompanied by the first meaningful use of remembered sound patterns". In other words, the child does not start to build up a phonological system before he or she has words. Acquisition is seen as the unfolding of a universally determined feature tree. That is, the child sequentially acquires phonological contrasts following general markedness principles. As a consequence, the order of acquisition is fairly fixed, with only a certain number of possible learning paths. The first contrast is between a maximally closed, minimally sonorant consonant (labial stop) and a maximally open, maximally sonorant vowel (low vowel /a/). Within the stop series the next contrast to be acquired is the contrast between a labial and a coronal (/p/-/t/) and within the vowels between high and low vowels (/i/, /u/ versus /a/), etc. Although Jakobson expressed development in terms of features, it is implicit in his approach that the development takes place within lexical representations. Jakobson's theory has been very influential, but as Kiparsky and Menn (1977) convincingly argue, it is very hard to falsify.

In recent work Fikkert & Levelt (2002) have investigated place of articulation (PoA) patterns in early production in great detail to investigate how PoA is represented in early word forms. To this extent they coded spontaneous production data for PoA, while abstracting away from all other phonological features. This has been done with all data of five of the youngest children from the CLPF database. These children varied in age between 1;0 and 1;7 at the start of a one-year period of data collection (Fikkert 1994, Levelt 1994). We assumed the main PoA distinctions: Labial, Coronal and Dorsal, for both consonants and vowels, as given in (1). All consonants in CVC(V) words were coded as Labial (P), Coronal (T), or Dorsal (K). All stressed vowels were coded as Labial/Dorsal (O)², Coronal (I) or Low (A). As low vowels do not have features under the Articulator node, but only under the Tongue Height node I will not discuss low vowels here (but see Fikkert & Levelt 2002).

² All back (Dorsal) vowels are round (Labial). Dutch also has front rounded vowels. However, the number of front rounded vowels produced by these children is very low, and is ignored here.



We coded all words that children targeted in the same way. Words with clusters were reduced to the PoA of the first obstruent in obstruent-liquid clusters, and to that of the second obstruent in s-obstruent clusters. Thus, a word like *fles* 'bottle' is coded as PIT, *school* 'school' as KOT. Once all produced forms and targets were reduced to abstract PoA patterns, two striking observations appeared.

First, the shape of words in the children's lexicons only gradually becomes more complex. At the earliest stage (I) all words are 'harmonic', i.e. all sounds of the word share PoA features, which seems to be determined by the stressed vowel of the word. Initially, most children only have labial POP and coronal TIT words, although some also have dorsal KOK word forms. The whole word shares just one PoA feature ($C1=C2=V$). The words do not seem to be segmentalized yet. Segmentalization is a gradual process. After a stage with only POP, TIT and for some children KOK words, PIP, TOT and KIK words appear. At this stage (II), the vowel may have a different PoA from the consonants, and can in fact be any vowel (symbolized by 'v'), while the consonants still share PoA features ($C1=C2$). Thus, the representations are more differentiated than at the previous stage. Still later, the two consonants of the word may also differ in PoA features. Now, the word is fully segmentalized, and starts to resemble the adult representations.

Within the 'full segmentalization stage' there is also a clear ordering. First, children produce PvT words (III). Subsequently, words in which the second consonant is dorsal appear, like PvK and TvK (IV). Coronal seems to be unrestricted and is assumed to be the default PoA in Dutch (Paradis & Prunet 1991, Levelt 1994). This means that if a segment has no PoA specification in the lexicon, it will be realized as coronal, as we will see below. Words with labial in final position (V) and dorsal-initial words (VI) are generally acquired very late. This is schematized in (2):

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(2) Stage	Development	Added production patterns
I	$C_1=C_2=V$	POP, TIT, KOK
II	$C_1=C_2$	PIP, TOT, KIK
III	$C_1=P, C_2=\emptyset$	PvT
IV	$C_2=K$	PvK, TvK
V	$C_2=P$	TvP
VI	$C_1=K$	KvT, KvP

The second striking observation is that children's early productions are very 'faithful'. That is, children use the same PoA features as required to produce the target words. This implies a selection strategy: only target words that can be produced correctly are attempted. At a later stage, a particular word pattern that has been produced for some time as a faithful rendition of a form in the child's lexicon will also be used for target words that the child is unable to produce correctly – and was unwilling to attempt before – resulting in unfaithful output patterns. In other words, once a child's production lexicon contains for example a certain number of PvT words, the child appears to generalize over this productive lexicon and derive a rule or constraint stating that labial consonants are at the left edge of the word: Labial Left (e.g., Levelt 1994).

- (3) Labial Left: [LAB]
 If the word contains a labial, this labial feature must be realized at the left edge.

As soon as this rule or constraint is introduced into the child's phonology, its presence may be felt in words like *kip* 'chicken' or *slapen* 'sleep', which will be produced, unfaithfully, with an initial labial, by either undergoing Consonant Harmony (4a) or Metathesis (4b), two processes commonly mentioned in the literature on child phonology:

- (4) Constraint [LAB at work]
- | | | | |
|----|---------------------|------------|--------|
| a. | Consonant harmony | | |
| | slofften /slɔfə[n]/ | 'slippers' | [pɔfə] |
| | kip /kɪp/ | 'chicken' | [pɪp] |
| b. | Metathesis | | |
| | kip /kɪp/ | 'chicken' | [pɪk] |
| | slapen /slapə[n]/ | 'sleep' | [patə] |

In other words, the child's generalization over his or her own productive lexicon has resulted in the beginning of an abstract phonological system with high-ranked markedness constraints.

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Similarly, once the child's lexicon contains a number of words in which the second consonant is dorsal, this apparently leads to the following generalization about the feature: Dorsal consonants are not realized word-initially; i.e. No Dorsal Left:

- (5) No Dorsal Left: *[DORS
Dorsal is not allowed at the left edge of a word.

As the result of the emergence of the constraint *[DORS dorsals are no longer permitted word-initially, not even in 'harmonic' words like *koek* 'cookie' or *kijk* 'look'. This is nicely illustrated in the data from Noortje in (6). While at an early stage KvK words, i.e. words with two dorsal consonants between any vowel (V), were correctly produced by Noortje (6a), at a subsequent stage, these words are realized with a word-initial default coronal. This lasts for a period of three months (6b). After this period, dorsal-initial words reappear in Noortje's productive vocabulary (6c), clearly signaling the relaxation of the *[DORS constraint.

- (6) Developmental production data of Noortje
- | | | | | |
|----|--|------------|-----------|------------------|
| a. | Holistic and partial segmentalization stage | | | |
| | koek | /kuk/ | 'cookie' | [kuk] (2;3.7) |
| | klok | /klɔk/ | 'clock' | [kak] (2;5.23) |
| | kijk | /keik/ | 'look' | [keik] (2;5.23) |
| | kikker | /kikər/ | 'frog' | [kik] (2;2.21) |
| b. | Full segmentalization stage, early | | | |
| | koek | /kuk/ | 'cookie' | [tuk] (2;8.17) |
| | klok | /klɔk/ | 'clock' | [dɔk] (2;8.17) |
| | kijk | /keik/ | 'look' | [teik] (2;8.17) |
| | kikker | /kikər/ | 'frog' | [tika] (2;9.1) |
| c. | Full segmentalization stage, late (adult-like) | | | |
| | kruk | /krək/ | 'handle' | [kyk] (2;9.29) |
| | kuiken | /kœykə[n]/ | 'chicken' | [kœyk] (2;10.12) |

The two observations – gradual segmentalization and specification of lexical representations and initial faithfulness – together have led us to the following interpretations of the facts. At first, children's representations are holistic in the sense that the whole word has one PoA and is largely unanalyzed. Subsequently, children discover that consonants and vowels may have their own specification. This leads to more differentiated representations, in which the consonants of the word still share PoA features. Finally, children can fully segmentalize words.

For reasons of efficiency of parsing children may have generalized

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over the words in their relatively small productive lexicon: If all segmentalized words are P-initial, this may result in the constraint: [LABIAL. In a similar vein, the constraint *[DORSAL may emerge at a later stage based on the fact that if a word has a dorsal, it always appears in C2 position. Ultimately, the child has to learn that these constraints are only soft constraints in the language, as Dutch does allow words to begin with dorsal obstruents, and does not require labial to be word initial.

Alternative explanations all fare less well. One obvious explanation could be that the developmental order follows from the frequency of the different patterns in the input (e.g., Bybee 2001). This explanation cannot account for the early stages in which words are completely or partially harmonic. Particularly, PvP and KvK words are of very low frequency in the target language; yet, they are produced early.

Others have argued that early production patterns may be explained in terms of ease of articulation (MacNeilage & Davis 2000, Davis *et al.* 2002). They have proposed four potentially universal organization patterns for babbling and early speech: the first and most basic pattern of labial consonants with central vowels (PA), subsequently, coronal consonants with front vowels (TI), followed by dorsal consonants with back vowels (KO), and finally words consisting of a labial consonant, a vowel and a coronal consonant (PvT). Although these patterns show similarity to the patterns described above, the model cannot account for the co-occurrence of labial consonants with round vowels, which are frequently attested in Dutch child language, nor for the U-shaped developmental pattern in (6) or the default behavior of coronal.

Optimality Theory does not offer a viable solution either. In this theory it is standardly assumed that representations are fully specified, that all markedness constraints outrank all faithfulness constraints at the initial stage, and that development implies the demotion of markedness constraints. Without going into much detail (see Fikkert & Levelt 2002), it will immediately be clear that the data in (6) are hard to account for. The words in (6b) are neither more faithful nor more marked than those in (6a), and if anything, the forms in (6b) seem to be less marked than those in (6a), suggesting promotion of markedness constraints, which goes counter the current ideas about developmental reranking. The forms in (6b) cannot be explained as instances of lexical diffusion either, as for a period of three months all dorsal-initial words are affected, old and new.

We argue that an account that assumes both initially underspecified and developing representations and a developing grammar (consisting of emerging constraints) provides an adequate and elegant description of and insight in children's early production data.

INFANT PERCEPTION AND EARLY WORD RECOGNITION

There is an interesting paradox if we consider the results from early perception studies. These studies all show that children have a remarkably good knowledge of the sound structure of their native language even before having a lexicon. Ever since the pioneering research by Eimas and colleagues (1971), we know that newborns are excellent universal listeners who are able to discriminate virtually all possible contrasts employed by human languages. In their influential work Werker and Tees (1984) have shown that the perception of consonants becomes language-specific at about ten months. Apparently, children become more efficient listeners and pay attention to what is of importance to understand their native language. Kuhl *et al.* (1992) have shown that vowel contrasts already become language specific at about six months of age. Thus, both in perception and production acquiring vowels precedes the acquisition of consonants. At nine months of age children are sensitive to the difference between phonotactically possible and impossible strings of segments in their native language, to low- and high-frequent phonotactic sequences, to the dominant stress pattern of their language (e.g., Jusczyk 1998). In other words, all this research shows that children already know quite a bit about their native language before they have uttered their first word.

This knowledge comes in handy. Knowing how possible words of the native language should sound, is very useful in segmenting the acoustic speech stream into words, which is a prerequisite for word learning. Does this knowledge reflect the child's phonological system? And if so, how can it be that children use their phonology for early speech perception, but only later build up a phonology for speech production?

Of particular interest are recent results from early word recognition studies, which to date have delivered contradictory results. Word recognition experiments have shown that 7 1/2 month-old children are able to recognize words (*feet, bike*) in running speech after a brief period of familiarization to those words. However, if the test word is slightly changed after familiarization (to *zeet* or *feek*, or to *gike* or *bipe*) children are no longer able to recognize the words (Jusczyk & Aslin 1995, Tincoff & Jusczyk 1996), suggesting that infants must have stored the words with phonetic detail. However, research by Werker and colleagues (1997, 2002) showed that perception is considerably less perfect if the lexicon is involved. They combined word perception with word learning and showed that 14 month-old English children can distinguish between

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words that sound dissimilar (*neem – lif*) in a word learning task. However, they could not distinguish between words that sound very similar (*bih – dih, bin – din*). In a pure discrimination task, however, they had no problems distinguishing between *bin* and *din*, suggesting that children are still able to perceive phonetic detail. These results indicate that discrimination of the sound patterns of lexical items is not the same as identification of these items in the lexicon. Werker and colleagues suggested two possible explanations: either words are not stored with all phonetic detail, but are more abstract, or the processing load in the word learning task was too high for 14-month-old children. I argue that the two are linked.

UNDERSPECIFICATION ACCOUNTS FOR BOTH EARLY PERCEPTION AND PRODUCTION

On the basis of production studies, we have argued for un(der)specified phonological representations. Given that the onset of speech more or less coincides with the age of the children in the experiments of Werker and colleagues, it could well be that children at this point in their development do not yet have fully segmentalized phonological representations. As these children have very small vocabularies (well below 25 words), it may be the case that these children still are in the first developmental stage (2), and that they have represented *bi(n)* and *di(n)* as holistic units, in which the vowel determines the PoA specification. In that case, both forms would have the same phonological representation (no specification of PoA features, as in (7ab)) and it is only expected that children do not distinguish the two in a word recognition study: Matching the features of the incoming signal with the stored features results ‘no-mismatch’ in (7ab). The fact that children can discriminate ‘b’ and ‘d’ in a pure discrimination task (features detected in the signal), does not mean that they use those features for specification in the lexicon.

(7) Word perception based on abstract phonological representations

word learned	lexical feature (stage I)	feature in signal (C)	matching condition
a. bin / din	[∅]	[lab] (bin)	no-mismatch
b. bin / din	[∅]	[cor] (din)	no-mismatch
c. bon / don	[lab]	[lab] (bon)	match
d. bon / don	[lab]	[cor] (don)	mismatch

A representational account makes the prediction that there is a difference between *bin-din*, with an underspecified coronal vowel (7ab) and *bon-don*, with a specified vowel (7cd). The prediction is that children are able to distinguish *bon* from *don*, as here *don* mismatches with *bon* (7d), but not *bin* from *din*. This is currently being tested and initial results seem to confirm this prediction (Fikkert & Levelt, in prep).

By assuming underspecified lexical representations we can account for the gradual and systematic changes encountered in child production studies. Moreover, we can also provide a straightforward account for the difference between discrimination of sounds, which is based on phonetic detail, and identification of words, which is based on stored phonological features. If it is assumed that lexical phonological representations are phonetically detailed, the difference between perception, recognition and production remains unaccounted for. Importantly, our account does not exclude the possibility that processing limitations underlie both production and perception in child language. Children can perceive all phonetic details, but only store the most salient phonological features in their mental representations. As children become better word learners, and have set up a phonological system to aid them in word recognition and word processing, they may be able to store more details. Similarly, in demanding perception tasks they may initially recover only the most salient features from the stored representation, while at a later stage when they become better in word learning, they will retrieve more features from the lexicon.

CONCLUSION

Acquisition is an important meeting place where linguistics and psycholinguists can lend each other an ear. We have seen that by using concepts from linguistics, in particular the PoA features in abstract phonological representations, insight can be gained into developmental patterns. These, in turn, can form a testing ground for psycholinguistic experiments. The abstraction over broad primary PoA features cannot be accounted for on purely phonetic grounds, as it is not immediately clear what the phonetic correlates of labial and dorsal consonants and vowels are. Rather, it seems to reflect a principled linguistic organization of sound structures. In turn, these abstract sound patterns can provide clear and testable hypothesis for both psycholinguistic research in general, and language acquisition in particular. Thus, acquisition studies may be a way to bridge the gap between linguistics and psychology.

I have furthermore argued that the set of constraints in child language

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emerges gradually, and it has to be seen whether ultimately children arrive at the same set of constraints that has currently been used in OT. Here, the detailed study of acquisition could ultimately feed linguistic theory. The study of child language acquisition has clearly shown that the current learnability models are all too simplistic in their assumptions of innate constraints and 'adult-like' representations. So far, constraints have hardly found their way into psycholinguistics experiments (but see Davidson *et al.* 2004). It is still a long but interesting way to test the psychological reality of linguistics theories.

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