The interpretation of phonological patterns in first language acquisition

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1. Introduction

Since the seminal work of Jakobson (1941/1968), phonological patterns observed in child language have been documented and analyzed from a number of perspectives. Throughout the relevant literature, an interesting paradox often manifests itself: while child language is generally characterized as a 'simpler' version of the target language, many types of phonological patterns observed in acquisition data create challenges for theories developed to account for more 'complex' adult systems. Phonologists within the generative framework have reacted to this problem in a number of ways, from tacitly or conspicuously ignoring acquisition data (e.g. Chomsky & Halle 1968: 331) to elaborating phonological models that account for phenomena observed in child phonology (e.g. Smith 1973, Bernhardt & Stemberger 1998) or, in some extreme cases, rejecting the validity of evidence from child production data for theoretical investigations of phonology (e.g. Hale & Reiss 1998). The disconnect between findings from child phonology and generalizations arising out of generative theories of grammar based on adult phonology has also been recruited in support of alternative, functionalist approaches to child phonology, including Stampe (1969) within *Natural Phonology* and, more recently, Vihman & Croft (2007) within *Construction Grammar*.

A general assumption connecting virtually all of these models is that children's phonological abilities are initially impoverished and gradually develop in the face of positive, interpretable evidence from the ambient signal. Regardless of theoretical or philosophical allegiance, researchers acknowledge that theories of linguistics should be learnable and, as such, empirically verified against language development facts. The question, then, is not about whether developmental phonology data should be considered —clearly they should— but about the *way* they should be incorporated into theoretical debates. As we discuss in this chapter, the main challenge lies in the interpretation of developmental patterns, given that differences between child phonology and adult phonology can be, and have been, attributed variously to perception, grammar, and production.

We begin our discussion with an overview of the types of patterns attested in the literature on phonological development. We then move on to phenomena that have featured in theoretical debates in the field, which we address in light of the main competing approaches to child language phonology. We conclude with desiderata for truly explanatory models of phonological development.

2. A brief survey of phonological patterns

This section presents a survey of the main types of segmental and prosodic patterns found in phonological development. As used here, the term 'pattern' refers to any systematic difference between the actual forms produced by a child and the (adult-like) forms the child is evidently

attempting. This definition is neutral as to the source of the discrepancy. For example, the child who says [t^hæt] for 'cat' might be said to display a process converting target [k] to [t], with /kæt/ as his/her underlying representation; alternatively, that child might be said to have stored /t^hæt/ as his/her lexical representation, which he/she is producing accurately. Both positions, and others, have been taken in the literature.

The overview offered below, which builds on previous surveys by Menn (1971), Ingram (1974), Ferguson & Farwell (1975), Ingram (1989), Smit (1993), Vihman (1996), Bernhardt & Stemberger (1998), Inkelas (2003) as well as the contributions to Kager, Pater & Zonneveld (2004) and to McLeod (2007), provides only a fragmentary view of the larger picture of child phonology, because the literature has thus far been able to focus on only a relatively small number of children, and predominantly on 'western' languages (cf. McLeod 2007). The possibility is high that phenomena unattested as of yet will be uncovered as research continues.

2.1. Segmental patterns

At the segmental level, a plethora of systematic discrepancies between child and adult pronunciations have been documented. As we can see from the list in (1), virtually all articulatory dimensions of speech are affected. For the purposes of this chapter, transcriptions between vertical bars represent adult-like, target forms. Arrows indicate correspondence between adult target forms and child productions, but should not be taken to represent generative phonological derivations; as stated above, this survey is neutral with respect to the question of the child's lexical representations.

(1) Segmental patterns (non-exhaustive list)

	Pattern	Illustration[1]
a) Place features	Velar fronting (to coronal)	|k| → [t]
	Coronal backing (to velar)	|t| → [k]
	Labialization	|t| → [p/t^{w}]
	De/palatalization	|ʧ| → [k]/|k| → [ʧ]
	Dentalization	|s| → [θ]
	Debuccalization	|s| → [h]
b) Manner features	Gliding/rhoticization	|r| → [w]/|w| → [r]
	Stopping/spirantization	|s| → [t]/|t| → [s]
	De/affrication	|ʧ| → [t]/|t| → [ʧ]
	De/nasalization	|m| → [b]/|b| → [m]
	De/vocalization	|j| → [l]/|ɬ| → [u]
c) Voicing features	De/voicing	|d| → [t]/|t| → [d]
	De/aspiration	|t^{h}| → [t]/|t,d| → [t^{h}]
	De/glottalization	|ʔ| → [k]/|k| → [ʔ]

Segmental patterns such as those in (1) are often context-sensitive, varying across segmental and prosodic contexts. For example, Rose (2000) shows that French target |ʁ| corresponds to various labial, coronal and velar consonants in the speech of Clara, a first language learner of Québec French. The place feature that target |ʁ| assumes in Clara's productions is harmonic with the place of articulation of other consonants present in the target form (e.g. *robe* |ʁɔb| → [w̲ɔb] 'robe'; *rouge* |ʁuʒ| → [ʝuʃ] 'red'; *carotte* |kaʁɔt| → [kaˈɡ̲ɜ]/[kəˈʝɔːtˀ] 'carrot'). Syllable context matters as well. The substitutions affect |ʁ| in singleton onsets but not in complex onsets (e.g. *citrouille* |sitʁʊj| → [θəˈtʁ̲uːj] 'pumpkin'). Also, when |ʁ| occurs in word-medial coda or word-final position in the adult target word, it undergoes deletion altogether (e.g. *ourson* |uʁsɔ̃| → [ʊˈsɔ̃] 'teddy bear'; *renard* |ʁənɑʁ| → [lena] 'fox').[2] Although substitution patterns are often referred to out of their larger contexts (as in the list in (1), which exemplifies patterns independently of any contextualization), complex conditioning of the kind illustrated by Clara's data is actually quite typical, as other examples discussed below also demonstrate.

[1] These patterns and those listed in later tables are not limited to the illustrations provided. For example, fronting and backing patterns in (1a) typically target voiced as well as voiceless consonants, even though this generalization is not without exceptions (e.g. McAllister 2009).

[2] See Rose 2000 for further discussion and analysis of these data.

2.2. Prosodic patterns

Systematic discrepancies between adult and child productions are also observed in the prosodic domain, i.e. syllable structure, word shape, or the location of stress or tone. A representative selection is offered in (2). These examples come from the general surveys cited in the introduction to section 2 as well as from targeted studies of prosodic development by Spencer (1986), Fikkert (1994), Demuth (1995), Gnanadesikan (1995[2004]), Barlow (1997), Pater (1997), Ota (1999), Rose (2000), Goad & Rose (2004) and Vihman & Croft (2007), *inter alia*.

(2) Common prosodic patterns (non-exhaustive list)

	Pattern	Illustration
a) Affecting syllables	C + liquid cluster reduction	|pleɪ| → [peɪ]/[leɪ]
	s + C cluster reduction	|skiː| → [kiː]/[siː]
	Coda deletion	|kæt| → [kæ]
	Right-edge cluster reduction	|tɛnt| → [tɛn]/[tɛt]
	Consonant/glide epenthesis	|liːoʊ| → [liːjoʊ]
b) Affecting word shapes	Vowel epenthesis/deletion	|bluː| → [bəluː]/ |əgɛn| → [gɛn]
	Syllable truncation	|ɛləfənt| → [ifənt]
	Syllable reduplication	|ɛləfənt| → [fæfæ]
	Stress shift	|ʤəˈɹæf| → [ˈʤiːɹæf]

Similar to the segmental patterns illustrated in (1), the source of the prosodic phenomena in (2) is often open to a number of interpretations. Many of these patterns closely resemble phonological subsystems independently observed in adult languages (e.g. syllable reduplication; McCarthy & Prince 1986[1995]), creating the temptation to analyze them as directly driven by the child's grammar. However, as we discuss further below, it is crucial that all available options be considered before any specific analysis is adopted. For example, evidence from infant speech perception shows that English-learning children tend to initially associate stressed syllables with word onsets (e.g. Jusczyk, Houston & Newsome 1999). This suggests that the apparent truncation of pretonic material in words such as *gaZELLE, aBOUT and guiTAR*, yielding productions like 'ZELLE', 'BOUT' and 'TAR', may originate from a speech segmentation error that yields an incorrect lexical representation, as opposed to being the product of a grammatical rule restricting the prosodic shape of phonological productions. However, perceptual or speech segmentation errors certainly cannot be held responsible for all prosodic patterns. For example, Fikkert (1994) documents a pattern of stress shift displayed by

Dutch learners who preserve both syllables of disyllabic words with final stress but systematically produce these forms with stress on the initial syllable, as exemplified in (3).

(3) Stress overgeneralization (data from Robin; Fikkert 1994)

gitaar	|χiːˈtaːr|	[ˈsiːtaː]	‘guitar’
		[ˈsiːtaʊ]	‘guitar’
giraf	|ʒiˈʁɑf|	[ˈʃiːɑf]	‘giraffe’
ballon	|bɑˈlɔn|	[ˈbuːɔn]	‘balloon’

Fikkert argues that these productions are conditioned by the learner’s grammar which, influenced by the predominant, trochaic stress pattern that exists in the target language, regularizes away lexical exceptions. Fikkert’s grammatical analysis is further motivated by the broad consensus that children are acutely sensitive to stress (e.g. Morgan 1996, Jusczyk 1997), a fact which argues against simple misperception of the target forms with final stress. (See Kehoe 1997, 1998 and Pater 2004 for related discussions.)

2.3. *Exotic patterns*

In addition to the two relatively clear types of patterns listed above, which have either parallels in adult language, direct phonetic motivations, or both, the literature on early phonological development contains an array of so-called ‘exotic’ patterns, some of which are listed in (4), whose analysis defies both clean-cut classifications and, often, theoretical accounts. The term ‘exotic’ is intended to convey that these patterns are not robustly attested in the literature on adult phonology.

(4) Some exotic patterns

Pattern	Illustration
a) Consonant harmony (affecting major place of articulation)[3]	|teɪbɬ| → [beːbu]
b) Vowel-to-consonant harmony (affecting major place of articulation)	|sxunə| → [bunə]
c) Long-distance consonant metathesis	|sak| → [kas]
d) Consonant fusion	|smoʊk| → [fok]
e) Velar fronting (across the board or in certain syllable positions)	|goʊ| → [do]
f) Chainshifts involving consonants	|s̲ɪk| → [θ̲ɪk]; |θ̲ɪk| → [f̲ɪk]
g) Dummy segment or syllable insertion	|məskiːɾoʊ| → [fi-giɾo]
h) Spontaneous language games	|əlæskə| → [əˈlæskə-ˈbæskə][4]

As one example of an exotic type of pattern, consider the intricate yet systematic interaction between segmental and prosodic factors conditioning the productions of Marilyn, a learner of European French documented by dos Santos (2007). First, Marilyn displays syllable truncation driven by the segmental characteristics of the consonants found in the target forms: when two consonants have identical continuancy features in the target form, Marilyn produces both of these consonants, as illustrated in (5a). Conversely, in (5b), target forms that contain consonants with different continuancy features undergo truncation of the initial syllable.

[3] While consonant harmony is well attested in adult languages, it never affects major place of articulation as it does in child language (e.g. Hansson 2001).

[4] The pattern illustrated here consists of final foot reduplication combined with [b] substitution in the foot-initial onset. Language games can take different forms across children; see Inkelas (2003) for some discussion.

(5) Segmentally-conditioned syllable truncation (dos Santos 2007)

a) Continuancy-harmonic onsets: production of both onsets (and related syllables)

appétit	|apeˈti|	[piˈti]	2;00.12[5]	'appetite'
biquet	|biˈkɛ|	[beˈkɛ]	1;11.13	'goat'
escargot	|ɛskaʁˈgo|	[kaˈko]	1;11.13	'snail'
chaussure	|ʃoˈsyʁ|	[lyˈly][6]	1;11.28	'shoe'

b) Continuancy-disharmonic onsets: truncation of the initial syllable

cassé	|kaˈse|	[ˈle]	1;11.13	'broken'
tennis	|teˈnis|	[ˈni]	1;11.02	'tennis'
château	|ʃaˈto|	[ˈto]	1;11.02	'castle'
jumeaux	|ʒyˈmo|	[ˈmo]	1;11.28	'twins'

An understanding of these data immediately calls for an investigation of the child's attempts at other target word forms. In this regard, dos Santos (2007) also shows that during the same developmental period, all consonants are systematically produced when they appear in CVC forms, as we can see in (6). Interestingly, target words with continuancy-disharmonic consonants display harmony in this context, as opposed to deletion (cf. (5b)).

(6) CVC targets: Consonant preservation and harmony (dos Santos 2007)

bottes	|ˈbɔt|	[ˈbɔt]	2;00.12	'boots'
coupe	|ˈkup|	[ˈkup]	2;00.25	'cut'
passe	|ˈpas|	[ˈpat]	1;11.13	'pass'
case	|ˈkaz|	[ˈkak][7]	1;10.17	'box'

As we can see from these latter examples, the shapes of Marilyn's outputs are constrained by a combination of segmental and prosodic pressures, namely the types of consonants (stop versus continuant) that are found in the target forms and the shape of the words in which the consonants appear (multisyllabic versus CVC). Similar to Clara's data described in section 2.1, the examples from Marilyn's productions illustrate how child phonological patterning often

[5] Here and elsewhere, ages are indicated using the Y;MM.DD format.

[6] While this example may suggest syllable reduplication, it is actually symmetrical with the other examples. Related to this is the fact that target fricatives which do not undergo deletion (or manner harmony; cf. examples in (6)) are pronounced as [l] at this stage. See dos Santos (2007) for additional discussion.

[7] The place harmony seen in this example arises through an independent process, as the child does not produce words that combine coronal and velar articulations at this stage. See dos Santos (2007) for additional discussion.

involves interactions between segmental and prosodic aspects of the developing phonological system.[8]

Partly because of their striking properties but also because of the theoretical challenges they pose, exotic patterns like those in (4) have given rise to a rich and often contentious literature on child language development (e.g. Menn 1971, Smith 1973, Braine 1974, 1976, Ingram 1974, Ferguson & Farwell 1975, Priestly 1977, Chiat 1983, 1989, Levelt 1994, Gnanadesikan 1995[2004], Velleman 1996, Pater 1997, Goad 2001, Menn 2004, dos Santos 2007, Vihman & Croft 2007, Fikkert & Levelt 2008, Inkelas & Rose 2008).[9] In the next section we discuss some of the fundamental questions relating to the interpretation of child phonological patterns, including exotic ones, and the formal apparatus needed to account for them. The discussion revolves around the degree of abstractness required to account for these phenomena.[10]

3. How abstract is child phonology?

The issue of abstractness in phonology has been —and continues to be— hotly debated in phonological theory, at least since Kiparsky (1968), and resides at the heart of theoretical controversy about child language development. Central questions, many of them pertaining to the degree of representational abstraction required to model children's grammars, emerge from a general lack of consensus about the phonetic or phonological level at which children operate from the onset of acquisition and throughout the developmental period. For example, phonologists often debate whether discrepancies between child and adult phonology are due to

[8] For further discussion of segmental-prosodic interactions, see also contributions to Goad & Rose (2003) and to Kager, Pater & Zonneveld (2004) as well as Inkelas & Rose (2008) and McAllister (2009).

[9] See Goad (in press) for a recent summary of other theoretical issues.

[10] In this context, we must also mention the conspicuous absence of patterns affecting vowels from most discussions of phonological development (e.g. in (1)). Two main facts contribute to this asymmetry. First is a general impression, probably wrong, that children tend to produce vowels more accurately than consonants. This impression may be due in part to the lack, until very recently, of high-quality recordings, and in part to difficulties inherent to the acoustic analysis of child language vowel productions, especially with regard to place of articulation. Fortunately, the democratization of digital recording systems, the increased availability of databases documenting child language productions (especially through the Phon & PhonBank initiative; e.g. MacWhinney & Rose 2008) and the development of methods enabling less equivocal interpretations of child language speech articulations and related acoustics now offer new and exciting research possibilities. These include the consideration of potential covert contrasts and other articulatory artifacts in our characterization of phonological development (e.g. Scobbie, Gibbon, Hardcastle & Fletcher 1996, Buder 1996, van der Stelt, Zajdó & Wempe 2005, Vorperian & Kent 2007).

perception-based issues affecting representation, differences in grammar, or lack of motor control over production.

While such questions are complex and cannot be resolved within the confines of this chapter, it seems clear that, just as adult phonological systems involve many different simultaneous levels of representation, children make generalizations about various kinds of representational units, depending on the types of evidence they are exposed to and able to interpret from the ambient language. Addressing this general observation, the field has gradually shifted from universalist claims about the unfolding of child phonology to a more evidence-based, individualist approach. Extreme examples of these two viewpoints can be found in Jakobson (1941/1968) and Vihman & Croft (2007). Jakobson, on the one hand, famously argued for a maturational path of acquisition which proceeds from one phonological feature to the next in universal fashion. On the other hand, Vihman & Croft argue that order of acquisition is determined by salient patterns in the ambient data, and can vary by individual as well as by language. A number of recent studies of infant speech perception, informed by theoretical models of categorization, have turned up support for the view that phonological structure and specificational detail emerge gradually within the lexicon. On this view, the child develops a phonetically detailed lexicon using inborn linguistic perceptual abilities, which are sharpened by language-specific exposure during the first year of life (see Werker & Fennell 2004 and Yoshida, Fennell, Swingley & Werker 2009 for recent summaries and discussions). Pierrehumbert (2003) proposes that the phonetic detail contained in early lexical forms serves as the primary ingredient for building abstract segmental categories (see also Beckman & Pierrehumbert 2004). As Pierrehumbert (2003: 119) suggests: "[…] the system of phonological categories includes not only segments, but also other types of discrete entities in the phonological grammar, such as tones, syllables, and metrical feet". Following similar reasoning, many acquisitionists have proposed a gradual emergence of phonological categories in the lexicon and established relationships between the emergence of these categories and phonological patterning. We return to these proposals in section 5.

The issue of representational abstraction in phonological development also has implications for any theory assuming a set of universal primitives, including those based on strong interpretations of the Continuity Hypothesis, discussed in the next section.

3.1. Child phonology and the Continuity Hypothesis

According to the Continuity Hypothesis (e.g. Macnamara 1982, Pinker 1984), the formal properties of the grammar do not change over the course of development. The child's grammar starts with the same theoretical primitives that the adult grammar ends up with. Within the generative framework, this means that child phonology uses the same types of rules or

constraints posited for adult systems. Each stage in phonological development is generally assumed to be compatible with the set of principles that regulate adult systems (e.g. Spencer 1986, Fikkert 1994, Levelt 1994, Demuth 1995, Freitas 1997, Goad 2000, Rose 2000, Goad & Rose 2004, and Fikkert & Levelt 2008). The Continuity Hypothesis extends beyond grammar to lexical representations as well. For example, within feature-geometric frameworks (e.g. Sagey 1986), accounts of segmental development typically posit the emergence of feature hierarchies on the basis of phonological contrasts (e.g. Brown & Matthews 1993, 1997, Rice & Avery 1995, Dresher 2004, Fikkert 2005; see also Jakobson 1941/1968 for an early discussion on the role of contrast in phonology). In most proposals, even the order of acquisition of the contrasts is fixed by the model, motivated by typological evidence and, at times, theory-centric learnability considerations, and thus falls under the scope of the Continuity Hypothesis. For example, the feature Coronal enjoys a special status in the literature on adult phonology, where it is often claimed to be inherently less complex than Labial or Dorsal (e.g. contributions to Paradis & Prunet 1991; cf. Hall, this volume). Many acquisitionists have relied on this claim while describing phonological development (e.g. Levelt 1994) or accounting for consonant harmony patterns (e.g. Pater 1997, Fikkert & Levelt 2008; see Fikkert, Levelt & van de Weijer 2008 for further discussion).

As the survey of exotic phonological phenomena reveals, however, child phonology sometimes requires phonological rules or constraints that are not independently motivated in adult phonological systems (e.g. Pater 1997 on child-specific constraints driving consonant harmony; see also Levelt & van Oostendorp 2007 in the context of segmental development). Similarly, lexical representations do not always conform to adult-based generalizations. For example, regarding the coronal asymmetry mentioned just above, Rose (2000: 175) points out that different children exhibit different featural behaviors in their productions, within and across target languages. Claims about the universality of phonological constructs and their emergence in acquisition are often at odds with the facts, especially when they are closely inspected.

In more functionalist approaches to phonological development such as the constructivist approach entertained by Vihman & Croft (2007), the Continuity Hypothesis receives a different interpretation. Within Vihman & Croft's approach, there is no formal distinction between competence and performance. Language acquisition, just like its use, relies on general cognitive mechanisms operating on schematic templates, the nature of which is claimed not to change in any fundamental way over the course of one's life. (See section 4.2.2 for additional discussion of Vihman & Croft's proposal.)

Whichever approach is favored, any theory of grammar is still obligated to explain why child phonology is different from adult phonology. We discuss a few of the toughest challenges in the next section.

3.2. Some empirical challenges

Exotic patterns or asymmetries in child phonological development, taken at face value, often suggest either rogue grammatical properties (e.g. Buckley 2003, Goad 2006) or, in some extreme cases, formal paradoxes. Such paradoxes are most evident in so-called chainshift patterns illustrated by the famous *puzzle-puddle-pickle* problem defined by Macken (1980), based on data from Amahl, an English-learning child whose productions were originally documented by Smith (1973). This chainshift takes the form of an A→B; B→C schema whereby a given phone arising from a substitution pattern may be the target of another substitution. For example, in Amahl's productions, the |z| of *puzzle* is realized as [d] (|pʌz̪l̪| → [pʌd̪l̪]), while |d| itself surfaces as [g] in words like *puddle* (|pʌd̪l̪| → [pʌg̪l̪]). Another chainshift, also found in Amahl's productions, involves the realization of word-initial |s| as [θ] (e.g. *sick* |s̪ɪk| → [θ̪ɪk]), a consonant which, when present in a target form, surfaces as [f] (e.g. *thick* |θ̪ɪk| → [f̪ɪk]). We discuss the former chainshift more in depth in section 4.[11] Such patterns are, at least in appearance, problematic for all theories of phonology in the sense that if a rule or constraint triggers the substitution of a target sound by another one, this target sound should logically be ruled out altogether from the child's output forms, at least within similar prosodic contexts.[12]

Other patterns are problematic because they contradict generalizations made from the study of adult languages. The case of positional velar fronting offers such an example. Velar fronting is a pattern whereby target velars |k, g| are fronted to coronals [t, d]. Context-free (across-the-board) velar fronting can be attributed the child's inability to either lexically represent or correctly articulate target velars. Neither of these potential analyses poses a difficult theoretical challenge beyond data interpretation *per se*. However, the positional version of velar fronting, whereby velars are neutralized to coronals in strong, but not in weak, prosodic environments (e.g. *go* |g̪o| → [d̪o]; *bagel* |ˈbeɪg̪l̪| → [ˈbeɪɡu]), is problematic. As Inkelas & Rose (2008) point out, theories of positional asymmetries in phonology share the prediction that neutralization of segmental contrasts should occur in prosodically weak, as opposed to strong, positions, as generally happens in adult language.[13] Positional velar fronting

[11] Additional discussions of the latter chainshift can be found in Hale & Reiss (1998) and Rose (2009).

[12] Chainshifts do occur in adult language as well. However, they tend to involve lenition or vowel quality, never major consonantal place of articulation (see e.g. McCarthy 1999, 2008; Mortensen 2006 for recent discussions).

[13] The extensive survey of consonantal place markedness in DeLacy (2002) upholds the generalization that contrast neutralization in prosodically weak environments, such as syllable codas or unstressed syllables, is frequent,

thus contradicts the generalization that contrasts are preserved in prosodically strong positions, and challenges theories based upon that generalization.

The incidence of innovated chainshifts and apparently rogue patterns such as positional velar fronting in child phonology contradicts the view that human developing and end-state (adult) grammars share the same basic properties. Of course, we at times observe sub-systems in adult grammars that exhibit phonological asymmetries or apparently odd properties. Many so-called 'crazy' rules in adult language (e.g. Bach & Harms 1972) have their origins in diachronic reanalysis (e.g. rule inversion), or telescoping of sound changes. Arguably, a large proportion of these apparent rules are morphologically conditioned and can be handled via suppletive allomorphy. Opacity, which is not infrequent in adult phonology, has been analyzed synchronically by an appeal to lexical contrast preservation (Lubowicz 2003) or to abstract (underlying) properties of lexical forms, justified by semantically-related morphological forms observed elsewhere in the lexicon (e.g. Kager 1999, McCarthy 1999, 2002, 2008 and Kiparsky 2000 for related discussions). Once put in their appropriate contexts, apparently rogue adult phonological subsystems can be reconciled with existing phonological theory and, in many ways, contribute to its elaboration.

In sum, morphological and lexical factors contributing to opacity and other phonological oddities in adult phonology are not directly applicable to most innovative patterns observed in child phonology. Recent literature, to which we turn next, suggests that, in addition to grammar itself, phonetic dimensions of speech perception and articulation play an important role in the exotic as well as in the ordinary, in children's phonological productions.

4. Theoretical approaches to child phonological productions

In this section, we survey a number of theoretical approaches to address empirical problems posed by child phonological productions. The sheer number of proposals available in the literature makes it impossible to provide a comprehensive survey of theoretical approaches to child language phonology. We thus restrict ourselves to contrasting representative examples of predominant approaches, and addressing related controversies. We then discuss how these approaches relate to the larger context of perceptual, lexical and articulatory development.

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while it is infrequent or unattested in strong positions, such as syllable onsets or stressed syllables. A noticeable counter-example to this generalization comes from Steriade (2001), who argues that 'strong' must sometimes be perceptually defined; neutralization of apical and retroflex consonants, for example, can occur in word-initial onsets but not word-finally, because the postvocalic position is perceptually optimal for these consonants.

4.1. Approaches assuming adult-like phonological representations

Since the influential study by Smith (1973), which set the tone for a vast program of research on phonological development within generative phonology and beyond, it has been largely assumed that the child's input is similar to the corresponding adult output form, as stated in (7). In analyses taking this assumption as their starting point, the child's pronounced form is generally derived from the adult form through ordered rules, parameter settings or constraint rankings.

(7) A 'standard' assumption (since Smith 1973):
Children's lexical representations are similar to corresponding adult phonetic forms.

This assumption is found in virtually all works couched in derivational versions of Generative Phonology, from standard *SPE* (Chomsky & Halle 1968), to autosegmental and prosodic approaches to phonology (e.g. Goldsmith 1976 and McCarthy & Prince 1986[1995], respectively). This assumption also holds in flavors of the non-derivational framework of Optimality Theory (henceforth, OT; Prince & Smolensky 1993[2004]) that draw on formal relationships between inputs and outputs (e.g. Correspondence Theory; McCarthy & Prince 1995). Common to these various models is the view that milestones in phonological development correspond to the relaxing of formal pressures on the child's grammar that militate against the production of complex phonological units contained in the input. For example, accounts of the acquisition of prosodic representations generally predict that children start with monosyllabic words displaying V or CV syllable structure and gradually expand the number and/or the complexity of the constituents allowed by their grammars (e.g. Spencer 1986, Fikkert 1994, Freitas 1997). The same general approach within OT is formally viewed as an initial ranking of markedness constraints over faithfulness constraints. The effect of the latter is typically evaluated against adult-like output forms, in accordance with the assumption in (7). The gradual demotion of the markedness constraints accounts for the concomitant appearance of more complex phonological structures in output forms (e.g. Demuth 1995, Gnanadesikan 1995[2004], Barlow 1997, Pater 1997, Rose 2000).

Approaches based on the assumption in (7) raise a number of theoretical issues. Some of the most central questions can be illustrated through a consideration of Smith's (1973) and Dinnsen's (2008) analyses of opacity effects. Let us first consider a representative dataset, from Dinnsen's recent discussion of one of Smith's chainshift patterns we described in section 3.2.

(8) Apparent chainshift, as described by Dinnsen (2008) (data from Smith 1973)

a) Velarization in nonderived environments

[pʌgl̩]	‘puddle’	[æŋkləz]	‘antlers’
[bɔkl̩]	‘bottle’	[bʌklə]	‘butlers’
[hæŋgl̩]	‘handle’	[trɔglə]	‘troddler’

b) Velarization blocked in morphologically derived environments

[kwæːtliː]	‘quietly’	(cf. [kwæːt] ‘quiet’)
[sɔftliː]	‘softly’	(cf. [sɔft] ‘soft’)
[haːdliː]	‘hardly’	(cf. [haːd] ‘hard’)
[taitliː]	‘tightly’	(cf. [tait] ‘tight’)

c) Velarization blocked in phonologically derived environments (stopped fricatives)

[pʌdl̩]	‘puzzle’
[pɛntl]	‘pencil’
[wɪtl]	‘whistle’

In an analysis that reflects generative phonology of its time, Smith (1973) accounts for the set of data in (8) using a series of ordered transformational rules deriving the child outputs from their target counterparts. First, he posits two basic rules, one for velarization (R3) and one for stopping (R24).[14]

A constraint-based analysis of the same data is offered by Dinnsen (2008), who invokes Comparative Markedness (McCarthy 2002), a version of OT in which the original conception of markedness is redefined by splitting each markedness constraint into two distinct versions of itself, one that is violated by a property that is fully faithful to the input (similar to original markedness violations), the other violated by a property that is not present in the input. Dinnsen accounts for the data in (8) through a combination of Input/Output as well as Output/Output markedness constraints targeting sequences composed of alveolar stops and liquids. For example, the velarization pattern in (8a) and the absence thereof in (8b) are formally distinguished through an Output/Output constraint ($OO\text{-}_{O}$*dl), which cannot apply to monomorphemic forms that do not display alveolar-liquid sequences in the input (e.g. ‘quiet’).[15]

Assessing the full theoretical implications of McCarthy’s (2002) theory of Comparative Markedness would go far beyond the scope of this chapter.[16] In the context of child language,

[14] In Smith’s (1973) original formulation, each rule is labeled R*n*, where *n* indicates the relative order of the rule in Amahl’s grammar.

[15] See Barlow (2007) for a similar approach to other cases of apparently opaque production patterns.

[16] See Hall (2006) for a discussion of Comparative Markedness in the context of adult phonology.

this proposal relies on the OT tenets that (a) all constraints are universal and (b) phonological development can be accounted for as reranking of constraints from an initial ranking within which markedness constraints outrank faithfulness constraints (e.g. Smolensky 1996; cf. Hale & Reiss 1998). Dinnsen's (2008) account of the facts in (8) is entirely compatible with these assumptions. As he points out, the opaque chainshift in (8) is not "inferable from the primary linguistic data to which Amahl would have been exposed" (p. 157). Amahl is nonetheless able to generate his chainshift by ranking the universal constraint penalizing 'old' coronals higher than the constraint penalizing derived ones.

Both the rule-based and the constraint-based account of the chainshift in (8) are based on the key presupposition in (7), shared by most generative approaches to acquisition, that the child's input is equivalent to the adult's output. In addition, Dinnsen's (2008) account must crucially assume that the child has access to morphological structure or, minimally, to grammatical awareness enabling a distinction between morphologically derived versus nonderived environments. However, Dinnsen does not provide any independent evidence for the validity of this assumption. As discussed in the next section, alternative accounts can be formulated that do not require any such, potentially unwarranted, assumptions.

4.2. Alternative views

A number of challenges have been posed for the assumption in (7), which underlies the rule-based and constraint-based analyses we have just summarized. In this section we review three proposals, each of which offers its own perspective on children's inputs and, consequently, on the phonological system that governs their outputs.

4.2.1. Child phonological productions as theoretically irrelevant

One response to puzzles like the one in (8) is to deny their grammaticality, attributing them to performance factors. Focusing heavily on issues relating to speech articulation in child language, Hale & Reiss (1998) offer a rather provocative solution. Keeping with a strong version of the Continuity Hypothesis, they use a series of empirical observations to undermine the theoretical relevance of production-based studies for phonological theory. They argue that "[child language] deviations from targets are largely due to performance effects" (p. 658), comparing child speech to "the intoxicated speech of the captain of the Exxon Valdez around the time of the accident at Prince William Sound, Alaska" (p. 669).

Since its publication, Hale & Reiss's (1998) article has been the subject of much controversy in the literature, with the positive result of encouraging reflection on how phonological productions in child language should be approached. The general consensus that has emerged is that while there is no doubt that surface effects (intoxication, immature vocal

apparatus) add noise which can obscure patterns in the data, this observation does not entail that we should throw the phonological baby out with the bath water. The study of phonological development based on production data, if conducted in a careful manner, is worthy of empirical and theoretical investigation.

4.2.2. Deriving the input from output considerations

Macken (1980), inspired by Braine's (1976) review of Smith (1973), sheds important light on differences between child and adult phonology. Macken argues that equating children's inputs to adults' outputs as per the assumption (7) may give rise to misanalyses of some child language data. She demonstrates that a reconsideration of this assumption can make child phonological systems much more transparent than they seem at first sight. In the case of the chainshift in (8), Macken argues that it is merely apparent, in that it can be decomposed into a series of simpler problems, each of which primarily involves either perception or production. According to Macken, Amahl's perception of coronal stops was influenced by the relative velarity of syllabic [l] in the contexts in (8a).[17] Words like *puddle* were thus represented with a velar consonant (i.e. /g/) in Amahl's early lexicon. In (8b) the absence of a syllabic lateral after the coronal stop explains in a simple way the absence of velarization of the preceding stop, without any need to refer to morphological complexity. Finally, in (8c), the consonant preceding the [l̩] is a fricative, whose continuancy and/or stridency arguably prevented the type of velar influence that affected coronal stops in (8a). These fricatives, however, underwent stopping in onsets, a pattern widely and independently attested in the literature on child language (e.g. Ingram 1989, Bernhardt & Stemberger 1998).

In the face of this explanation of Amahl's apparently complicated production patterns, which appeals to relatively basic perception and production factors, one could be tempted to drop accounts based on grammatical processing altogether. This is in many ways the view espoused by Vihman & Croft (2007), who propose the constructivist, *Radical Templatic* model of phonology and phonological development. Within this model, the word is represented as a phonotactic template that directly encodes all melodic and prosodic characteristics of output (phonetic) forms. With regard to acquisition, Vihman & Croft's proposal can be divided into two main claims. First, phonological learning proceeds through implicit inferences based on memorized word forms: "The child gradually develops first one or a small number of phonological templates, then a wider variety of them, while at the same time inducing a range of other phonological categories and structures from the known word shapes" (Vihman & Croft

[17] This account also implies that laterals in words such as *antlers* also displayed a degree of velarity. Another potential influence in this context is the glottalization of the coronal preceding the lateral.

2007: 686). Second, template specification is constrained by the child's own productive abilities: children gradually specify their template as they discover how to reproduce the types of phonotactics that are present in their memorized target forms.

Vihman & Croft's (2007) view that the shape of children's lexical templates are governed by their own productive abilities presents, at the theoretical level, a circularity problem, in the sense that both the phenomena observed and their origins are the same. While this may be seen as a virtue in *what-you-see-is-what-you-get* constructivist approaches to grammar, it poses a challenge to approaches that formally separate grammatical processing from lexical representation.

Outside of theoretical considerations, it is undeniable that articulatory planning and execution are involved in speech production and, as such, may influence the learner's productions, especially at young ages. Vihman & Croft's (2007) proposal nicely highlights this fact. However, it is unclear whether all speech errors observed in child language should be related to the domain of production. For example, children are often not influenced by their own production mistakes during speech perception. This is demonstrated by Chiat (1983), who documents perceptual and productive abilities of English-learning Stephen. This child displays systematic velar fronting patterns, on the one hand, but shows, on the other, perfect discrimination abilities between alveolars and velars. Stephen's system thus illustrates the formal separation that must be made between perceptual and productive abilities. It also highlights, once again, the importance of considering the child's overall system in any investigation of developmental speech patterns.

4.2.3. Deriving outputs from statistical influences

Without addressing apparent phonological paradoxes such as the one illustrated in (8), but in a move away from intrinsic linguistic conditioning, Levelt, Schiller & Levelt (1999/2000) turn the focus to statistical pressures from the ambient language. They argue that the order of acquisition of syllable types (e.g. CV > CVC > CCV) in monolingual Dutch-learning children can be predicted through the relative frequency of occurrence of these syllable types in the ambient language. Levelt et al. further argue that the variability observed across groups of learners with regard to the acquisition of certain syllable types is also correlated with frequency figures from the adult language. Their argument thus highlights frequency as a potentially determining influence in child language development, an observation that matches many of the findings about infants' abilities to statistically process the ambient signal (e.g. Jusczyk 1997 for a summary).

However, further verifications of the hypothesis that frequency drives order of acquisition or the emergence of patterns of speech production in child language has yielded a series of

criticisms from both empirical and theoretical perspectives (e.g. Kehoe & Lleó 2003, Demuth 2007, Edwards & Beckman 2008, Rose 2009; see also Brown 1973 for early refutations of statistical approaches). Critiques of the statistical approach generally contend that while input statistics can play a role in the emergence of phonological patterns in language development, and while it is important to look at properties of the ambient language as a whole, both linguistic and non-linguistic, frequency is only one of the several factors that can affect the developing phonological system and its outcomes in child spoken forms. Clearly, no frequency-based explanation can account for the chainshift exemplified in (8) or other patterns such as consonant harmony or velar fronting, to name a few.

4.3 Interim discussion

The approaches briefly addressed above far from exhaust the range of proposals available in the literature. Nonetheless, they express relatively clear views of child phonology, each of which highlight crucial areas of consideration about child phonological data. Each of these proposals, however, faces a number of relatively similar challenges, especially since they often neglect to situate the patterns observed in their larger context, that of an emerging system influenced by a variety of independent factors, whose combined effects may at times yield phonologically unexpected, yet entirely logical outcomes (Rose 2009). For example, Hale & Reiss' (1998) general argument against the validity of child language production data for theoretical investigation is based on a *prima facie* interpretation of these productions, without much consideration for the grammatical factors that may contribute to them.

While the most central object of study in both phonology and phonological development should evidently be the grammatical system, this system is connected to a series of perception- and production-related mechanisms, each of which has a potential influence on the shape of the developing lexicon and its manifestation in child speech. In light of this, we suggest that the ideal approach to phonological development should encompass all relevant considerations, a number of which are discussed in the next section.

5. Building a path between speech perception and phonological productions

During the past decade, some of the patterns observed in child phonological productions have been reconsidered in their larger context. For example, thanks to recent advances in research on infant speech perception, we now know more about the shape of the emerging lexicon (e.g. Yoshida, Fennell, Swingley & Werker 2009 for recent developments) and how pressures from the ambient language may impact productive abilities (e.g. Edwards, Beckman & Munson 2004). The variability observed within and across developmental paths has been assessed from learnability and grammatical perspectives (e.g. Dresher 1999 as well as contributions to Goad

& Rose 2003 and to Kager, Pater & Zonneveld 2004). A positive result from this literature is the fact that grammatical explanations for some apparently puzzling patterns observed in children's productions now incorporate elements from both speech perception and production. In sum, the grammar no longer bears sole responsibility for differences between child and adult phonology, and child language productions can be better reconciled with phonological theories based on patterns in adult language.

5.1. The development of lexical representations

The question of the emergence of lexical representations and how they relate to the remainder of the phonological grammar is at the centre of many current questions. A review of the recent literature on this topic reveals a promising convergence of interests between theoretical and experimental linguists and psychologists (e.g. Pater, Stager & Werker 2004, Kager, van der Feest, Fikkert, Kerkhoff & Zamuner 2007, Yoshida, Fennell, Swingley & Werker 2009; see also Pater, this volume). Recent highlights from this literature strongly suggest that the child's early lexicon is phonetically detailed but lacks phonological sophistication. Related models of categorization also suggest that segmental and prosodic categories emerge from implicit computations of the types of phonetic distributions that appear in the early 'phonetic' lexicon (e.g. Pierrehumbert 2003, Werker & Curtin 2005).

These proposals support Macken's (1980) contention that early input representations may contain artifacts of the child's misunderstanding of some of the phonotactics that exist in the adult language. Similar positions have been taken by Locke (1983), Menn (1983), Waterson (1987), Levelt (1994) and Vihman & Croft (2007), *inter alia*. Within the generative framework, Goad & Rose (2001, 2004) and Fikkert & Levelt (2008) establish explicit relationships between the child's developing phonological representations and the types of error patterns observed in early phonological productions. For example, Goad & Rose (2001, 2004) propose that prosodic representations gradually emerge in the lexicon through the child's implicit analysis of the distributional evidence available from the words stored within the (still developing) lexicon. While obstruent + sonorant onsets (e.g. [pr, tr, kr]) display clearly rising sonority profiles, this is not the case for s + consonant onsets, which show different sonority profiles, including flat (or, arguably, falling) sonority s + obstruent clusters (e.g. [sp, st, sk]; cf. [sl, sr, sw]). Goad & Rose propose that children may be temporarily misled by superficial aspects of the evidence and, thus, develop early syllabic representations on the basis of sonority until the distributional

facts are understood, specifically about the types of phonotactics that govern the appearance of s + consonant clusters in these languages.[18]

5.2. The expression of phonological categories in child language

Beyond grammatical development, the child's productions are also subject to factors pertaining to physiological growth and motor control, the effects of which must also be considered in any interpretation of child language production data.

Productive abilities figure prominently in works focusing on the transition between late babbling and early word productions. For example, Kern & Davis (2009) show that children learning different languages gradually attune their general productive abilities to the types of consonant and vowel combinations that are the most prominent in the ambient language. This literature thus emphasizes the child's progressive gain in control of his/her speech articulations. Also focusing on articulatory factors, Vihman & Croft (2007) highlight the fact that children's usage of early words and their pronounced forms are generally constrained by motor limitations that are gradually overcome during the course of development. These proposals, based on children's babbling and earliest word productions, suggest that basic bio-mechanical pressures that hinder early phonological production gradually give way to the types of articulations that are required to faithfully reproduce the full range of phonotactics found in the target language.

Data from slightly older learners, however, suggests that the link between lexical representations and related word productions is generally less direct. For example, in their explanation of positional velar fronting, Inkelas & Rose (2008) propose an interaction between grammatical and articulatory factors. Positional velar fronting consists of the pronunciation of velar consonants as coronal in prosodically strong positions (e.g. in word-initial or otherwise stressed onsets) but not in weak positions (e.g. non-initial onsets of unstressed syllables; codas), as exemplified in (9) (see also Chiat 1983, Stoel-Gammon 1996, McAllister 2009 and section 4.2.2. above).

(9) Positional velar fronting (Inkelas & Rose 2008)

a) Prosodically strong onsets

[ˈt͡ʰʌp]	*cup*	1;09.23
[ˈd͡oː]	*go*	1;10.01
[ˈhɛksəˌd͡ɔn]	*hexagon*	2;02.22

[18] From a broader perspective, these proposals also support the view that prosodic structure is specified in the developing lexicon (e.g. Golston 1996: 718ff and references therein).

b) Prosodically weak onsets; codas

[ˈmɑŋ̲ki]	*monkey*	1;08.10
[ˈbejg̲u]	*bagel*	1;09.23
[ˈpædjɔ̲k]	*padlock*	2;04.09

As already mentioned in section 3.2, Inkelas & Rose (2008) point out that positional velar fronting is unexpected from a theoretical standpoint since positional segmental neutralization in adult phonology generally occurs in prosodically weak, rather than strong, positions. In an analysis that reconciles the pattern with phonological theory, Inkelas & Rose argue that positional velar fronting derives from an interaction between the child's developing grammar and grammar-external, articulatory factors. They propose that children who display positional velar fronting are in fact attempting to produce stronger articulations in prosodically strong contexts. However, because of a combination of physiological and motor factors (proportionally larger tongue body, shorter palate; limited control of tongue articulations), the strengthening of target velars results in an articulation that extends too far forward, into the coronal area of the hard palate, yielding a fronted velar release.[19]

Inkelas & Rose's (2008) proposal potentially extends to the analysis of other apparently problematic positional substitutions. For example, in the pattern of positional stopping illustrated in (10), target fricatives undergo stopping in prosodically strong but not weak positions.

(10) Positional stopping (Chiat 1989, Rvachew & Andrews 2002, Marshall & Chiat 2003)

a) Stopping in prosodically strong onsets

[bɪˈp̲ɔ]	*before*
[ˈd̲u]	*zoo*
[kəˈt̲ino]	*casino*

b) No stopping in other (prosodically weak) positions

[ˈpɜːs̲ən]	*person*
[ˈmɪs̲]	*miss*
[ˈkev̲]	*cave*

19 Note that this analysis still applies whether the pattern is fully neutralizing or not (e.g. Edwards, Gibbon & Fourakis 1997) as we are in both cases witnessing a difference in articulation that is prosodically-driven. See also McAllister (2009) for additional arguments in favor of Inkelas and Rose's (2008) original proposal.

While positional stopping may suggest a fairly heavy articulatory component (strengthening of fricative articulations in prosodically strong positions), it also requires a grammatical reference to stress and word edges, in a way similar to that of positional velar fronting.

Grammatical influences, whether they relate to lexical representations or their expression in spoken forms, are also evidenced in long-distance patterns such as consonant harmony (Goad 1997, 2001, Pater 1997, Rose 2000, 2002, dos Santos 2007, Fikkert & Levelt 2008, Levelt, this volume) and metathesis (e.g. Ingram 1974, Menn 1976, Velleman 1996, Macken 1996, Rose 2000, 2002, dos Santos 2007). For example, in cases of long-distance metathesis, consonantal place or manner features are preserved but swapped across vowels in systematic ways. This is illustrated in (11) by the productions of W, a learner of English, who produces every word-initial target fricative in word-final position (original data from Leonard & McGregor 1991, as reported by Velleman 1996).

(11) Manner-conditioned metathesis patterns (Leonard & McGregor 1991)

[uz̲]	*zoo*
[aɪnf̲]	*fine*
[ops̲]	*soap*
[nupis̲]	*Snoopy*
[taps̲]	*stop*

Systematic, word-level distributional patterns of this kind demand a grammatical analysis that transcends perceptual or articulatory factors.[20]

Finally, recent analyses of early word forms by Levelt & van Oostendorp (2007) and Fikkert & Levelt (2008) focus on the emergence of phonological features in the lexicon as well as their interaction in early word productions, which they claim to be responsible for other theoretically intriguing patterns such as consonant harmony. Readers interested in these topics may consult the chapters by Fikkert and by Levelt in this volume. From a formal perspective, this research offers new and interesting ways to provide a bridge between the emergence of phonological representations and their expression in children's early productions.

[20] One could object that [s] is hard to locate temporally in the signal and therefore is particularly prone to perceptual 'migration'. However, such an observation would not predict why [s] systematically goes to the end of the word, rather than to any other location within the word.

6. Conclusion

Phonological patterns observed in child language offer a central source of evidence for our understanding of phonology as a grammatical system. However, careful analysis is required, as these patterns can be triggered by a number of potentially conspiring factors, be they perceptual, grammatical, or articulatory, the combination of which may elude limitations imposed by approaches that are theoretically or empirically too narrow. Recent experimental advances, combined with a growing body of scientific literature on child phonological production, show that phonological categories familiar from the literature on adult phonology cannot be taken for granted in the investigation of child language productions, especially at early stages in phonological development. Any analysis of child phonology must therefore question all properties of the child's target language that may affect development as well as consider all of the factors that might influence production throughout the relevant developmental period. This is a complicated challenge for practitioners as well as for the elaboration of theoretical models. However, theoretical simplicity cannot take precedence over the more central consideration of explanatory adequacy.

Several topics have been left aside in the above discussion, including disordered or protracted phonological systems. The characterization of these systems poses it's own challenges, despite the fact that many of the patterns discussed above are also attested in clinical data (e.g. Bernhardt & Stemberger 1998, contributions to Dinnsen & Gierut 2008). One central debate in this context pertains to whether the difference between these and typically developing child phonologies is qualitative or quantitative. While this debate lies outside the scope of this chapter, we contend that a method in which perception, grammar and production are integrated into the explanation is the best one for all human phonological systems, no matter their characteristics or degree of development.

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