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Language acquisition in optimality theory*

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Abstract

In optimality theory (OT) the essence of both language learning in general (learnability) and language acquisition (the actual development children go through) entails the ranking of constraints from an initial state of the grammar to the language-specific ranking of the target grammar. This is the common denominator in all OT studies on language acquisition and learning. There are many unsettled issues, however. Are the constraints innate or do they emerge during acquisition (nature-nurture)? And if they emerge, where do they come from? What is the initial state? Does the (re)ranking of constraints only involve the demotion of markedness constraints, the promotion of faithfulness constraints, or can it be achieved by both the demotion and the promotion of constraints? Another issue is whether comprehension and production are mediated by the same grammar or whether there is one grammar for comprehension and another for production. This article reviews the current state of affairs in language acquisition studies in OT and ends with some critical remarks and speculations on how the field is likely to develop.

1. The concept of learning and acquisition in OT

1.1. The rise of optimality theory and its consequences for acquisition

In optimality theory (Prince and Smolensky 2004), a grammar consists of a set of constraints on wellformedness (markedness constraints), which are violable and typically conflicting with faithfulness constraints, which govern the mapping between an input (or underlying form) and an output (the overt or surface form). Suppose we have the markedness constraint NoCoDA, which bans codas, and the faithfulness constraint MAX-IO, which states that input segments must have output correspondents, i.e.,

no deletion. Violation of the highest ranked constraint (indicated with a violation mark “*”) is fatal (indicated with an exclamation mark “!”). The grey boxes indicate that the candidate is not longer in the running, as a fatal violation has occurred. Hence, the two different rankings of NoCODA and MAX-IO deliver different optimal output candidates, as shown in the constraint tableaux in (1a) and (1b):

(1) Constraint tableaux

(a)

Input: /dɔg/		
Output candidates	NoCODA	MAX-IO
☞ [dɔ]		*
[dɔg]	*!	

(b)

Input: /dɔg/		
Output candidates	MAX-IO	NoCODA
[dɔ]	*	
☞ [dɔg]		*!

This implies that an output of an input-output mapping can never be rejected because it violates certain constraints or too many constraints. An output can only be rejected if there is a better (or more harmonic) output available. Languages share an important subset of the constraints (albeit not necessarily all of them), which is why we may call these constraints “universal” (Prince and Smolensky 2004). However, individual languages rank these universal constraints differently in their language-specific hierarchies. Thus, a particular constraint can have very strong (categorical) effects in a language, which ranks that constraint high in the hierarchy, while in another language the same constraint has hardly any effects, due to its low ranking. When a set of constraints is identified, the possible rankings of these constraints will generate the possible types of languages that the theory predicts, also referred to as the factorial typology.

Optimality theory arose in the early nineties in phonology (Prince and Smolensky 2004; McCarthy and Prince 1993, 1994), where it caused dramatic changes in the last decade. OT had a major impact on studies of acquisition, especially in phonology, but more recently in syntax, semantics, and pragmatics, too. Most phonological theories prior to optimality theory were concerned with determining underlying segmental representations of words and rules relating these underlying representations to sur-

face forms. Various related surface forms were derived from a single underlying representation by means of (context-dependent) rules. The aim was to arrive at an economical and adequate description of lexical phonological representations. In the SPE rules system (Chomsky and Halle 1968), there were very few restrictions on possible rules. With the rise of nonlinear phonology the enriched segmental representations placed severe restrictions on possible segmental rules: only feature spreading, fusion and deletion were allowed (McCarthy 1988; Goldsmith 1995). In general, the amount of segmental information stored in the lexicon was restricted as much as possible, giving rise to several branches of underspecification theory and underspecified lexical representations (e.g., Archangeli 1988; Steriade 1995).

At some point in the derivation the segmental representations underwent prosodification: the segmental string was subject to syllabification rules, and subsequently, syllables were formed into higher metrical structures by metrical stress rules. These prosodic rules are thus procedures that construct prosodic representations on top of the segmental string. However, these prosodic representations were not assumed to be part of the stored phonological representations, as the prosodic structure is largely predictable. In this sense, prosodic structure is crucially different from segmental structure: segmental structure is essentially stored, and may be altered by phonological rules to create different output forms, whereas prosodic structure is created by prosodic rules and always refers to output forms only.

Although prosodic rules often created the “correct” metrical structures, it was often the case that a number of rules resulted in the same output structure. For example, the rule inserting an onset and the rule reducing a onset cluster both have the effect of creating an unmarked simple onset. By placing wellformedness conditions on possible onsets in the output the common motivation behind two very different rules is expressed directly. In general, it often appeared to be more successful to place restrictions on output structures, than to provide a set of unrelated rules to do the job. This (and other concerns) led to the rise of OT (for a recent overview see McCarthy 2007), which is a formal model of linguistic wellformedness and expresses markedness on output structures directly in the theory. Initially, OT was mostly applied to prosodic phenomena. However, as markedness also plays a role in segmental phenomena, these became under the spell of OT as well.

Phonological acquisition studies follow the same historical development as phonological theory itself.¹ Early studies focused on segmental rules that related an adult target word (the input) to the child’s output form (Smith 1973; Ingram 1974; among others). The general assumption

is that children have mental representations of target words that are essentially adultlike, based on the assumption that words are correctly perceived. The rules turn the target forms into simplified output forms. With the introduction of nonlinear phonology possible segmental rules were restricted to those motivated by the now more elaborate phonological representations (e.g., Spencer 1986; Stemberger and Stoel-Gammon 1991; see also Menn 1978). In the course of acquisition rules could be changed, reordered or deleted, until in the final-state all rules typical of child phonology were suspended with. Although the rule types used are similar to adult phonology, the rules themselves that characterize the child's phonology were often specific to child language and did not relate to the adult phonological rules. In other words, continuity between child and adult phonology was not assumed. Contrary to the situation in segmental phonology, in prosodic phonology continuity was explicitly assumed, as representations were assumed to be governed by principles and parameters (Dresher and Kaye 1990; Fikkert 1994), which crucially assumed that all intermediate prosodic systems children could arrive at must be possible prosodic systems. In other words, here continuity was an essential property of the theory, and more on a par with syntactic theories (e.g., Lightfoot 1999).

However, research on the interaction of segmental and prosodic acquisition also took notion of the existence of word templates in child language: Children's output forms often obeyed particular child-specific wellformedness constraints (Macken 1979; Waterson 1971; Menn 2004). For instance, Macken provides data where her Spanish subject Si strictly adheres to a $[C_{\text{labial}}VC_{\text{coronal}}V]$ template, as shown by the data in (2).

(2) Si's labial-coronal word templates

zapato	<i>shoe</i>	[pwat:o]	(1;8.7)
manzana	<i>apple</i>	[man:a]	(1;9)
Fernando	name	[mano]	(1;9)
elefante	<i>elephant</i>	[batə]	(1;9)

(Macken 1979)

These are early attempts to express constraints on outputs in acquisition. Other notable early uses of constraints are found in for instance Levelt (1994), and Fikkert (1994). Currently, constraining outputs is central in the main branch of present-day phonology: OT.

The field of acquisition of phonology in OT is in fact split into two subdivisions. In one division research is based on empirical data: child language acquisition data are studied and developmental patterns are unraveled. The other division investigates learnability issues: because an important requirement on grammars is that they are learnable, the process

of language acquisition can be modeled independently of actual acquisition data. Notable exceptions that combine both are Boersma and Levelt (2000), Tessier (2006), and Jesney and Tessier (2007). Ideally, the model mimics real language acquisition, but this is neither a necessity for proving that a particular grammar is learnable, nor is it of much concern in actual learnability studies. Often the term “learning” is used in the latter context, while “acquisition” refers to child language development; in practice, however, the terms are frequently used interchangeably. Learnability models of phonology are rare before OT, which must essentially be due to the lack of continuity between child and adult phonologies with respect to *segmental* phonology. Phonological theories captured in a principle-and-parameter framework have led to a number of learnability models for *prosodic* phonology, in particular of word stress (e.g., Dresher and Kaye 1990; Gilles et al. 2000). Although these have been reasonably successful as the number of parameters involved was limited, for more complex phenomena they are more difficult to create due to the fact that the learning space increases dramatically with each parameter.² In many current OT proposals, continuity is an explicit assumption: at each stage of development the child’s (sub)phonology must correspond to a possible (sub)phonology of a human language. Before OT it was nearly impossible to restrict the hypothesis space for the learner. However, OT — at least in some versions of it — places clear restrictions on the space of possible grammars that the learner must consider (Tesar and Smolensky 1998, 2000). Consequently, OT not only had a major impact on the child language studies, it also inspired a significant number of learnability studies in recent years (e.g., Tesar and Smolensky 2000; Boersma 1997; Boersma and Hayes 2001; Prince and Tesar 2004). However, so far, learnability studies have not taken actual acquisition patterns, or real learners, into account (but see Boersma and Levelt 2000; Hayes 2004). In this paper we focus on children’s actual language acquisition. In the next section, we first provide the basic architecture of OT, before we turn to acquisition data from both phonology and syntax/semantics.

1.2. OT: the basic architecture³


In OT the grammar of a language consists of a set of ordered constraints: highly ranked constraints have priority over constraints that are lower ranked. Markedness or wellformedness constraints evaluate output candidates, rather than inputs. Faithfulness constraints evaluate the input-output mapping. Output candidates are evaluated according to the constraint ranking of the language. Candidates that are most favored by the

highest ranked constraint are passed along to the next constraint in the hierarchy, where the evaluation process is repeated until the optimal candidate — the output — is found. Importantly, constraints can be violated, but only minimally so. Moreover, violations do not add up. That is, more violations of lower ranked constraints cannot be stronger than one violation of a higher ranked constraint. Also, if a lower ranked constraint is violated more than once, it cannot overrule the violation of a higher ranked constraint.

Although the basics of OT for phonology and syntax are essentially the same, the input-output mappings in phonology are different from those in syntax and semantics. In phonology both the input and the output are forms (an underlying representation and a surface representation) and faithfulness constraints require them to be identical. In OT syntax the input is a meaning and the output is a form (syntactic structure); therefore, in OT syntax faithfulness cannot be identity. The same holds for OT semantics where the input is a form and the output is a meaning. In these domains faithfulness is a relation of association rather than of identity (cf. Mattausch 2004).

Constraints often are in conflict. If a markedness constraint conflicts with a faithfulness constraint, then if the markedness constraint is dominant, the input will not always be realized faithfully, and hence, the relevant faithfulness constraint might get violated. But if the faithfulness constraint is higher ranked than the markedness constraint and there is a conflict between the two, this will induce the violation of the markedness constraint, and a marked output candidate becomes optimal. While constraints can be violated, violation is always minimal in the optimal output candidate. This is shown in the tableau in (3), where the left column gives the competing output forms for the input form consisting of the Dutch target word /pus/ ‘cat’, which is realized as [pu] by a child; the other columns give the constraints and their violation marks.

(3) Constraint tableau

	Input: /pus/ ‘cat’				
	Output candidates	ONSET	NoCODA	DEP-IO	MAX-IO
(a)	 [pu]				*
(b)	[pu.si]			*!	
(c)	[pus]		*!		
(d)	[us]	*!	*		*

In (3a) the output is realized as [pu] (with an unparsed final consonant), which is the optimal candidate, indicated by ☞, given the constraint ranking. The highest ranked constraint that the optimal form violates is MAX-IO. All other candidates violate constraints higher ranked than MAX-IO, which is the only constraint violated in (3a). In (3b) a vowel is epenthesized: a DEP-IO violation. The completely faithful candidate (3c) violates the NoCODA constraint, while candidate (3d) violates ONSET, NoCODA and MAX-IO. The mechanism of evaluation is the same in all versions of OT: all constraints apply in parallel and the constraint hierarchy determines the relative constraint strength. However, theories may vary considerably in their assumptions concerning the nature of constraints, the initial ranking of constraints and how this ranking can change in the course of development. In addition, theories differ in their assumptions concerning input representations, which reside in the mental lexicon.

1.2.1. *The nature of constraints.* In “classical” or nativist OT all constraints are assumed to be universal (cf. Prince and Smolensky 2004; Gnanadesikan 2004; Kager 1999). If all constraints are universal,⁴ grammars can only differ in the constraint rankings. This important principle is at the heart of the factorial typology: the logically possible rankings of the constraints should correspond to all and only possible human languages. Acquiring a grammar amounts to learning the language-specific ranking of the constraints. The constraints themselves do not require learning in the “nativist” version of OT, as they are universal.

Others have argued that all constraints are functional. Although these functional constraints could in principle still be universal (and in fact often are), they are either grounded in phonetics — articulatory or acoustic — (Boersma 1998; Kirchner 1997; Hayes 1999; Hayes et al. 2004), or in communicative functions (Haspelmath 1999; Bernhardt and Stemberger 1998; Stemberger and Bernhardt 1999). Stemberger and Bernhardt (1999), for example, argue that constraints serve communication and aim at reducing processing load and constraining information processing. Constraints grounded in phonetics often make reference to fine phonetic detail, which is usually not the case with the “classical” constraints, which typically only refer to symbolic phonological categories.

Nothing in the OT model (but the factorial typology) crucially hinges upon the assumption of universality of constraints. Although the common assumption in “classical” OT is that constraints are universal, in other versions of OT researchers have argued that constraints emerge in the course of development (e.g., Boersma 1997, Pierrehumbert 2003;

Fikkert and Levelt 2008).⁵ However, even among the emergentists there are many different proposals concerning the ontogeny of constraints. Some argue that all constraints are grounded in phonetics and emerge when children are able to perceive or produce phonetic categories (Boersma 1997). Others argue that markedness constraints are generalizations over the input that a child hears, and hence reflect input frequencies (e.g., Hayes 2004; for a similar point in other frameworks see Pierrehumbert 2003, Beckman and Edwards 2000). Yet others argue that constraints emerge as generalizations over children's own lexicons (Fikkert and Levelt 2008; see also Waterson 1971, Ferguson and Farwell 1975; Menn 1983, for similar pre-OT views). When these constraints have emerged they remain part of the child's grammar, although the ranking still may change. Similarly, Legendre (2006: 811) states that there is arguably no syntax before verbs appear in child speech, suggesting that the constraints appear in the course of development. The emerging constraints do however not differ from those of which the adult grammar is composed (see Note 2). Yet, if constraints emerge in the course of development, this has important consequences for acquisition and learning⁶, in particular for views on the initial state.

1.2.2. Constraint rankings and the initial state: consequences for learning and acquisition. It is generally assumed that in the initial state markedness constraints outrank faithfulness constraints ($M \gg F$) (see Demuth 1995; Gnanadesikan 2004; Tesar and Smolensky 1998, 2000; Hayes 2004; Legendre 2006). This assumption is based on the fact that children's early utterances typically are unmarked. Other arguments for $M \gg F$ as the initial state come from learnability arguments, and mimic the arguments in favor of the Subset Principle in acquisition (Berwick 1985; Manzini and Wexler 1987): if children start out assuming a grammar that is more marked (and more faithful), i.e., $F \gg M$, many grammars become unlearnable (Smolensky 1996). Once the child produces forms faithfully, i.e., targetlike, and at the same time is violating markedness principles, there will never be evidence for the child that would force him or her to go back to a ranking where the relevant markedness constraint outrank the relevant faithfulness constraint. In the absence of such evidence the learner will not change $F \gg M$ to the required $M \gg F$ setting. A third argument comes from the production-comprehension dilemma (Smolensky 1996), which is discussed below in Section 1.2.3.

Alternatively, constraints may emerge during development. Some have argued that markedness constraints emerge during acquisition as generalizations over the output lexicon (Fikkert and Levelt 2008). Initially children aim at producing targets as faithfully as they can. Hence, when

markedness constraints emerge this gives rise to a state in which $M \gg F$.⁷ Hale and Reiss (1998) have assumed an initial setting in which faithfulness constraints outrank markedness constraints, i.e., $F \gg M$. Under this assumption, the child stores lexical items faithfully, and deviating patterns must be explained outside linguistics, for instance by underdeveloped articulatory and processing skills. Although this view could in principle hold for lexical phonology, as children have heard all the words they know produced correctly,⁸ for other levels of phonology and syntax this view is untenable.

On the assumption of $M \gg F$ as the initial state, the child has to learn that certain marked structures are permitted in the native language, and hence demote the relevant markedness constraints below the relevant faithfulness constraints (Tesar and Smolensky 1998, 2000). Alternatively, the child could aim at becoming more faithful to the input and promote faithfulness constraints (Gnanadesikan 2004; Bernhardt and Stemberger 1998). Although in practice, the two approaches are highly similar, conceptually they are different. This process of demotion or promotion may work well as long as the input does not contain too much variation. If a language does contain variation with regard to particular structures strict demotion of markedness constraints (or promotion of faithfulness constraints) is insufficient. Partial rankings allowing floating constraints (over a certain range in the constraint hierarchy) may be needed, which is the motivation for the proposal of stochastic OT and its associated learning algorithm (Boersma 1997; Boersma and Hayes 2001; Legendre 2006).

In most versions of OT learning is assumed to be error driven:⁹ when the child (or learner) discovers that his or her output does not match the input, this provides evidence to the learner that his or her grammar needs to change: by demoting some markedness constraints that are high-ranked in the current grammar (or promoting some faithfulness constraints that are low-ranked, depending on the algorithm one assumes) a new grammar will be achieved. This process is repeated until all constraints have the “adult”-like position in the hierarchy. In fact, most research on acquisition and learning has focused on constraint reranking. Although this may sound like a case of explicit learning, one way to interpret the process is that the cognitive system is alerted when it hears something unexpected, i.e., an input that violates the current grammar. However, this does not have to reach the learner’s consciousness.

Another important issue concerns the question of when the initial state is altered. Does it happen on the basis of the child’s own production, or does it start in infant perception, long before the first words are uttered? Most studies on phonological acquisition have taken children’s

“unmarked” output forms in production as evidence for the initial stage of $M \gg F$, and therefore implicitly assume that children may change their grammar on the basis of their own production errors. By comparing their own output to the target children may discover that there is a mismatch, and hence that they need to change their grammar.

Evidence from infant and child perception studies has shown that infants already have acquired substantial knowledge of the sound patterns in their language before they produce any words (Jusczyk 1997, 1998; Gerken 2002; Kuhl 2000). In Section 2.1.3, we address results from speech perception research that have consequences for assumptions on the initial state in phonology (Boersma 1998; Hayes 2004; Pater 2004; Jusczyk et al. 2002; Davidson et al. 2004). Yet, results from comprehension studies have shown that the reverse can also happen: that production is ahead of comprehension (Hendriks and Spenader 2006). Results from infant and child perception studies have also renewed the interest in the learning of phonological representations, to which we turn next.

1.2.3. *Input representations.* Although learning entails discovering the rank order of the constraints, underlying lexical representations must also be learned, as they are clearly language specific. Most discussions have focused on production where the underlying representations are the input forms in the constraint tableaux. For phonological production these inputs are the underlying sound structure of words that form part of the mental lexicon (Prince and Smolensky 2004), and hence here input has a different meaning than the input a child receives from the environment. For comprehension the input in phonology is the acoustic signal that needs to match to an optimal candidate among the stored representations, although often more intermediate levels between underlying representation and acoustic form are assumed, as will be discussed in Section 2.1 (e.g., Boersma 1998; Pater 2004).

In the area of OT syntax (which refers to production) the input is assumed to be the message the speaker intends to get across. Usually, this “meaning” consists of the basic components of the intended utterance, which may include lexical items, predicate-argument structure, and tense and aspect information. In other words, OT syntax takes the perspective of the speaker, who intends to get across a certain message (a meaning) and looks for the optimal way of expressing it (the optimal form). In OT semantics (comprehension), the input is a form (an utterance), and the hearer has to determine the interpretation of that form in the given context (the optimal interpretation). Thus, OT semantics takes the perspective of the hearer. Optimization is either from meaning to form (OT syntax) or from form to meaning (OT semantics). However, adult com-

munication is essentially bidirectional in the sense that the speaker has to take into consideration the perspective of the hearer in deciding what is the optimal form for a certain meaning, while the hearer must take into account the perspective of the speaker in assigning the optimal interpretation to an utterance.


Input representations have not received much attention in OT, primarily because of the principle of *Richness of the Base* (Prince and Smolensky 2004), which states that the constraint ranking will provide the optimal output candidate for every input. In other words, there are no language-specific restrictions on input representations. Systematic properties of the lexicon are the result of *Lexicon optimization*, which ensures that those input forms are selected for storage that are faithful to the perceived forms.

In most research on phonological acquisition the learning problem is drastically simplified by assuming that children perceive words accurately, and that their input form is somehow identical to that assumed for adults.¹⁰ Similarly, in the area of syntax-semantics it is often assumed that comprehension precedes production. On this assumption, the only task the child is facing is to get to the right constraint ranking. Smolensky (1996) argues that this is a plausible assumption and illustrates his point with the example sketched in (4). The tableau in (4a) represents the production of the word *cat*, and in (4b) its comprehension is modeled. Note that in this context, *comprehension* does not refer to the proper understanding of the meaning of the word *cat*, but just to its phonological interpretation (i.e., the underlying phonological form). As in (3), DEP-IO and MAX-IO are faithfulness constraints, which respectively prevent insertion and deletion of segmental material. IDENT-IO is a faithfulness constraint against replacing segments or features.

(4) a. Production of the lexical item *cat*

Phonological input: /kæt/	Markedness	Faithfulness		
Output candidates	NoCODA	DEP-IO	IDENT-IO	MAX-IO
[kæt]	*!			
☞ [kæ]				*
[kæta]		*!		
[tæ]			*!	*

b. Phonological interpretation of *cat*

Input: [kæt]	Markedness	Faithfulness		
Output candidates	NoCODA	DEP-IO	IDENT-IO	MAX-IO
 /kæt/	*			
/kæ/	*	*!		
/tæ/	*	*!	*	
/dɔg/	*		*!*	
/skæti/	*			*!*

In (4a) the constraint ranking ensures that an input *cat* is produced as [kæ] by the child, with highly ranked markedness constraints ($M \gg F$). The question is whether the child has indeed stored /kæt/ as his or her input representation, or whether the input reflects her output, i.e., /kæ/, as the latter underlying form would produce the same output from. The tableau in (4b) presents children’s phonological interpretation of the word /kæt/ assuming the same constraint ranking. If perception is accurate, the child perceives [kæt]. This perceived form is now evaluated against possible candidates for the underlying representation. It will always violate NoCODA. Hence, only faithfulness constraints matter in evaluating the optimal candidate. Therefore, the candidate that is most faithful to the perceived form will be the optimal underlying representation corresponding to the perceived form. In essence, then, input equals output.¹¹ Of course, a consequence of this logic is that the grammar can only change upon detecting errors in the child’s production, which has indeed been the implicit assumption in most empirical research on acquisition within OT, as we will see in the next sections. Yet, this seems to be too much of a simplification. There are cases where production is ahead of comprehension, as the following example will show.

A similar type of analysis can be given for semantic interpretation delays in the acquisition of the grammar (Hendriks et al. 2005). Chapman and Miller (1975) found that in order to determine the subject and object in a transitive sentence young children use animacy as a cue in comprehension, but not in production (see also Lindner 2003 and Section 2.2 below). The children in Chapman and Miller (1975) correctly utter sentences like ‘the car is hitting the boy’ when asked to describe a scene in which a car hits a boy. However, upon hearing a sentence such as ‘the car is hitting the boy’, half of the children misinterpret this sentence.

They interpreted it as meaning that the boy hits the car. Hendriks et al. (2005) provide an OT analysis, where the following constraints are relevant. The universal markedness constraint ANIMACY requires that in a transitive sentence, the subject (i.e., the agent) outranks the object (i.e., the patient) in animacy. The faithfulness constraint on word order PRECEDENCE demands that the subject precedes the object in a transitive clause. That is, this constraint requires iconicity between the input meaning (the order of the first and second argument, i.e., the agent and the patient of a transitive predicate) and the output form (the order of the subject and the object). According to Hendriks et al. (2005), the children that misinterpret the type of sentence mentioned above have the markedness constraint ANIMACY outrank the faithfulness constraint on PRECEDENCE. This means that in the sentence ‘the car is hitting the boy’ they interpret the animate noun phrase *the boy* as the subject of the clause and the inanimate noun phrase *the car* as the object, even though *the car* precedes *the boy*. Hence, their interpretation of the input sentence is that the boy is hitting the car, an interpretation which satisfies ANIMACY while it violates PRECEDENCE, as shown in (5a):

(5) a. Interpretation of *the car is hitting the boy*

Input: The car is hitting the boy.	<i>Markedness</i>	<i>Faithfulness</i>
Output candidates	ANIMACY	PRECEDENCE
Hit (the car, the boy)	*!	
☞ Hit (the boy, the car)		*

b. Production of *the car is hitting the boy*

Input: Hit (the car, the boy)	<i>Markedness</i>	<i>Faithfulness</i>
Output candidates	ANIMACY	PRECEDENCE
☞ The car is hitting the boy.	*	
The boy is hitting the car.	*	*!

In production (from meaning to form), however, ANIMACY does not play a role because it is either vacuously satisfied or vacuously violated. The input is the meaning that the speaker wishes to express. Suppose, a speaker (child) wants to describe a situation when the car is hitting the boy. In that case, the subject (agent) does not outrank the object (patient) in animacy. Therefore, ANIMACY is violated, irrespective of the order in

which the subject and the object are eventually put, and as a consequence only the faithfulness constraint matters in evaluating the optimal candidate. The candidate that is most faithful to the intended meaning will be the optimal form. Thus, children who misinterpret the sentence (5a) because of their wrong ranking of ANIMACY and PRECEDENCE, will still produce the adultlike sentence correctly as illustrated in (5b).

For adults, the faithfulness constraint PRECEDENCE, outranks the markedness constraint ANIMACY, which guarantees that they always interpret the first noun phrase as the subject of the clause, independently of its relative animacy. Children will get the correct adultlike interpretations only when they have acquired the right ranking of the two constraints.

In phonology the usual assumption has been that perception precedes production. Yet, the interpretation of a perceived form depends on the phonology of the language. For example, in some languages a mid vowel patterns with the low vowels, while in other languages, it may pattern with high vowels. These vowels could be phonetically very similar in both types of languages. Consequently, they would lead to different input representations, unless one assumes that stored underlying representations are, in fact, the phonetically detailed representations that one hears, rather than (abstract) phonological representations (as for instance in much infant speech perception studies, such as Swingley and Aslin 2000). In essence, in phonology conflicts may arise in both directions too, in production and in perception, although this point has not been addressed in phonology.

This discussion raises yet another important issue: how much detail is stored in the lexicon? If representations are very detailed, constraints also need to refer to those details, and, consequently, the distinction between phonology and phonetics is likely to disappear altogether. Yet, this could still be captured in OT. If, however, only basic forms and meanings are stored and detail is abstracted away from in underlying representations, then the important question is how do children acquire a lexicon and the grammar in tandem? The issue is even more complex if scenarios exist in which production precedes perception. We will come back to this issue below. This addresses the underinvestigated issue of the division of labor between the grammar and the lexicon.¹²

The remainder of this paper is set up as follows. In Section 2.1, the main insights that have come from OT studies of child language data from phonology are presented. Section 2.2 focuses on recent developments in OT studies of child language in the domain of syntax and semantics. Section 3 provides a final summary, discusses the main controversies and unresolved issues and Section 4 concludes with speculations about future development.

2. Acquisition studies in OT

2.1. *Phonological acquisition*

The recurrent pattern in child language data is that children's output is considerably less marked than the corresponding adult target forms. This is true both for segmental, syllabic and higher prosodic structure. Hence, the starting hypothesis in much research on phonological acquisition is that children begin with markedness constraints outranking faithfulness constraints. What they have to learn is the language-specific ranking of markedness and faithfulness constraints by either demoting markedness constraints (Tesar and Smolensky 2000) or promoting faithfulness constraints (Gnanadesikan 2004; Bernhardt and Stemberger 1998; Stemberger and Bernhardt 1999), or both (Boersma 1997; Boersma and Hayes 2001).

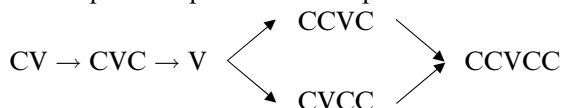
We will first discuss some studies addressing the acquisition of prosodic structure, as OT accounts have been very successful in accounting for prosodic phenomena, including its acquisition. Subsequently, we turn to segmental phonology, in which the constraints invoked to account for the data sometimes give the impression of being much more child language specific rather than universal. In addition, in the segmental phonology much more variation is attested in child language data. Finally, we turn to results from infant and child perception studies that have tested claims of OT.

2.1.1. *Prosodic structure.* Prosodic structure is usually assumed to be absent in the stored input representations: as syllable structure and foot structure are largely predictable and seldom contrastive, there is no need to store this information in the mental lexicon.¹³ If prosodic structure is indeed absent in the stored representations (input), the child's produced syllable structure cannot be evaluated by faithfulness constraints referring to syllable structure directly. What is evaluated is whether the child's output form has more (insertion; MAX-IO violations) or less segments (deletion; DEP-IO violations) than the target.

Two prosodic phenomena are well studied in child language: the stage at which children's output forms adhere to the minimal word, where unfaithfulness is often evidenced by truncation (see Pater 1997) and the acquisition of syllable structure. Here we will focus on the latter. Levelt and colleagues present a well worked out proposal on the acquisition of syllable structure (Levelt et al. 2000; Levelt and van de Vijver 2004). For their investigation they took into account all stressed syllables¹⁴ produced by twelve children acquiring Dutch (Fikkert 1994; Levelt 1994), and

determined for each child the order in which syllable types first appeared in the child's production. There turned out to be only two developmental paths used by the children to reach the final state grammar, which are given in (6):

- (6) Developmental paths in the acquisition of Dutch syllable structure



The data provide evidence for an initial state with only unmarked CV syllables: all syllable markedness constraints are satisfied (NoCOMPLEX, ONSET, NoCODA), resulting in the grammar in (7a).¹⁵ In principle, there are three possible ways to proceed: by producing codas, onsetless syllables, or onset clusters. Only the first option was chosen by all twelve children, showing that the first step entails demoting NoCODA below FAITH (7b).¹⁶ Subsequently, ONSET is demoted below FAITH (7c), and finally, complex onsets/codas appear (7d), and words are produced faithfully.

- (7) Developmental grammars at each developmental stage
- Stage 1 NoCOMPLEX, ONSET, NoCODA > FAITH
 - Stage 2 NoCOMPLEX, ONSET > FAITH > NoCODA
 - Stage 3 NoCOMPLEX > FAITH > ONSET, NoCODA
 - Stage 4 FAITH > NoCOMPLEX, ONSET, NoCODA

The development looks like the schoolbook example to demonstrate constraint demotion in OT. In addition, it demonstrates that each developmental grammar corresponds to a possible adult grammar. However, on closer inspection there are a number of issues that need further explanation. First, when the child's grammar allows CV, CVC and V structures, one would expect VC structures to be also allowed. Similarly, if the child's grammar allows for initial and final clusters, syllables with both initial and final clusters (CCVCC) are also expected to be possible. Yet, these are typically absent. This is captured in Levelt et al. (2000) by invoking local conjunction, stating that the conjoint constraint is violated only if both parts of the conjoined constraint are violated. Thus, {ONSET, NoCODA} is violated only in VC structures.¹⁷ Intuitively, it seems natural that VC is more marked than either CVC or V as it violates two markedness constraints. This is an instance of the so-called "worst-of-the-worst" scenario. The question is whether this relative markedness should be expressed in the grammar. We are not aware of grammars of adult lan-

guages that avoid VC, while allowing V and CVC syllables, although Levelt and van de Vijver mention a potential example: Sentani. By allowing conjoined constraints the number of constraints will multiply rapidly, as markedness at all levels could in principle participate in joined constraints.¹⁸

The second issue is why there are only two possible learning paths attested among the many possible paths. Levelt and Van de Vijver (2004) argue that the trigger to development is input frequency. In fact, the developmental data exactly follow input frequency patterns. Where frequency is not telling, as in the case of initial and final clusters, which occur with very similar frequencies in Dutch, children follow their own preferred learning paths. The account presented above involved the demotion of universal markedness constraints, but an account based on frequency (the most frequent syllable type is acquired first) would make the same predictions.

In a recent comparison of acquisition data from Dutch, European Portuguese (Freitas 1997) and French (Wauquier-Gravelines and Suet-Bouret 2004), Fikkert et al. (2004) found that while Dutch children acquire CVC before V, French and Portuguese children have the opposite order of acquisition in stressed syllables, while — like in Dutch — the CVC syllables are more frequent than V syllables in both languages.¹⁹ Hence, input frequency cannot be the only predictor of developmental paths.²⁰

A further issue is the question what triggers development. It is usually assumed that learning is error-driven (e.g., Dresher and Kaye 1990; Fikkert 1994; Tessler and Smolesky 1998, 2000). It may be the case that the child's discovery of faithfulness violations functions as an alert system and indicates that the system should be changed. The next step would then be to analyze where the system needs to be repaired, i.e., which markedness violations need to be demoted. This could lead to an intermediate stage where more variation is attested than either before and after the constraints have been reranked (Boersma and Levelt 2000; see also Hohenberger and Peltzer-Karpf this issue). This is sometimes expressed by allowing constraints to float in a particular domain of the constraint hierarchy (for an example from syntax see Legendre et al. 2002), which allows multiple rankings at a particular stage of development.

The development sketched in (7) also does not express the fact that syllable structure is very much dependent on segmental structure. This is particularly clear if we consider early onset and coda consonants. Onsets are typically realized as plosives, and particularly fricatives in onset position are often replaced by stops at early stages of acquisition, as shown in the Dutch data in (8a). At later stages, the strategy is replaced by a

different one: now, children choose to not realize an onset, rather than to realize a consonant with an unfaithful manner of articulation, as shown in (8b) (for similar observations in German see Grijzenhout and Joppen-Hellwig 2002 and in French Wauquier-Gravelines and Suet-Bouret 2004). It is not the case that onsets are no longer allowed: although fricatives are not realized (8b), other onsets (i.e., plosives and nasals) are realized faithfully. Rather, it is the interaction between *ONSET* and **FRICATIVE* (Fricatives are not allowed) that is responsible for the nonrealization of initial fricatives. At the initial stage *ONSET* was ranked too high to allow for deletion, but with *ONSET* demoted in the course of development, empty onsets become more optimal at this stage of development.

(8) Initial fricatives in Dutch (data from Fikkert 1994)

- a. fiets /fits/ 'bicycle' [tis] Noortje (2;1.17)
- b. fiets /fits/ 'bicycle' [Its] Noortje (2;6.05)

Thus, structural wellformedness at several levels may interact, often obscuring otherwise regular patterns. Yet, OT provides an elegant way to account for such interactions.

2.1.2. *Segmental structure.* In the domain of segmental phonology there are also clear markedness effects to be seen in child language data, but the uniformity evidenced in the acquisition of prosodic structure is less striking in this domain. Whether an initial stage can be identified where markedness outranks faithfulness ($M \gg F$) is not at all clear. It has long been known that a universal order of acquisition of segmental contrasts (as hypothesized by Jakobson 1968 [1941]) is not feasible (see for instance the overview in Ingram 1989). Even children acquiring the same language often show a remarkably different order in which segmental contrasts are acquired, although at the very early stages there are many similarities. Other than assuming that this reflects child-specific constraint rankings no explanations have been offered in OT. Maybe a thorough analysis of the individual child's lexicon and his/her input may provide some insights into what causes a particular grammar, but such studies have not been performed yet.

A similar situation arises with respect to segmental processes. Certain processes often occur in child language, such as stopping (**FRICATIVE*), fronting (**DORSAL*) and final consonant deletion (*NoCODA*) (e.g., Ingram 1974), but none of these processes occur in the language of all children acquiring even the same language (e.g., Morrisette et al. 2003). Moreover, it is not evident that all processes found in child language are attested in adult languages. A striking example is consonant harmony, a typical

phenomenon in child language (cf. Vihman 1978; Stemberger and Stoel-Gammon 1991; Berg 1992; Levelt 1994; Pater and Werle 2003; Rose 2000; Goad 2001; Fikkert and Levelt 2008). Some examples are given in (9):

(9) Consonant harmony

- a. English (Pater and Werle 2003) data from Trevor

dog	[gɔg]	(1;5.14)
coat	[kɔk]	(1;5.18)
bug	[gɔg]	(1;5.18)
cup	[kʌk]	(1;5.13)
- b. Dutch (Fikkert and Levelt 2008); data from Jarmo

vis	'fish'	[sɪf]	(1;9.08)
bad	'bath'	[bɑp]	(1;9.22)
boek	'book'	[bʊp]	(1;10.08)
vogel	'bird'	[fɔfɔ]	(2;1.22)
pakken	'take'	[kʌkə]	(2;1.22)

This process is so intriguing because consonant harmony of primary place of articulation is fairly common in child language, but does not occur in adult languages, which rather strive for asymmetry (Frisch et al. 2004). Consonant harmony (CH) can therefore be said to be a child-specific phenomenon. The question is: Why does CH arise and what does it tell us about the child's developing grammar and/or representations? Most analyses in OT have accounted for consonant harmony by positing either constraints that demand the similarity of consonants in a particular domain (word), such as AGREE (Pater and Werle 2003), constraints against certain combinations of sounds, such as NoSEQUENCE(CORONAL ... LABIAL) (Bernhardt and Stemberger 1998), or constraints that align particular features to particular edges in the word, such as [LABIAL: Align a labial feature to the left edge of a word (Levelt 1994; Goad 2001; Fikkert and Levelt 2008). In the latter approach consonant harmony is the epiphenomenon of general place of articulation patterns in the child's language. In accounts that explain consonant harmony in the grammar, it must be assumed that the constraints causing consonant harmony are low ranked in adult languages, and might show up as emergence of the unmarked (see Fikkert et al. 2005a).

As to the origin of the constraints that cause CH, Pater and Werle (2003) assume that they are universal. Pater (1997) assumes that constraints are created by the child. Bernhardt and Stemberger (1998) motivated the constraints by means of the principle of ease of articulation or ease of processing. Fikkert and Levelt (2008) argue that they emerge in

the course of development as generalizations over the child's own lexicon. If constraints can emerge, this means that it is possible to find U-shaped developmental patterns, where at an earlier stage the effect of a constraint is not felt, simply because the constraint was not yet present. This is shown in (10). At an early stage of development the Dutch child Noortje produces "harmonic" dorsal-vowel-dorsal words, as shown in (10a). Several months later, these initial dorsals are no longer allowed, and across-the-board all initial dorsals are replaced by coronals (10b). This situation lasts for a few months before initial dorsals show up again (10c).

(10) U-shaped development (data from Noortje)

- | | | | | | | |
|----|--------|----------|-----------|---|---------|---------|
| a. | koek | /kuk/ | 'cookie' | → | [kuk] | 2;3.7 |
| | klok | /klɔk/ | 'clock' | → | [kɔk] | 2;5.23 |
| | kikker | /kɪkər/ | 'frog' | → | [kɪk] | 2;2.21 |
| | kijk | /keik/ | 'look' | → | [keik] | 2;5.23 |
| b. | koek | /kuk/ | 'cookie' | → | [touk] | 2;8.17 |
| | klok | /klɔk/ | 'clock' | → | [tɔk] | 2;8.17 |
| | kijk | /keik/ | 'look' | → | [teik] | 2;8.17 |
| | kikker | /kɪkər/ | 'frog' | → | [tikə] | 2;9.1 |
| c. | kruk | /kək/ | 'stool' | → | [kyk] | 2;9.29 |
| | kuiken | /kœy kə/ | 'chicken' | → | [kœy k] | 2;10.12 |

Fikkert and Levelt argue that at the early stage the child's grammar does not yet have a constraint against dorsal consonants. At this stage, all words in the child's productive lexicon have consonants agreeing in place of articulation, hence features are not yet aligned to specific consonants, but to words (10a). This is no longer the case at the next stage, when words with consonants differing in place of articulation appear. Clearly by now the constraint against initial dorsals (*[DORSAL]) has made its appearance in the child's grammar, as shown in (10b). At a later stage (10c), this markedness constraint is demoted on the basis of sufficient positive evidence (i.e., the existence of many dorsal-initial words in her lexicon). Thus, at least some markedness constraints emerge during the course of acquisition. Crucial in the analysis is the claim that at the initial stage of acquisition the child's representations is different from the target in the sense that they are not yet segmentized. The issue of how children acquire lexical representations and how much these may differ from the input forms they hear is an issue that has also been addressed in perception studies.

2.1.3. *Perception studies.* Research on speech perception has shown that infants and young children are excellent perceivers: they are able to

distinguish a wide array of — often subtle — contrasts in tasks that demand pure discrimination. Yet, there is also ample evidence that children are not such good perceivers if they have to distinguish meaningful contrasts, i.e., if lexical identification is at stake (see for overviews Jusczyk 1997, 1998; Boysson-Bardies 1999; Kuhl 2000; Gerken 2002; Fikkert 2007). This research makes clear that speech perception is not to be mistaken for linguistic identification. The former does not require lexical access and seems to be much more accurate or faithful than the latter, which accesses the lexicon, and, in fact, may be quite unfaithful. If perception can be unfaithful, then the model proposed by Smolensky sketched above in Section 1.2.3, in which perfect perception of target forms is assumed, is too simplistic.²¹ This is explicitly addressed in Pater (2004), Boersma (1997, 1998), and Boersma et al. (2003).

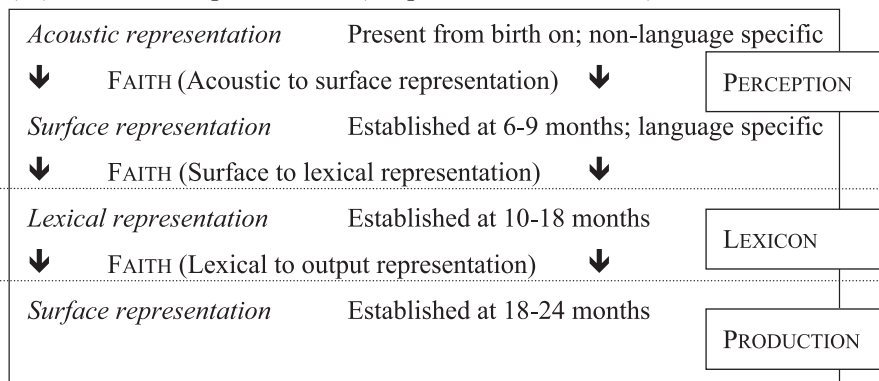
Both Boersma and Pater propose that the grammar, in particular the set of markedness constraints, also plays a role in perception; its role is to regulate the markedness of representations that are constructed on the basis of the acoustic signal. That is, the markedness constraints are the same for both perception and production, which accounts for why we find parallels in child perception and production. For example, Jusczyk et al. (1999) have shown that young infants do start segmenting iambic words, such as ‘guitar’, as ‘tar’, i.e., they initially do not parse the unstressed syllable. Similarly, at early stages of word production children do not produce initial unstressed syllables. Yet, at the time that children produce ‘tar’, they already have learned to segment the word correctly in word segmentation tasks. In other words, the phenomenon — ignoring initial unstressed syllables — occurs in both perception and production, but the time at which they do so differs in perception and production. Pater (2004) argues that while the markedness constraints are assumed to be the same for both perception and production, the faithfulness constraints differ: perception-specific faithfulness constraints are often ranked higher with respect to markedness constraints than the corresponding production-specific faithfulness constraints, which is why perception is often ahead of production. The grammar with the perception-specific faithfulness to lexical representations only starts playing a role once there is a lexicon, and thus representations to be faithful to. When children start building a lexicon, children’s initial lexical representations may be reduced in segmental complexity (markedness) compared to what they perceive. Evidence for such a model is taken from studies of early word perception.

The important study of Stager and Werker (1997) and secondals (see Pater et al. 2004 for an overview) shows that 14-month-old English learning children have no problem distinguishing between two similar

sounding nonce forms like *bih* and *dih* in a pure discrimination task, but they are unable to do so in a word-learning task. One interpretation of these results is that the word forms in the lexicon are less detailed than the ones perceived. This can be modeled by assuming that surface forms are input to the (perception) grammar and deliver optimal lexical forms as output. In this process, acoustic detail irrelevant for storage in the lexicon is ignored.²²

Pater (2004) addresses the fact that early perception of segmental contrasts (before 6–9 months) is not language specific. At this point in development, infants listen accurately to the acoustic signal and there is no language-specific grammar yet. From 6–10 months children prefer to listen to contrasts that their mother language employs over other contrasts; moreover, they are no longer able to perceive certain contrasts that are not part of their native language (Werker and Tees 1984). Hence, perception starts to be language-specific. Children are now able to ignore certain acoustic details in the signal. At this stage there are no lexical representations, yet. This implies that there must be a set of faithfulness constraints mediating between the acoustic signal and the surface representation, in which some information is abstracted away from in a language-specific way. When lexical representations appear, perception seems even less faithful, as we just saw, suggesting yet another set of faithfulness constraints mediating between surface and lexical representation. Production appears yet later, and as we saw above, children frequently violate faithfulness constraints in favor of markedness constraints in early word production. This step is expressed by the grammar, which is mediating between lexical representations and surface representations that now refer to children's own produced output forms. The model with the various levels of representation, along with relevant faithfulness constraints, as proposed by Pater (2004) is sketched in (11). The child starts out with just acoustic representations, and gradually the number of different representational levels increases. These levels correspond to different OT grammars. However, only the ranking of faithfulness constraints is different at different levels. The markedness constraints and their ranking remain constant at each level of the model during a particular developmental stage. In the course of development, constraints (including the markedness constraints) get reranked. When markedness constraints are reranked, this again applies to every level in (11). However, faithfulness constraints are re-ranked for each level separately. In (11), the approximate age at which the different representations appear in the child's system is indicated.

(11) Levels of representation (adapted from Pater 2004)



A question that is currently under debate in much of the psycholinguistic, phonetic, and phonological literature is how many levels of representations persist at different developmental stages towards the adult system, especially in perception, and how much detail is stored in the mental lexicon. Some argue that phonological representations are underspecified (e.g., Fikkert and Levelt 2008; Lahiri and Reetz 2002) while others argue for detailed phonetic representations in young learners' lexicons (e.g., Swingley and Aslin 2000, 2002; Werker et al. 2002). Some argue that the acoustic signal is mapped directly onto the stored lexical representation (Lahiri and Reetz 2002). Others argue that there are various intermediate representations, each with their own status in the model.²³ The combination of controlled experimentation and well-developed linguistic theories will undoubtedly shed more light on this issue in the future. For an elaborate discussion of the current state of affairs in phonological acquisition the reader is referred to Fikkert (2007) and Boersma and Levelt (2004). The next section will deal with OT accounts for acquisition studies in the domains of syntax and semantics.

2.2. Acquisition studies in OT syntax and semantics

OT is a formal theory of constraint interaction in language that is not restricted to the domain of phonology, but can be applied to syntax and semantics as well (see Legendre 2001; Ackema and de Hoop 2006 for two recent introductions of its application in syntax and Hendriks and de Hoop 2001 for the first application in semantics). As we have seen in the previous sections, in phonology both the input and the output are forms. In perception the acoustic signal is mapped onto a stored lexical

representation. In production, the direction is from stored lexical representation to an articulated production form. The constraints solve conflicts between the stored representation and the articulated form (in production) or the acoustic form (in perception). But, as pointed out in Blutner et al. (2006), if we consider other aspects of language such as its syntax or its semantics, the input and output to the process of optimization differ more dramatically. Because competing candidates are assumed to be semantically equivalent in OT syntax, the central question in OT syntax seems to be: Given a certain meaning, what is its optimal form? And in OT semantics, the relevant question must be: Given a certain form, what is its optimal interpretation? Thus, OT syntax can be seen as taking the point of view of the speaker, while OT semantics as taking the point of view of the hearer. A speaker wishes to convey a certain meaning (or intention) and evaluates the candidate expressions of this meaning against a set of ranked constraints. The optimal form is chosen by the speaker to express the input meaning. For a hearer, the direction of optimization is the other way around. A hearer hears (or reads) a certain utterance (a form) and evaluates the candidate interpretations of this meaning against a set of ranked constraints. In principle, the set of constraints can remain constant, although some constraints will only be activated in one direction of optimization and not in the other, in a similar way as we saw in 2.1.3. This may hold for markedness constraints (which penalize marked forms in OT syntax, and marked meanings in OT semantics), but also for faithfulness constraints (which may require a certain form to be mapped to a certain meaning, and/or the other way around).

As we have seen in the domain of OT phonology, an important assumption is that children, when learning their native language, have to learn the particular constraint ranking of their language. Once children have the relevant set of constraints at their disposal (whether these are innate or learned), the acquisition process is one of reranking constraints. Legendre et al. (2002) have provided an OT analysis of constraint reranking in the domain of syntax, which we discuss in 2.2.1, whereas Hendriks et al. (2005) provided evidence for constraint reranking in the acquisition of interpretation. We will briefly discuss the analysis of Hendriks et al. (2005) in 2.2.2 (see also Section 2.1.3 above).

2.2.1. *Production.* The process of child acquisition in syntax involves learning the relative rankings of the constraints. Legendre et al. (2002) propose that children at a certain stage may have a partial ordering of constraints, which explains not only the existence of particular child forms, but also the frequency with which these forms appear. This has not been extensively addressed in previous formal work on syntactic ac-

quisition. The analysis successfully predicts over three stages the frequency with which children use tensed, agreeing, and nonfinite verbs. Also, it is shown that tense and agreement inflection follow independent courses of acquisition in child French. Tense production starts and ends at near-adult levels, but suffers a “dip” in production at the intermediate stage, while agreement develops linearly. According to Legendre et al. this profile suggests an analysis in which tense and agreement compete at the intermediate stage. An example of a nonfinite root form is presented in (12):

- (12) *Ranger* *Christian*
 clean.up INF Christian
 ‘Christian cleans up.’
 (Grégoire 1;10.20)

An example of a form, which is fully marked for tense and agreement is given in (13):

- (13) *Et moi j’ai roulé sur moi la belle voiture.*
 and I I’ve run over me the beautiful car
 ‘I have run the beautiful car all over me.’
 (Grégoire 2;3.0)

The set of constraints that is used for the analysis consists of two markedness constraints, *F (No functional heads) and *F² (No pairs of functional heads, i.e., tense + agreement), and two faithfulness constraints, PARSE-T(ENSE) and PARSE-A(GREEMENT). There is a fixed ranking *F² >> *F and the faithfulness constraints ‘float’ over a certain range in the ranking. For example, if the ranking is *F² >> *F >> PARSE-T >> PARSE-A the output will be a nonfinite form, and if the ranking is *F² >> PARSE-T >> *F >> PARSE-A the output is a tensed form. The floating or partially ranked constraints allow the model to make frequency predictions. For example, at a certain stage in the acquisition process the child has the set of 12 total rankings:

- (14) Set of total rankings: STAGE 4B; Input = dance.1sg.PAST
- | | Output |
|--|-------------------------------------|
| 1. PARSE-T >> PARSE-A >> *F ² >> *F | j’ai dansé (= +tense
+agreement) |
| 2. PARSE-A >> PARSE-T >> *F ² >> *F | j’ai dansé |
| 3. *F ² >> *F >> PARSE-T >> PARSE-A | danser (= –tense
–agreement) |
| 4. *F ² >> *F >> PARSE-A >> PARSE-T | danser |
| 5. *F ² >> PARSE-A >> PARSE-T >> *F | je danse (= –tense
+agreement) |

6. $*F^2 \gg \text{PARSE-T} \gg \text{PARSE-A} \gg *F$ a dansé (= +tense
–agreement)
7. $\text{PARSE-A} \gg *F^2 \gg \text{PARSE-T} \gg *F$ je danse
8. $\text{PARSE-T} \gg *F^2 \gg \text{PARSE-A} \gg *F$ a dansé
9. $\text{PARSE-A} \gg *F^2 \gg *F \gg \text{PARSE-T}$ je danse
10. $\text{PARSE-T} \gg *F^2 \gg *F \gg \text{PARSE-A}$ a dansé
11. $*F^2 \gg \text{PARSE-A} \gg *F \gg \text{PARSE-T}$ je danse
12. $*F^2 \gg \text{PARSE-T} \gg *F \gg \text{PARSE-A}$ a dansé

The model now predicts the form *j'ai dansé* (+tense, +agreement) to occur in $2/12 = 17\%$ of the cases, whereas in the real data this form occurs in 19% of the cases (in stage 4B of the acquisition process). Thus, the analysis pits structural realization of tense features and agreement features (faithfulness constraints) against constraints on maximal complexity of syntactic structure (markedness constraints) and it predicts how often the verb is realized with or without tense and with or without agreement at a given stage of development. The acquisition process is one of reranking constraints, but in particular, this reranking occurs by spreading constraints across ranges in the rankings, narrowing in on the correct adult ranking.

2.2.2. Comprehension: constraint reranking. As was pointed out above, it is often (although not always, as shown in [10]) the case that children's phonological perception precedes their production of a given form. Also, it is often assumed that children's comprehension of a form (understanding the meaning) precedes their production of it. However, there are cases where correct comprehension lags behind correct production. Here we will discuss one such case.

A remarkable delay in comprehension has been found with word order in early two- and three-word utterances in English. In an experiment with 15 young children (1;8–2;8), Chapman and Miller (1975) found that in production these children use the canonical subject-verb-object order. Their mean correct response when they saw an action with an animate subject and object was 83.7%. For example, they would say “boy hit girl”, “hit girl” or “boy hit”, but rarely “girl hit boy” or “hit boy”, after having watched a scene where a boy doll hits a girl doll. However, these same children, when tested on the same type of sentences in a comprehension experiment, significantly less often used word order information as a cue to subject-object status. Instead, they used the animacy of the arguments as an important cue in understanding a transitive sentence. When interpreting a sentence such as (15), their mean correct response was only 66.5%.

(15) *The boy is hitting the girl.*

When hearing (15), children frequently interpret this as ‘the girl is hitting the boy’ instead of the other way around. Apparently, for a young child this sentence can mean both ‘boy hit girl’ and ‘girl hit boy’. The problem with sentence (15) is that both arguments (the subject and the object) are animate. Generally, in the languages of the world, subjects are often animate while objects are often inanimate. Indeed, when the subject is animate and the object is inanimate, as in (16c) below, the children performed much better, while their performance was worse with sentences such as (16b) below with an inanimate subject and an animate object. Several off-line and online experiments in Dutch and English have proven that besides word order, animacy is an important source of information in the comprehension process. For instance, McDonald (1987) compared the validity of different cues in choosing the subject of transitive sentences and relative clauses. Experiments in which subjects had to assign the agent role after listening to a sentence showed that, in Dutch, animacy was a better cue than word order, whereas, in English, the reverse was the case. Lindner (2003) found that German-learning children use animacy as a cue for interpretation before they learn to use grammatical markers such as case and agreement. The results of Chapman and Miller (1975) show that also for English children animacy is an important cue for interpreting of a transitive sentence.

In principle, for each sentence in (16) below, there are two candidate interpretations, a subject-before-object (SO) and an object-before-subject (OS) interpretation.

- | | | | | |
|------|----|------------------------------|----------------------|---------|
| (16) | a. | The boy is hitting the girl. | [+animate; +animate] | SO / OS |
| | b. | The car is hitting the boy. | [−animate; +animate] | SO / OS |
| | c. | The girl is hitting the car. | [+animate; −animate] | SO / OS |
| | d. | The car is hitting the boat. | [−animate; −animate] | SO / OS |

Adults invariably arrive at the SO interpretation as the optimal interpretation, irrespective of the animacy properties of the arguments, thereby providing evidence for the strict dominance of the word order constraint PRECEDENCE which requires the subject to precede the object, over ANIMACY which favors an animate subject (cf. de Hoop and Lamers, 2006):

(17) Adult grammar: PRECEDENCE » ANIMACY

For young children, the ranking is not so clear yet. Suppose children have PRECEDENCE outranked by ANIMACY, then for them animacy would be a more important cue than word order in determining the interpretation of a sentence with a subject and an object. In other words, when children

have ANIMACY high ranked, we expect them to have the least problems in the correct understanding of a sentence with an animate subject and an inanimate object and the most problems when it is the other way around. Chapman and Miller indeed found this pattern in comprehension, with children performing best (93.8%) on sentences like (16c), intermediate (66.5% and 65.2%, respectively) on sentences like (16a) and (16d), and worst (50.1%) on sentences like (16b).

Hendriks et al. (2005) claim that production can be modeled with the same two constraints as comprehension. However, in production, the animacy of the subject and the object (the agent and the patient) is already given in the input (as part of the meaning the child wants to express) and therefore does not contribute to the optimization of the form. The only constraint that plays a role in production therefore is the pure word order constraint PRECEDENCE, which requires the subject to precede the object. Irrespective of their ranking, the two constraints ANIMACY and PRECEDENCE predict that children produce the order in which the subject precedes the object word (see Section 1.3 above). This prediction is borne out. All children, also those who have not learned the right ranking of the two constraints yet (in comprehension), perform (almost) adultlike in the production experiment. Similarly, Lindner (2003) found that German children correctly use subject-verb agreement in production around 2;6 but they seem to understand it only by the age of 5 years.

Thus, even with the same set of constraints and the same ranking of these constraints in the child's grammar, the different directions of optimization (from meaning to form or from form to meaning) can yield different outcomes in how well children perform. If children indeed use the same grammar both for production and comprehension, then the different directions of optimization may explain cases where comprehension lags behind production (as in the experiment discussed here) or *vice versa*.

In addition to constraint reranking, we will argue that language acquisition requires an extra step. Children have to learn to optimize not only from form to meaning or the other way around (unidirectional optimization), but from form to meaning and from meaning to form *simultaneously* (bidirectional optimization, cf. Blutner 2000). Children have to learn to take into account the perspective of the hearer when they are speaking and the perspective of the speaker when they are interpreting. The bidirectional optimality theoretic approach to language acquisition that will be presented in Section 2.2.3 allows us to answer the question why children sometimes acquire adultlike interpretations at such a late age, even when they seem to have acquired the grammatical rules that allow them to produce the forms correctly at a much earlier stage. We argue that these instantiations of "late acquisition of interpretation" con-

form to a general pattern: children choose the “unmarked” (more frequent, less complex) interpretation both for “unmarked” as well as for “marked” forms. While adults will deviate from this pattern when needed, children aged 4 to 11 often fail to do so. In the next section, we will see that adults, who optimize bidirectionally, assign a marked, i.e., suboptimal, meaning, to a marked, i.e., suboptimal, form. Children, however, assign the unmarked meaning to both the marked and the unmarked form, as this meaning violates the fewest constraints. The cause for children’s failure to employ bidirectional optimization may lie in the cognitive demands of bidirectional optimization, which forces the language user to simultaneously take both hearer and speaker perspective into account. That is, adults are able to reason (unconsciously) about the speaker’s alternatives when interpreting a sentence: the speaker must mean *A* when he utters *A*, because if he meant *B*, he would have said *B*. By contrast, children as long as they only optimize in one direction (as a hearer when comprehending, and as a speaker when producing) can interpret *A* as *B* if *B* is the optimal interpretation both for *A* and *B*. They do not take into consideration the fact that the speaker should have used *B* to express *B*. Although this may play a minor role in phonology too, this is much more important in the domain of syntax and semantics.

2.2.3. *Production and comprehension: bidirectionality.* As has been observed in the literature, delays in correct comprehension are not restricted to the early stages of language acquisition, as in the experiment discussed in Section 2.2.2 above. In Dutch for example, indefinite objects can occur either to the right or to the left of a sentential adverb. These two positions are associated with two different interpretations of the indefinite object, which can be labeled the referential (18a) and nonreferential (18b) reading.

- (18) a. *Je mag een potje twee keer omdraaien*
 you may a pot two time around-turn
 ‘You may turn a pot around twice.’
 b. *Je mag twee keer een potje omdraaien.*
 you may two time a pot around-turn
 ‘You may turn a pot around twice.’

Note that the position to the right of the adverb in (18b) is the canonical (unmarked and most frequent) position for the indefinite object in Dutch. For adults, the marked position (to the left of the adverb, as in [18a]) is associated with the marked (referential) reading of the indefinite object. However, Krämer (2000) discovered that most children below age 7 do not make this association yet and interpret the indefinite object

nonreferentially in both positions. Hence, whereas an adult will turn around one pot twice upon hearing sentence (18a), and two different pots when they hear (18b), children will turn two different pots in both cases. This follows the crosslinguistic generalization that subjects are usually referential, while objects are usually nonreferential. De Hoop and Krämer (2006) hypothesize that children optimize unidirectionally while adults optimize bidirectionally. That is, children choose the optimal (unmarked) meaning of the indefinite object, independent of its position, and are not yet capable of taking into account the speaker's perspective. By contrast, adults know that the speaker could have chosen the unmarked position to express the unmarked meaning. Hence, if a speaker instead chooses to put the indefinite object in the marked position to the left of the adverb, this means that the speaker wants to express the marked (referential) reading for the object.

A similar case for late comprehension that results from children's incapability to optimize bidirectionally is presented in Hendriks and Spenader (2006). Several studies have shown that children interpret pronouns such as *him* incorrectly as referring to the subject half of the time. Consider the following sentences:

- (19) a. *Bert is washing him.*
 b. *Bert is washing himself*

While adults can only interpret *him* in (19a) as referring to *somebody else than Bert*, children can get a coreferential reading of the pronoun *him* such that it refers to *Bert*. Hendriks and Spenader (2006) argue that for adults coreference between the pronoun *him* and the subject *Bert* is blocked by bidirectional optimization. That is, an adult hearer will draw the conclusion that coreference is not possible because there is a better form to express coreference, namely *himself*, as in (19b). Notoriously, children until the age of 6 to 7 allow *him* to denote coreference as well, displaying the so-called "pronoun interpretation problem" (e.g., Chien and Wexler 1990; Grimshaw and Rosen, 1990).

For their analysis, Hendriks and Spenader use PRINCIPLE A, a faithfulness constraint which interacts with REFERENTIAL ECONOMY, a markedness constraint (Burzio 1998). In their most basic form they can be formulated as follows:

- (20) PRINCIPLE A: A reflexive must be coreferential (bound locally).
 (21) REFERENTIAL ECONOMY: Avoid pronouns.

The second constraint is radically simplified for the purpose of the present discussion and may seem a bit ad hoc therefore, but it actually involves a markedness hierarchy reflecting the view that expressions with less refer-

ential content are preferred over expressions with more referential content (Burzio 1998). Because Burzio considers reflexives to have no inherent referential content, while pronouns have some, the effect of this constraint subhierarchy is that reflexives are preferred to pronouns. Thus, for our discussion it suffices to formulate the constraint simply as in (21). If we now consider a reflexive and a pronoun, respectively, and we evaluate the candidate interpretations against the two constraints, we observe that unidirectional optimization yields the right optimal interpretation for a reflexive (namely, the coreferential reading), but it gives us two optimal interpretations for a pronoun (the coreferential as well as the disjoint reading). This is illustrated in the following tableaux:

(22) a. Interpretation of *himself*

Input: Bert washes himself.	<i>Faithfulness</i>	<i>Markedness</i>
Output candidates	PRINCIPLE A	REFERENTIAL ECONOMY
☞ coreferential (himself = Bert)		*
disjoint (himself = Ernie)	*!	*

b. Interpretation of *him*

Input: Bert washes him.	<i>Faithfulness</i>	<i>Markedness</i>
Output candidates	PRINCIPLE A	REFERENTIAL ECONOMY
☞ him = Bert		*
☞ him = Ernie		*

For children, object pronouns are ambiguous between a coreferential and a disjoint reading. This behavior is expected under the assumption that children optimize in one direction only, either from form to meaning [as in 22]) or from meaning to form. By contrast, adults not only adopt the hearer's perspective in comprehension, but simultaneously take into account the speaker's alternatives. If the speaker wants to express a coreferential reading, then the reflexive *himself*, would be the optimal form for this meaning. Because there is a better form to express coreferentiality, the use of a pronoun for this reading is blocked.

In other words, adults bidirectionally compute optimal pairs of forms and meanings. An indefinite object to the left of a sentential adverb in

Dutch gets a referential reading, and a pronominal object gets a disjoint reading, simply because the nonreferential reading is best expressed by an indefinite object to the right of an adverb in Dutch, and a coreferential reading is optimally expressed by a reflexive form. Adults link unmarked forms to unmarked meanings, and marked forms to marked meanings. But children, at least until the age of six, optimize in one direction only, either from form to meaning, or from meaning to form. In order to become adultlike in comprehension, children have to learn to take into account the speaker’s perspective as well.

Hendriks and Spenader’s analysis also predicts that although children acquire the interpretation of pronouns only late, they produce them correctly, because optimizing from meaning to form, the interaction of the two constraints yields the pronoun for the disjoint meaning, and the reflexive for the coreferential meaning, as illustrated in the following two tableaux:

(23) a. Production of *himself*

Input: Bert washes Bert (coreferential meaning)	<i>Faithfulness</i>	<i>Markedness</i>
Output candidates	PRINCIPLE A	REFERENTIAL ECONOMY
☞ Bert washes himself.		
Bert washes him.		*!

b. Production of *him*

Input: Bert washes Ernie (disjoint meaning)	<i>Faithfulness</i>	<i>Markedness</i>
Output candidates	PRINCIPLE A	REFERENTIAL ECONOMY
Bert washes himself.	*!	
☞ Bert washes him.		*

On the basis of the outcomes of unidirectional optimization, it is predicted that children will produce both reflexives and pronouns correctly. Indeed, recent work supports this prediction (de Villiers et al. 2007; Spenader et al. 2006).

In this section we discussed the recent hypothesis by de Hoop and Krämer (2006) and Hendriks and Spenader (2006) that children only optimize unidirectionally. This means that when they interpret a certain form, they only take the hearer's perspective, which explains the non-adult like interpretations of certain forms, such as indefinite readings for scrambled objects and coreferential readings for pronominal objects. Recently, van Hout (2007) has given a similar analysis for another delay in comprehension: the acquisition pattern of the aspectual meanings of past tense forms in Dutch.

3. Summary of similarities and differences of various approaches to OT

After the exposition of phonological, syntactic and semantic acquisition, we turn to the common properties of OT with respect to language acquisition in 3.1, while in 3.2 we make some critical remarks.

3.1. Commonalities in OT acquisition research

First, there are a number of basic assumptions in OT, which are uncontroversial in all OT approaches to language acquisition:

- A grammar consists of a set of constraints that are ordered in a language-specific way.
- Markedness constraints aim at avoiding marked structures, and are neutralizing contrasts, while faithfulness constraints aim at minimizing the difference between input and output form, and induce contrasts in the grammar. Hence, markedness and faithfulness are usually in conflict.
- In an early (initial) state of acquisition markedness constraints outrank faithfulness constraints ($M \gg F$).
- Learning involves constraint reranking.

OT is a framework that is embraced by many different views on linguistics, already within the subdomain of phonology. For example, OT is used by phonologists assuming that phonology is abstract and symbolic, as well as by phonologists that assume that phonology is grounded in phonetics and is usage based. In OT syntax too, some have argued for functional constraints to account for typological patterns, while others adhere more to abstract constraints.²⁴ Some argue that the grammar should reflect frequency of linguistic patterns, while others argue that frequency is a matter of the lexicon, not of the grammar. Consequently, there is disagreement in both the nature of the constraints (gradient, functional and/or universal), as well as their source (innate, functional or

emergent). There is also fundamental disagreement on the nature of what exactly is stored in the mental lexicon, opinions ranging from very detailed to very basic (abstract) representations. Yet, the vocabulary used to express constraints, constraint interaction and violations is shared by all approaches to OT.

3.2. *Differences among OT approaches*

The various OT approaches all assume that language learning entails the (re)ranking of constraints, but differ in the way constraint reranking is accomplished. Learning can result in an instantaneous change in the ranking of constraints, or can be more gradual, in which case the relevant markedness and faithfulness constraints move closer towards each other, but do not necessarily result in a reranking of the constraints, or are even unranked, i.e., constraints are floating at a particular stages, giving rise to variation.

Initially, OT was implicitly designed to model production: a generator takes an input (underlying representation) and delivers a set of outputs, while the evaluator is evaluating the outputs given the grammar (the language specific constraint ranking) and delivers an optimal output form. There have been attempts to extend the model to also account for perception, although they have not received sufficient attention. While in laboratory phonology and psycholinguistics the assumption of prelexical representations (that are in between the acoustic input and the stored representation) is fairly standard, in OT phonology most researchers still assume a single mapping from input (stored representation) to output (surface form). In phonology, the raw acoustic input is ultimately mapped onto an optimal underlying representation (possibly via one or more intermediate surface representations): the output of the perception grammar. In semantics, the form of the sentence has to be mapped onto a semantic interpretation. There is ample evidence that perception is also guided by the grammar. And nowadays OT is not only applied to phonological interpretation, but to semantic interpretation as well.

The question is whether the same grammar is used for production as for perception and comprehension. Here opinions differ: some argue that the same grammar is at stake (Smolensky 1996), others argue that the grammars for perception and production only differ in the faithfulness constraints, i.e., that there are perception-specific faithfulness constraints (Pater 2004). Under this assumption, if perception changes the grammar, it only affects the perception-specific and production-specific faithfulness constraints, but the markedness constraints do not differ for perception

and production. Changes in the ranking of markedness constraints are still essentially error driven, i.e., they occur when children “know” that their own output forms differ from the target forms, and how they differ. The changes involve the demotion of markedness constraints, gradually or not. Yet others have argued that there is a different grammar for perception and production (Boersma 1998).

4. Future development

In this final section we speculate on further developments within OT and their consequences for acquisition. With so little conformity in OT, naturally, acquisition and learning do not receive a unified explanation either. However, all OT approaches assign a central role to markedness, as it is built into the grammar. As the initial state favors neutralizations to the unmarked, markedness also plays a key role in acquisition. Hence, much future work in acquisition is likely to focus on the nature and ontology of markedness constraints.

One of the main challenges is to account for why acquisition is so slow in phonology and involves so many “errors”. Despite the fact that children have been shown to be great statistical learners, and their discrimination abilities are excellent, it takes them quite some time to acquire certain statistically significant patterns in the phonological system of their language. A child acquiring English has heard many instances of dorsal initial words, as they appear, for instance, in the very frequent words *can*, *go*, *car* and *cat*. There is thus ample evidence for the setting $\text{IDENT}_{\text{dorsal}} \gg *[\text{dorsal}]$. That is, faithfully producing dorsals should outrank the ban on initial dorsals. Yet, the process of fronting, which causes dorsals to be replaced by coronals, remains active for quite some time in the phonology of many children (Morissette et al. 2003). To complicate factors, while dorsal-initial words may regularly undergo fronting in early child language, other initial consonants (in particular coronals) often show up as dorsal consonants in the process of Consonant harmony. In Consonant harmony dorsals are preferred in initial position, as regressive harmony of dorsal features seems to be the unmarked case of consonant harmony in English (cf. [9], Pater and Werle 2003). This shows that it is important to look beyond explaining a single process in acquisition, and to consider the developing system as a whole, as far as feasible (cf. Fikkert and Levelt 2008).

Another topic for future investigating is the division of labor between grammar and lexicon, particularly in acquisition: if certain output forms are the result of grammar, it is expected that new forms also show the

same grammatical effects. However, if a particular output is due to mis- or underrepresentation of certain words, the effect may only be found in those particular lexical items, but not others. This is an empirical issue that must be further investigated. With the rise of OT, the structure of the output has been much more in focus than the structure of stored phonological representations, yet the combined evidence from child language perception and production necessitates more detailed research into how representations get stored in a developing lexicon — both with respect to the nature of representations, as to the levels of representation needed.

Another issue is whether perception always precedes production or whether there are cases in which the opposite is true. Particularly in the area of syntax/semantics both situations can be found, and this may well be the case for phonology too.²⁵ Van der Feest and Fikkert (2005) and van der Feest (2007) tested the relation between perception and production in 20- and 24-month-olds and showed that the asymmetries in the production of place of articulation features and voicing show up in perception as well. Moreover, they appear around the same time, questioning the correctness of assuming separate faithfulness constraints for perception mediating between surface and lexical form. Studies like these suggest that phonological representations may indeed be abstract, and hence that mismatches may occur between the input to the perception (i.e., the acoustic signal) and the output (the stored abstract representation), but more evidence is needed from different languages, different paradigms, etc.

Section 2.2 showed a number of studies from the syntax-semantics interface where, during language acquisition, production precedes comprehension. Hendriks et al. (2005) show that the role of grammar in production can be different from the role of the grammar in comprehension. This does not mean that there are two grammars; rather it indicates that there are two directions of optimization: from meaning to form (production) or from form to meaning (comprehension). In addition, several recent studies have argued that while adults combine both directions of optimization, children until the age of six or seven have not acquired that ability yet (de Hoop and Krämer 2006; Hendriks and Spenader 2006; van Hout 2007). That is, adult hearers take into account the alternative forms the speaker could have used but chose not to. The evidence from syntax and semantics indicate that children not only need to learn how to match form (sentences) to meaning (in perception), and meaning to form (in production), they also need to do both at the same time to produce listener-oriented forms, and to perceive in such a way that they are able to take the perspective of the speaker into account. This is essen-

tial in effective communication. Thus, constraint reranking is not sufficient to explain what children must learn in order to become adultlike in their use of language. Note that because bidirectional optimization requires awareness of their conversational partner's choices, a theory of mind which children are assumed to acquire around age 5, seems to be a prerequisite for making the transition (Hendriks and Spenader 2006).

Juszyk et al. (2002) and Davidson et al. (2004) set out to empirically test some of the claims made on the basis of learnability considerations. They tested the correctness of the principle of richness of the base and the assumption that the initial state is $M \gg F$, by using a head-turn preference paradigm. Their results show that 4½-month old infants show evidence for the $M \gg F$ order. At this age children have not shown to be sensitive yet to language-specific patterns in the input. Hence, their behavior must reflect universal grammar. Although perception studies of this kind (with prelinguistic children) are rare in phonology and essentially nonexistent in syntax, this is an interesting approach to test the theoretical underpinnings of OT.

The principle of richness of the base ensures that the language user's intuitions are expressed in the grammar. It states that languages cannot place restrictions on what possible lexical items are. Hence, the grammar cannot arise by way of making generalizations over the lexical forms, because they are the consequence of constraint ranking (and must exist before representations). Yet, others have argued that grammars are generalizations over the lexicon. This issue needs further exploration. The principle of richness of the base is also necessary to account for loan word adaptation: loans that do not conform to the grammatical structure of the borrowing language, i.e., when the donor language allows for more marked structures, often are not realized faithfully, but undergo changes in the direction of the native grammar. Both in child phonology and loan phonology language users resort to less marked structures than evidenced in the target they are attempting. However, there is an important difference between adaptations in child language and adaptations in loan phonology: while children often are unfaithful to the targets by not producing all input segments or features, which typically result in MAX-IO violations, in loan phonology speakers often try to be as faithful as possible to the target and avoid deleting any material from the input; rather, they parse all features, but insert material to avoid markedness violations, typically causing DEP-IO violations. This suggests that Faithfulness constraints in the initial state favor DEP-IO \gg MAX-IO in first language acquisition, but MAX-IO \gg DEP-IO in many cases of loan word phonology. If this is indeed the case, we expect such differences to also show up in first versus second or foreign language acquisition. Additional evidence

for some of the learnability claims in OT are therefore likely to come from the comparison between L1 and L2 acquisition and loan phonology.

Similar arguments have been used in historical change (e.g., McMahon 2000). Here OT can be addressed from several angles. On the assumption that change originates in first language acquisition due to imperfect learning (Paul 1970[1890]), we expect to find changes to go into the direction of the unmarked, as has also been the traditional claim in much early work on change (e.g., Kiparsky 1968). However, others have argued that change is rooted in second/foreign language acquisition due to language contact (see papers in DeGraff 1999). As in the case of loan phonology discussed above, change is predicted to go into the direction of the unmarked as well. Both views on the origin of change might have different implications when we take a closer look at how markedness is resolved, for instance by MAX-IO (L1) or by DEP-IO (L2) violations?

Yet, we know that many changes cannot be viewed as solely reducing markedness at one particular level, and even if this is the case, it often has consequences for the language system as a whole, including morphological and morphophonological regularities. For instance, the deletion of a marked segment may lead to more marked prosodic structures, or to more marked morphological systems. This is true for language change, and also for language acquisition. The challenge is to discover how changes or development in different components of the grammar effect the language system as a whole, in what ways conflicts are resolved, which factors drive change, and how a grammar reaches a relatively steady state. We have a long way to go before we can answer these questions. However, OT has provided us with a way of modeling interactions at different levels.

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1. For an elaborate discussion of the current state of affairs in phonological acquisition the reader is referred to Fikkert (2007) and Boersma and Levelt (2004).

2. Learning models for stress are the exception. For example, Dresher and Kaye (1990) explicitly assume continuity, as the metrical principles and parameters were assumed to be innate. Moreover, metrical parameters in UG come with a default setting and a learning cue. In the acquisition of syntax the issue of continuity is a hallmark of many principles-and-parameter approaches to language acquisition (Macnamara 1982; Pinker 1984).
3. There are a number of good overview articles or books: Kager (1999) and McCarthy (2002, 2007) for phonology and Legendre (2001) for syntax.
4. The universality of constraints does not necessarily mean that constraints are innate (Smolensky 2006: Note 8). Nor does it mean that when constraints appear/emerge in the course of development they are language-specific: they could very well be universal.
5. Universal constraints need not be innate, but may also be universally induced (Tesar and Smolensky 2000). In “classical” OT many constraints are also functional (such as the sonority-based constraints), but they do not necessarily need to be.
6. Fikkert and Levelt (2008) argue that new phenomena often appear in the child’s output when new constraints have emerged, and may lead to instances of U-shaped development.
7. Hayes (2004) argues for an initial state where $M \gg F$ for the “ordinary” constraints, but for high faithfulness in Output-Output constraints, ensuring that morphophonological alternations do not disturb early learning. See also the discussion on consonant harmony in Pater (1997).
8. The fact that children’s forms often differ systematically from the target forms in ways that cannot easily be accounted for on grounds of an immature articulatory apparatus, also makes this view unlikely for phonology.
9. Not everyone assumes error-driven learning. In some models learning is driven by the statistics of the input, i.e., it is lexicon driven (for example, in Boersma’s 1998 gradual learning model).
10. A reviewer stated that it is clearly not assumed that children have access to adult underlying representations, but that their production map goes from the adult surface representation to their own reduced form. We fully agree. Nevertheless, in the literature on phonological acquisition, the implicit assumption is that the input to the child’s grammar is very similar to the input to the adult system.
11. This is true until allomorphic variation is learned, as this may lead to restructuring of input representations (see, for instance, Hayes 2004). This seems to be a fairly late process and is not often investigated in actual child language acquisition (but see Bernhard and Stemberger 1998; Kerkhoff 2004, 2007; Fikkert and Freitas 2006; Zamuner et al. submitted).
12. This issue is currently addressed in research on morphological (optimal) paradigms and the treatment of exceptions in phonology. Some argue that grammar has essentially nothing to do with the lexicon (Kager 2008); others argue that both are tightly linked and that constraints mirror the lexicon (Pierrehumbert 2003).
13. As far as we know no language ever uses syllable structure contrastively. Stress, however, can be contrastive, such as in English *abstráct* (verb) — *ábstract* (noun). Moreover, stress is lexical in some languages. However, even if stress is lexical, foot structure need not be stored in the lexicon. On the assumption of the principle of richness of the base there is nothing preventing predictable structure in the underlying representation, though, and some researchers claim that reference to prosodic structure is necessary (see for discussion Pater 2004; Tesar and Smolensky 2000; Boersma and Levelt 2004).

14. They ignored vowel length and did not include syllables in which the sonority sequence generalization was not obeyed, i.e., syllables starting with /s/-obstruent-clusters were ignored.
15. NoCOMPLEX is shorthand for NoCOMPLEXONSET (no complex onsets are allowed) and NoCOMPLEXCODA (no complex codas are allowed).
16. Here, FAITH generalizes over both MAX-IO and DEP-IO.
17. Similar problems arose in Principles and Parameters account of acquisition of syllable structure (see Fikkert 1994).
18. Other examples that are more difficult to grasp — even when invoking constraint conjunction — are the following: liquids are allowed in onsets, but only in the weak branch of a complex onset, not as singletons (Fikkert 1994), or fricatives are allowed in onsets, but only in complex onsets; in simplex onsets they are realized as glides (Waterson 1971).
19. The French data are based on Dauer (1983), the European Portuguese data on d'Andrade and Viana (1994).
20. Interestingly, in French the development depended also on position: word-initial syllables followed the path CV > V > CCV, while word-final (stressed) syllables followed the path CV > V > CVC (Fikkert et al. 2004).
21. But if perception is faithful and input representations are adultlike, and if the grammar is acquired in perception prior to production, the explanation for deviating production data must lie outside the grammar and the lexicon, and can only be due to performance constraints (underdeveloped articulatory system or restricted memory) (Hale and Reiss 1998). Yet, this does not explain the fact that the processes in perception and production often look very similar. In fact, this would be sheer coincidence.
22. For an elaborate discussion about the word learning experiments and their significance for lexical representations see Werker et al. (2002) and Fikkert (to appear).
23. Fitzpatrick and Wheeldon (2000) provides a comprehensive overview of representations in perception (in adults).
24. In the domain of syntax, functional typological analyses, especially those dealing with “competing motivations” (Du Bois 1985), are perfectly compatible with optimality theory. While OT syntax is already known to be fit for typological analysis, recently the use of bidirectional OT has been discovered to account for typological data, in particular see de Swart (2006) for an account on negation and de Hoop and Malchukov (2007) on case-marking patterns.
25. The example of the U-shaped development in (10) actually may present such a case: the child is producing dorsals initially, but may not have perceived dorsal as a feature of the word-initial consonant, but rather as feature of the word, in which case (10a) presents an example in which production precedes perception. See also Fikkert et al. (2005b) and Fikkert (to appear) for experimental results indicating that this may indeed be the case.

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