

Modeling children's early grammatical knowledge

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Theories of grammatical development differ in how much abstract knowledge they attribute to young children. Here, we report a series of experiments using a computational model to evaluate the explanatory power of child grammars based not on abstract rules but on concrete words and phrases and some local abstractions associated with these words and phrases. We use a Bayesian procedure to extract such item-based grammars from transcriptions of 28+ h of each of two children's speech at 2 and 3 years of age. We then use these grammars to parse all of the unique multiword utterances from transcriptions of separate recordings of these same children at each of the two ages. We found that at 2 years of age such a model had good coverage and predictive fit, with the children showing radically limited productivity. Furthermore, adding expert-annotated parts of speech to the induction procedure had little effect on coverage, with the exception of the category of noun. At age 3, the children's productivity sharply increased and the addition of a verb and a noun category markedly improved the model's performance.

Bayesian unsupervised grammar induction | language acquisition | usage-based approach

Most children produce their first multiword utterances at ≈ 18 months of age. Their earliest productions usually consist of imitated speech acts, such as *Lemme-see* or *Where-the-bottle* or *Birdie*. Such utterances are grounded in social scenarios that the child will have played out many times; hence, their function is simple and presumably relatively straightforward for the child to determine. Successful participation in social life, however, requires a far more diverse range of communicative acts in which the child puts together bits of language creatively in novel utterances to produce a wide array of meanings.

What happens over the next few years is a topic of fierce dispute. Early work tracked children's emerging generalizations by using observational data, often proposing simple rules by which children recombine familiar words and phrases (1). However, such work fell from favor with the arrival of generative grammar and the proposal that children's multiword productions are possible not because of learning but rather because of innate categories and rules, a so-called universal grammar (UG) (2). The UG hypothesis has fallen in popularity in recent years, with even Chomsky and coworkers (3) arguing that the only innate component of language is the ability to build recursive structures. Nonetheless what has remained is a bias for thinking about the child's linguistic knowledge in terms of abstract categories and rules.

A number of researchers have recently challenged this assumption. They have argued that to assume continuity between child and adult language preempirically is inappropriate. Studies using databases of real usage have shown that children's speech for at least the first 2 years of speech is actually remarkably restricted, with certain constructions produced with only a small set of frequent verbs (4) and a large number of utterances being built from lexically specific frames (e.g., refs. 5–7). These data have been supported by a substantial body of experimental work (e.g., refs. 8–11). The account of language development supported by such work is that a child's progress to linguistic productivity is gradual, starting with knowledge of specific items and restricted abstraction (e.g., refs. 12 and 13), rather than general categories and rules.

Although the evidence supporting this view is strong, it tends to be isolated to a construction here or an utterance frame there. What any theory of language development needs is an evaluation that tests whether it can account for child speech in general. In this article we carry out just such an experiment. We present a computational procedure that we use to extract grammars from ≈ 28 h of a child's speech. The grammars consist of lexically specific constructions and contain no fully abstract rules. We use these grammars to parse up to 2 h of the child's subsequent productions. We measure the coverage and the predictive fit of the models and compare them with fully abstract grammars. We then evaluate the explanatory value of adding different kinds of categorical information to our grammars at different points in development.

Our Grammars

As in cognitive grammar (14), construction grammar (13), and similarly to related frameworks [e.g., head-driven phrase structure grammar (HPSG) (15)], the usage-based approach assumes a continuum from concrete pieces of language such as words or set formulas to more abstract constructions, in that they are all symbols that are meaningful in the same way. For convenience we will borrow a convention from HPSG and refer to all as signs. A first kind of sign (a concrete sign) could be a single word like *drink*, a whole utterance such as *I want a drink* or a part utterance like *want a drink*. The second kind of sign consists of some concrete speech of any length and any number of slots into which material can be put. We will refer to this latter variety as schemas. These signs are lexically specific in that they are built around specific words. However, they are assumed to cluster together into groups of similar items, equivalent to basic semantic categories. These groups constrain the ways in which the signs can be combined. So using the example categories of referent, process, and attribute (16), example signs might be *Mummy PROCESS* or *I want REF* or *ATT ball* or *PROCESS a REF*.

Such an approach may seem a far cry from generative models of grammar. It does not assume the word to be the principal symbolic unit or compositionality to be the default case. However, the grammars we propose are formally equivalent to context-free grammars (CFGs), which Chomsky (17) recognized as the minimal power necessary to account for most human languages including English. Some possible productions are shown in Fig. 1. A speaker can produce an utterance in a number of ways. They may simply produce a formula that has been entered into the grammar as a concrete sign, as in Fig. 1A. However, they might also combine schemas with concrete signs. Either concrete signs or schemas can go into slots of other signs, allowing fully hierarchical utterances (an operation we refer to as insert). The nonadjacent dependency seen in Fig. 1B requires more power than a finite-state grammar.

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agrees with experimental findings. For example, ref. 9 showed that children at 23 months are able to use novel nouns as arguments of familiar verbs that they had not seen them used with before, suggesting that they are able to infer the behavior of new items based on their similarity to seen items. The findings for verbs also agree to some extent with experimental findings. For Brian the addition of a verb category has almost no effect at 2 years, suggesting little generalization of knowledge across forms. Ref. 8 found that children at 25 months were not productive in their use of eight novel verbs learned over a several-week period, using them only in the constructions with which they had encountered them. However, experimental results reflect average development and some children showed greater competence. Similarly the more precocious Annie shows effects of all of the three parts of speech we tested for at both 2 and 3 years. It is important to note that our choice of categories here is very coarse. It seems unlikely that children jump from having no notion of verbs or nouns as classes of items to fully general categories. The improvement in coverage we see when adding categories could perhaps be produced by positing far narrower categories. So we should temper our claims to say that the impact of abstraction that we find suggests that neither child's knowledge of the set of nouns they use is entirely lexically specific at age 2, and the same for verbs at age 3.

Discussion

According to the usage-based account, a child's knowledge of language builds up slowly, beginning with fully concrete speech acts acquired by direct imitation, progressing to a productive competence with constructions but one that is still for the most part specific to particular words or sequences of words, before they are able to infer how to generalize appropriately and display the kind of category-based productivity that characterizes adult speech. In Exp. 1 we found that, at 2 years, lexically specific grammars inferred from only 26–28 h of the speech of two children were able to perspicuously account for their later productions and had high predictive value (low perplexity) relative to a fully abstract PCFG. In Exp. 2 we found evidence that the grammars did capture something of the children's specific knowledge states. In Exp. 3, we found that the addition of a noun category improved the coverage of the grammars for both children at age 2, whereas the addition of knowledge of verbs had limited explanatory value. We found that the grammars at age 3 offered a less perspicuous account of the data. It

was clear from the complexity of the analyses that, for the advanced Annie, speech has moved far beyond simple formulaic schemas. And furthermore we found that for Brian at age 3, for whom the lexically specific grammars still gave a reasonably perspicuous account of the data, the addition of a verb category also had a significant impact on coverage. Overall, this finding that early in development children's speech can be accounted for as effectively with generalization over only nouns as with additional generalization over verbs, whereas later in development wider generalization (although perhaps not so wide as used here) is needed to achieve the widest coverage supports a usage-based account of development.

It is important to acknowledge the limits of this analysis. First, we have not addressed how the child acquires the categorical knowledge that we see developing. Second, as we have emphasized throughout we use only a sample of a child's speech ($\approx 5\%$ of their total productions over the period). That a mere sample can provide a grammar that gives such good coverage supports our claims that the children are limited in their productivity. However, we must also recognize that the children are capable of producing utterances not found in our test data. Finally, any production study can only tell us about what children know how to produce. It has often been claimed that young children have extensive knowledge of grammar that they are simply unable to use in production because of performance demands. Such an argument has been particularly strong among those who believe that a core component of children's grammar is innate knowledge of UG (25), but it has in recent times been made by authors who are not so committed to this perspective (26). This position is logically impossible to falsify with empirical methods. However, there has recently been some suggestion that children show evidence of grammatical knowledge for certain tasks [e.g., word order-based discrimination of semantic roles in a preferential looking study (27)] that they do not show on other tasks [e.g., production (8); act out (10)]. Others have reported contrary results (28), and we would prefer to think in terms of a graded representations account (29) that is quite consistent with a usage-based perspective. In any case, what we have done here is to show that lexically specific explanations, according to standard methods of assessment, provide a good account of children's language use at early points in development.

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