Conceptual and prosodic cues in child-directed speech can help children learn the meaning of disjunction

Masoud Jasbi
masoudj@stanford.edu
Department of Linguistics
Stanford University

Akshay Jaggi
ajaggi@stanford.edu
Department of Linguistics
Stanford University

Michael C. Frank
mcfrank@stanford.edu
Department of Psychology
Stanford University

Abstract

Current theories of word learning focus on cues and mechanisms that help children's acquisition of open-class words such as nouns and verbs. Little is understood about the role of input in children's acquisition of closed-class words such as articles and connectives. This paper investigates the cues in child-directed speech that can help the interpretation and acquisition of the connective disjunction-word *or*. Study 1 uses a large corpus of parent-child interactions to show that despite low occurance of *or* in child-directed speech, children quickly reach the adult level of production for this word by age 4. Study 2 uses annotations on a subset of parent-child interactions to show that disjunctions in child-directed speech are accompanied by reliable cues to the correct interpretation (exclusive vs. inclusive). We present a computational model that learns from a handful of annotated examples to correctly predict the interpretation of a disjuntion. These studies suggest that reliable cues in child-directed speech can assist rapid acquisition of functional categories such as disjunction words.

Keywords: language acquisition; word learning; logical words; conjunction, disjunction.

Introduction

When we think of words, we often think of nouns like *cat*, adjectives like *red*, or verbs like *run*. These classes of words - called **content words** - have thousands of members and constantly add new ones like *Google*, *crunk*, or *chillax*. Their meanings often refer to concrete and tangible entities or events in the world. This is not the case for **function words** like *and*, *or*, *of*, and *the*. Functional classes have few members and rarely accept new ones. Their meanings are highly abstract and provide the glue that holds content words together to form complete thoughts. These properties make function words challenging for theories of word learning. While there has been a lot of research on cues and mechanisms that assist children's acquisition of content words, very little is known about cues that help children learn the meaning of function words. In this study, we make the initial steps by looking at the disjunction word *or* in parents' and children's speech.

The word *or* has long been a lab rat in linguistics and language acquisition. This interest in *or* is mainly due to its close connection to logical disjunciton. In formal logics, there are two types of disjunction: inclusive and exclusive. An **inclusive disjunction** such as "A $\vee$ B" is true when either A, B, or both are true. An **exclusive disjunction** such as "A $\oplus$ B" is true only when A or B is true but not both. The linguistic connective *or* can receive an inclusive interpretation like "A $\vee$ B" or an exclusive one like "A $\oplus$ B". For example, a waitor may ask if you would like something to eat or drink, not excluding the possibility that you would like both. However, the waitor may later ask if you would like to see the dessert menu or have the cheque, suggesting that you should chose one or the other.

A large body of research in formal semantics and pragmatics seeks to specify the meaning of *or* and factors that determine its interpreation as inclusive and exclusive. Grice (1975) argued that the core meaning of *or* is inclusive disjunction. The exclusive interpretation is the result of modifying this inclusive meaning by factors external to *or* itself. He suggested that upon hearing "A or B", we may exclude the possibility of both A and B being true simply because we reason that the speaker could have used the connective *and* instead of *or*. Therefore, the exclusive interpretation is the result of this pragmatic reasoning on the speaker's choice of *or* instead of *and* and not part of the meaning of *or* itself. Geurts (2006) argued that in many cases, exclusive interpretations stem from the inconsistent meaning of the options. For example, "to be or not to be" is exclusive simply because one cannot both be and not be! In an experimental study, Pruitt & Roelofsen (2013) showed that in questions, exclusive interpretations are the result of a rise-fall intonation. In short, while the meaning of *or* itself is inclusive, the situation where both options are true may be excluded by pragmatic reasoning, inconsistent options, or a rise-fall intonation.

How do children learn the meaning of *or* given all this complexity in interpreting a disjunction? Morris (2008) investigated instances of *and* and *or* in parents' and children's speech. He found that *and* occurs about 3 times every 100 utterances in the speech of parents while *or* occurs only once or twice every 400 utterances. More importantly, children reach the adult level of production for *and* relatively quickly and around the age 3 but their productions of *or* do not reach

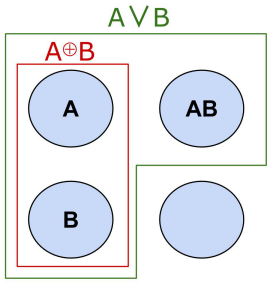

Figure 1: Inclusive disjunction (A$\vee$B) is true in situations where A, B, or both AB are true. Exclusive disjunction (A$\oplus$B) is true in situations where only A or only B is true.

the adult level in the first five years. He also found that the majority of *or* examples children hear (75-80%) and produce (%90) have an exclusive interpretation. Based on these findings, he concluded that children's acquisition of *or* is slow and they understand its meaning as exclusive before they add the inclusive meaning to their repertoire.

On constructivist accounts of the acquisition of disjunction, children learn the meaning of *or* by paying attention to how parents use it in different contexts. They form usage-rules and expand their usage repertoire as they grow up. The prediction is that children's production of *or* is slow and gradual, mirroring what they hear from parents. Morris (2008) found that *and* is about 13 times more frequent than *or* in parents' speech to children. As predicted by the constructivist account, Morris (2008) reported that children also learn to produce *and* much more quickly than *or*. They reach the adult rate of *and* at age 3 while for *or* there is a gradual increase in production, possibly reaching the adult level at ages 5 or 6. The faster acquisition of *and* is consistent with the constructivist theory that emphasizes the role of usage frequency in children's linguistic development. Morris (2008) also reported that the majority of *or* examples children hear are exclusive. He reported that the majority of *or*'s children produce are also exclusive. Therefore, the inclusive semantics of *or* is developed after the exclusive interpretation.

However, several comprehension studies of *or* in different linguistic contexts show that children as young as three-years old interpret *or* as inclusive disjunction (Crain, 2012). This finding is surprising given Morris (2008)'s finding that the majority of *or* examples children hear are exclusive. How do children learn the interpretation of disjunction as inclusive if they rarely hear it? We call this the **learning puzzle of disjunction**. Crain (2012) suggests that instead of learning from the parents' usage of *or*, children rely on the innate knowledge that the disjunction operator in their native language must have an inclusive meaning. This nativist account predicts that *or* is learned relatively quickly and accurately by children.

Here we present an alternative answer that provides a synthesis between the nativist and constructivist accounts. We show that children can use regularities in parents' usage of *or* to learn the interpretation of disjunction from a handful of examples. In study 1, we use a large scale corpus study of parents and children's speech to show that both *and* and *or* appear relatively quickly in children's speech and reach the adult rate by the age 4. This finding is consistent with the comprehension studies that show children have an adult-like understanding of these words by the age four. In study 2, we replicate Morris (2008)'s finding that the majority of *or* examples in child-directed speech have an exclusive interpretation. However, we also show that these exclusive interpretations correlate systematically with two factors external to *or*: intonation and consistency of the options. Exclusive interpretations are either inconsistent in nature (e.g. clean or dirty) or carry a distinct rise-fall intonation. We show that setting aside these cases, the interpretation of a disjunction is inclusive.

We argue that if children track the interpretive cues that accompany a disjunction, they can tease apart the role of the word *or* from factors that accompany and enhance it to shape the exclusive interpretation. This way children can discover that exclusivity corrleates with rise-fall intonation and inconsistent options, while *or* itself does not exclude the option of both disjuncts being true. We implement this novel account in a decision-tree that correctly learns to predict the interpretation of a disjunction with 80% accuracy after only a few examples. Our results show that the richness and systematicity of children's linguistic input allows rapid acquisition of disjunction with no need for an innate assumptions specific to the meaning of disjunction. We discuss the important implications of this work for the theories of word learning in the last section.

Study 1: Corpus Study

First, we conducted an exploratory investigation of *and* and *or* productions in parents and children. The goal of the study was to find out when children start producing these words and when they reach the adult rate of production. We conclude that children start producing *and* around 1.5 or 2 years of age, and *or* between the ages of 2 and 3. They reach the adult rate of production for *and* around 3 and for *or* around 4 or possibly earlier.

Methods

We accessed the Child Language Data Exchange System (CHILDES, MacWhinney (2000)) via the online platform childes-db and its associated R package childesr (Sanchez et al., in prep). We extracted all instances of *and* and *or* from the English corpora (ENG-NA and ENG-UK). We limited our analysis to the data between one and six years because there is limited data outside this age range. We computed the relative frequency of connective production by dividing the total number of *and*/*or* in the speech of fathers, mothers, and children at a particular age by the total number of words spoken at that age. We present the relative frequency as parts per thousand.

Results

In figure 1, we show the relative frequencies of *and* and *or* in the speech of parents and children between one and six years. In the speech of parents, *and* is produced around 20 times per thousand words while *or* is only produced around 2 times per thousand words. This confirms previous findings that *or* is much less frequent in child directed speech than a similar function word such as *and*.

And and *or* seem to show different developmental trajectories in the speech of children. For *and*, there is a rapid increase in its production between the ages of 1.5 and 3 before it reaches the adult rate around the age 3 and stay at that level until the age 6. For *or*, on the other hand, we see a slow increase from the age 2 until at least age 6, as it approaches the adult rate. This difference in the development of *and* & *or*

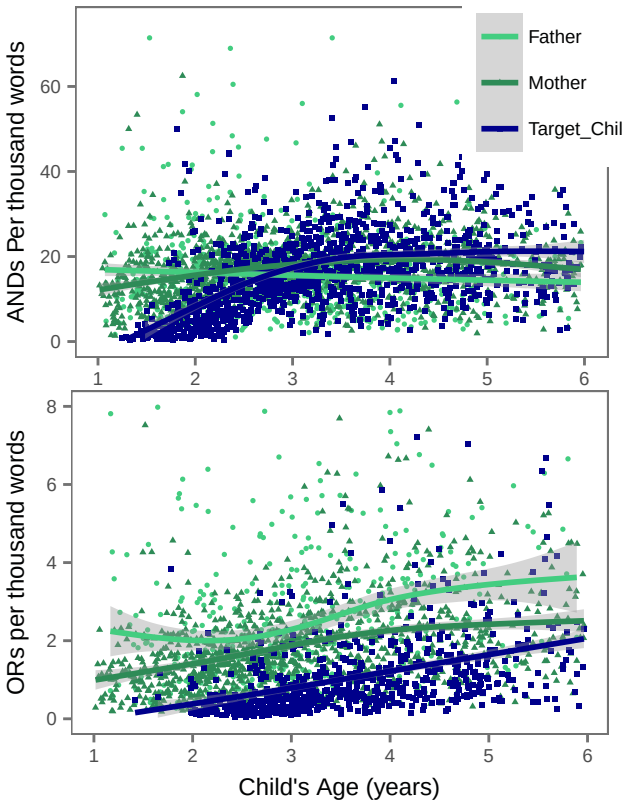

Figure 2: The relative frequency of AND (top) and OR (bottom) per thousand words in the speech of fathers, mothers, and children between the ages of 1 and 6.

production was attributed to the frequency of these items in child-directed speech. Since *and* is much more frequent than *or*, it is learned much faster than *or*. Morris (2008) argued that such patterns support the item-based and usage-based acquisition of logical words.

However, the analysis above does not control for other factors that can affect the production of words by children. An important factor to control for is the development of speech acts. While content words such as *dog* or *chair* may appear freely in different types of speech acts, function words are highly constrained by the type of speech acts they can appear in. For example, it is reasonable to assume that question words such as *how* and *why* are much more likey to occur in questions than statements (declaratives). If parent-child interaction is such that parents ask more questions than children, it is not surprising to find higher rates of *how* and *why* production in parents than children. Therefore, it is important to control for the speech act a function word appears in.

Figure 2 shows the relative frequencies of *and* and *or* in questions vs. declaratives, in the speech of parents and children between one and six years. Here, the relative frequency is computed by dividing the total number of *and*/*or* in a question/declarative in the speech of fathers, mothers, and children at a particular age, by the total number of words in a question/declarative spoken at that age. As before, we present the relative frequency as parts per thousand.

The results show similar developmental trajectories for the production of *and* and *or* in children. For both words, there is a relatively rapid incease in their frequency between the ages of 2 and 4 before reaching the parent rate at the age of 4 and staying at that rate until the age of 6. This pattern of production is consistent with the nativist observations that the acquisition of *and* and *or* is rapid and that children have an adult-like comprehension of these two connectives at the age 4.

Summary

In this study we found that *and* is a lot more frequent than *or* in child directed speech. Looking at the relative frequency of *and* and *or* between the ages of 1 and 6, it appeared as if children show radically different developmental trajectories for these two connectives. Children's production of *and* seemed to sharply increase around the age 1.5 and reach the adult rate around age 3 while *or* production increased slowly and linearly until it reached the adult rate at age 6. However, we showed that this discrepency is to a large part due to the distribution of function words in different speech acts. Since *or* is more frequent in questions and children produce fewer questions than parents, the frequency of *or* in children's speech is underestimated if we normalize by the total number of words they produce. Instead, when we look at the production of *and* and *or* in specific speech acts - declaratives and questions - and normalize by the total number of words produces in each speech act, we see that *and* and *or* show similar developmental patterns. We argue that the developmental trajectory of *and* & *or* is best described as a quick increase in production between the ages of 2 and 4 and staying around the parents' rate between the ages 4 and 6. This is compatible with the comprehension studies which suggest children understand *and* and *or* by the age four.

Study 2: Annotation Study

Study 1 showed that even though *or* is not very frequent in child-directed speech, children learn and produce it relatively quickly and reach the adult rate around the age 4. In Study 2, we conducted a detailed and small-scale investigation of *or* productions in child-directed speech. The goal of the study was to find out how children learn the meaning of *or* from such little data. We conclude that children hear significantly more exclusive uses of *or* supporting Morris (2008)'s findings. However, we also find that the exclusive uses of *or* are rich in structures that index the exclusive interpretation. These indicative structures include rise-fall intonation and consistency of the options. Exclusive interpretations are either inconsistent in nature (e.g. clean or dirty) or carry a distinct rise-fall intonation. We then show that a decision tree model can learn to accurately (>80%) predict exclusivity using this information after seeing few (<20) examples. Instances of *or* without these indices are most likely interpreted as inclusive.

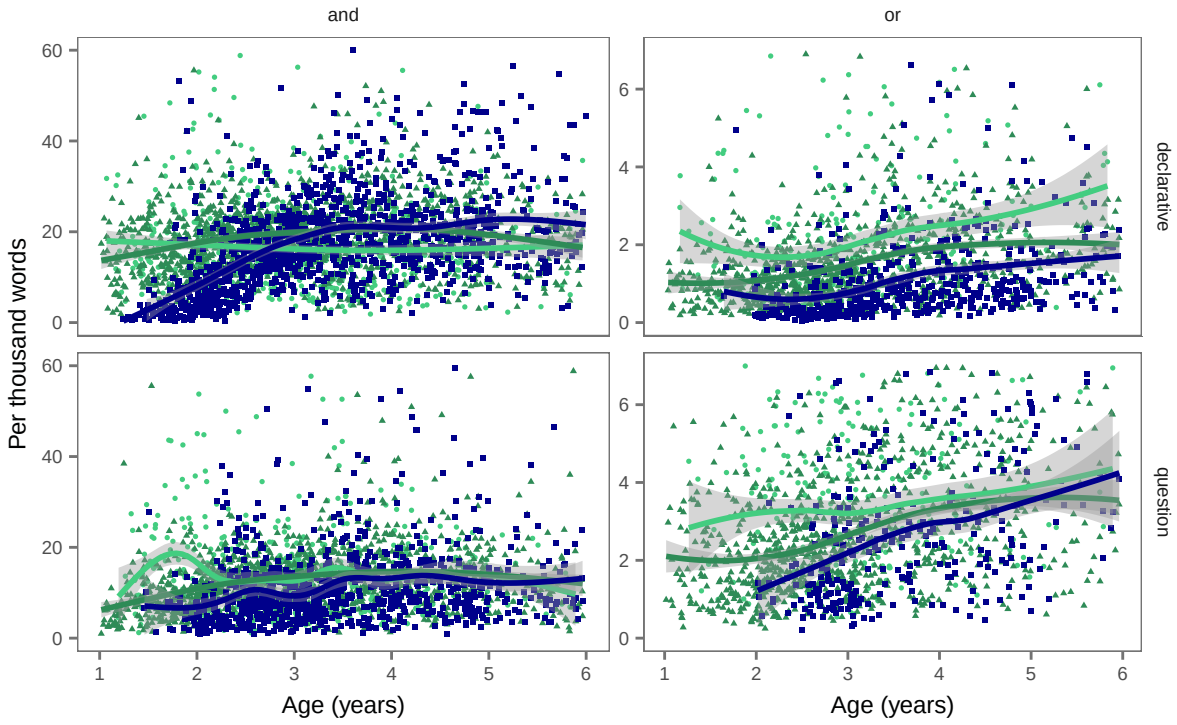

Figure 3: The relative frequency of AND (left) and OR (right) per thousand words in declaratives and questions in the speech of fathers, mothers, and children between the ages of 1 and 6.

Methods

We accessed the Providence corpus (Demuth, Culbertson, & Alter, 2006) via the phonbank section of the TalkBank system. We extracted all instances of *or* along with the two utterances before and after to provide context using the CLAN software. We annotated the examples for three major categories: 1. Interpretation 2. Intonation and 3. Conceptual consistency. Table 1 shows these categories along with their subcategories and an example for each subcategory.

Disjunction The first category - disjunction interpretation - was our dependent measure. Annotators listened to a disjunction like "A or B" and decided whether the speaker intended to imply "not both A and B" (exlcusive) or "possibly both A and B" (inclusive).

Intonation For the second category - intontation - annotators listened to the sentence containing disjunction and decided whether the intonation contour on the disjunction is rise-fall, rise, or flat. Table 1 includes examples that are prototypically read aloud with the intonation contour they are subcategorized as.

Consistency Finally, for conceptual consistency, annotators decided wether the propositions that make up the disjunction are inconsistent. Our annotators used the following diagnostic to decide the consistency of the disjuncts: Two disjuncts were marked as inconsistent if replacing the word *or* with *and* produced a contradiction. For example, changing "the ball is in my room and your room" to "the ball is in my room and your room" produces a contradiction because the propositions cannot be both true at the same time. In such cases, the inclusive meaning is simply not available due to the nature of the propositions themselves and not the interpretation of the connective. It is important to note here that this is a particularly strict diagnostic. In many cases, the possibility of both propositions being true is ruled out based on prior knowledge and expectations of the situation. For example, when asking people whether they would like tea or coffee, it is often assumed that people choose one or the other. However, wanting to drink both tea and coffee is not conceptually inconsistent. It is just very unlikely. Our annotations of consistency are very conservative in that they consider such unlikely cases as consistent.

Category	Subcategory	Examples
Interpretation	Exclusive	Wanna stay or go?
	Inclusive	Anything to eat or drink?
Intonation	Flat	I'll get tea or coffee.
	Rise	Anything to eat or drink?
	Rise-Fall	Wanna stay or go?
Consistency	Consistent	I'll get tea or coffee.
	Inconsistent	Wanna stay or go?

Table 1: Annotation categories and examples.

Finally, to test inter-rater reliability, the two raters annotated the same 240 utterances. The interrater reliability was calculated over 8 iterations of 30 examples each. Training

only completed after 3 consecutive iterations had substantial agreement between the raters (Cohen's $\kappa > 0.7$) for all categories.

Results

First, similar to Morris (2008), we found that the majority of *or* examples in CDS receive an exclusive interpretation ($\sim$%65). Figure 3 shows this difference in distribution. However, the rate of exclusive interpretations change systematically when we break the data down by prosody and consistency (Figure 4). Given a rise-fall intonation contour, a disjunction is almost always interpreted as exclusive. Similarly, if the propositions are inconsistent, the disjunction is most likely interpreted as excluisive. When either of these two features are absent, a disjunction is more likely to receive an inclusive interpretation.

A mixed-effects binomial logistic regression using the pakcage {lme4} (Bates, Maechler, Bolker, Walker, & others, 2014) in R with the fixed effects of intonation and consistency, as well as the random effects for children, found both intonation and consistency significant in interpreting disjunctions. Disjunctions were more likely to be interpreted as exclusive if they received a rise-fall intonation (β=-3.79, z=1.66, $p < 0.001$) or if they were inconsistent (β=-2.2, z=2.08, $p < 0.001$). Disjunctions were more likely to be interpreted as inclusive if they were consistent and received a rising (β=0.58, z=0.24, $p < 0.001$) or flat intonation (β=0.38, z=0.27, $p < 0.001$).

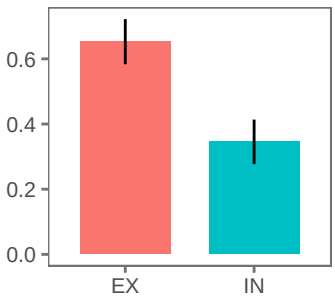

Figure 4: Proportion of exclusive and inclusive interpretations of disjunction in child-directed speech. Error bars represent bootstrapped 95% confidence intervals

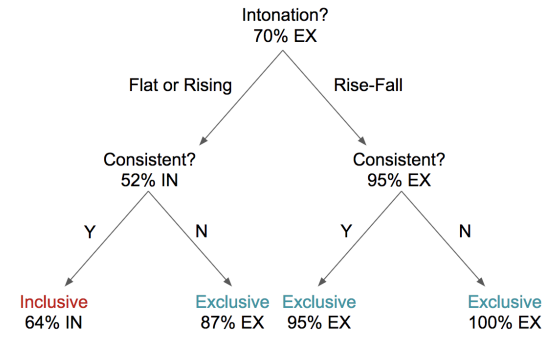

Figure 6: Optimal decision tree training on 100 datapoints. Provides series of two binary decisions to decide exlcusivity interpretation. Intonation > 1.5 are rise-fall while intonation < 1.5 are flat or rising. Consistency > 0.5 are consistent while consistency < 0.5 are inconsistent.

Next, using Sci-kit Learn's Decision Tree Module (Pedregosa et al., 2011), we built a predictive model to train on annotated *or* utterances and predict the exclusivity of unseen *or* utterances (annotated for intonation and consistency). We randomly sampled 100 examples for training and 300 examples for testing. Averaged over 100 trials, the average accuracy of a binary tree was 83%. More remarkably, the tree achieved an average of 80% accuracy after training on only 20 examples. The control flow of the average decision tree on a single example is as follows. If *or* has neither rise-fall nor inconsistent disjuncts, it is marked inclusive. Otherwise, exclusive. The success of such a simple tree indicates that children could use a simple model to rapidly learn the exclusive interpretation of *or* from little data.

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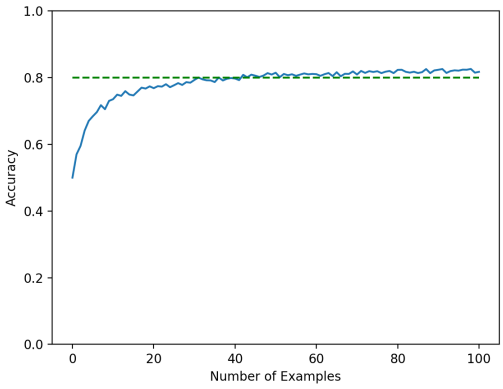

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\caption[Decision Tree Accuracy as a function of number of examples seen]{Decision Tree Accuracy as a function of number of examples seen. Tested on a constant 300 examples. Dashed line marks 80% accuracy threshold.} \end{figure} \end{CodeChunk}

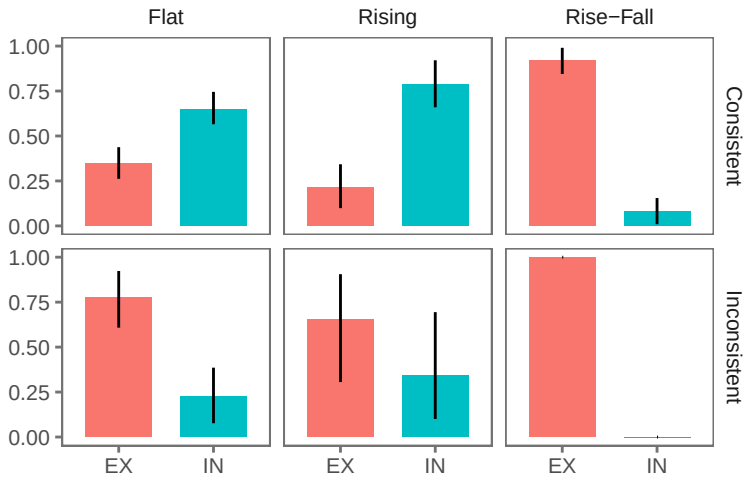

Figure 5: Distribution of exclusive and inclusive interpretations broken down by intonation (flat, rise, rise-fall) and consistency. Error bars represent bootstrapped 95% confidence intervals

Summary

In study 2, we confirm Morris (2008)'s finding that exclusive interpretations of *or* are far more common than inclusive interpretations. However, we also show that the majority of these exclusive interpretations coincide with systematic indicators. Disjunctions that are accompanied by rise-fall intonation or inconsistent disjuncts are far more likely to be exclusive. Disjunctions that do no bear these features are more likely to be inclusive. Accounting for these external factors, a simple decision tree can rapidly learn to predict the exclusive interpretation of the disjunction.

Discussion

Studies presented in this paper resolve two puzzles in children's acquisition of disjunction. First, previous studies suggested a discrepency between children's production of *or* and their comprehension. Comprehension studies showed that children have an almost-adult-like interpretation of *and* and *or* at around the age 4. However, production studies suggested that *and* is learned and produced quickly while children are slower in reaching the adult rate of production for *or*. Study 1 showed that when we control for the environments (speech acts) that these connectives are suitable for, we observe that both *and* and *or* are learned relatively quickly and produced at an adult rate around the age 4. This is compatible with the comprehension studies that show 3-to-5-year-olds understand the meaning of *or* as inclusive disjunction and *and* as conjunction.

The second puzzle that this study addressed was the (apparent) discrepency between what they hear from parents and the knowledge they manifest in comprehension studies. Previous studies showed that the majority of *or* examples children hear receive an exclusive interpretation, yet in comprehension tasks they interpret *or* as inclusive disjunction. Study 2 showed that even though the majority of *or* examples are exclusive, this exclusivity is due to prosodic and conceptual properties of the disjunction and not *or* itself. We showed when we break down interpretations of disjunction in child-directed speech by prosody and concpetual consistency, the vast majority of exclusive interpretations are either inconsistent conceptually (e.g. clean or dirty) or are accompanied by a distinctive rise-fall intonation. Otherwise, a disjunction that does not bear these properties is more likely to be interpreted as inclusive. This finding suggests that if children break down disjunction interpretations by cues that accompany them, they can learn the adult like interpretation of disjunction from child-directed speech. We showed that a decision tree can use prosody and conceptual consistency to identify the correct interpretation using less than 20 examples.

The account presented in this paper has implications for the theories of form-meaning mapping in general and more specifically theories of function word acquisition. Form-meaning mapping in child language acquisition is often construed as the task of associating a novel and isolated form such as *gavagai* to a delimited concept such as rabbit and storing it in memory. However, the case of disjunction paints a more complicated picture. For disjunction, it is not enough to isolate the word *or* for mapping and the learner needs to also consider the prosodic contour that accompanies *or*. When mapping to meaning, it is not enough to simply consider the overall interpretation and the learner should take into account the conceptual properties of the accompanying words and phrases. In other words, mapping the form *or* to its meaning involves considering both other forms as well as concepts that accompany *or* and its core meaning.

Finally, the acquisiton of *or* is important for form-meaning mapping in function words such as determiners (e.g. *the*, *a*), connectives (e.g. *and*, *or*, *if*), and auxiliaries (e.g. *might*, *should*, *can*). The word learning literature has mostly focused on the acquisition of content words such as nouns, adjectives, and verbs. Theories of word learning for content

words often rely on the physical and observable cues present in the child's surroundigs to learn the relevant meanings. Such theories face difficulty when dealing with function words since most function words do not have observable cues to their meanings. The research presented here provides early indication on the types of cues that can help children learn the meaning of function words.

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