Explicit in Implicit cues of conceptual hierarchy in CDS

Anonymous CogSci submission

Abstract

[Should be replaced with the new absotract]Cognitive development is often characterized in term of discontinuities, but these discontinuities can sometimes be apparent rather than actual and can arise from continuous developmental change. To explore this idea, we use as a case study the finding by Stager and Werker (1997) that children's early ability to distinguish similar sounds does not automatically translate into word learning skills. Early explanations proposed that children may not be able to encode subtle phonetic contrasts when learning novel word meanings, thus suggesting a discontinuous/stage-like pattern of development. However, later work has revealed (e.g., through using simpler testing methods) that children do encode such contrasts, thus favoring a continuous pattern of development. Here we propose a probabilistic model describing how development may proceed in a continuous fashion across the lifespan. The model accounts for previously documented facts and provides new predictions. We collected data from preschool children and adults, and we showed that the model can explain various patterns of learning both within the same age and across development. The findings suggest that major aspects of cognitive development that are typically thought of as discontinuities, may emerge from simpler, continuous mechanisms.

Keywords: word learning, cognitive development, computational modeling

Introduction

A hallmark of conceptual knowledge is its hierarchical organization. For example, a husky can be categorized as a dog, but it can also be categorized as a mammal, an animal, or a living being. Hierarchical organization is fundamental to human cognition as it allows, among other things, the propagation of knowledge through inference. For example, upon learning that all living beings are made out of cells, one can conclude that dogs are made of cells, too.

How do children acquire conceptual hierarchy? Early accounts considered conceptual hierarchy to be the consequence of the emergence of a domain-general logic of class-inclusion [explain a bit more] (Inhelder and Piaget 1964). However, researchers have noted that children can acquire hierarchy in a specific domain before mastering the domain-general logic of classes (Chi et al., 1989; Carey, 1985; Inagaki and Hanato,2002; Keil, 1981).

There are signs that children as young as 3 years old show hierarchical knowledge in various domains (e.g., animals, clothes, and food). Such signs include using super-ordinate words like "food" and "animal" according to parent report (Fenson et al., 1994) and, more importantly, being able to extend the meaning of novel words to superordinate categories even controlling for perceptual similarity (Liu, Golinkoff, & Sak, 2001; Callanan, 1989).

Some researchers proposed that children learn conceptual hierarchy thanks to parents' verbal scaffolding (Vygotsky, XX). For example, analyses of parent-child interactions in the lab have shown that parents rarely introduce words at the superordinate-level without also providing the basic level term (Blewitt, 1983; Shipley et al. 1983,; Callanan, 1985). For example, parents rarely point to an object and say "this is an animal!". Instead, they usually *anchor* the super-ordinate word "animal" at the basic level by saying something along the lines of "This is a duck; a duck is a kind of an animal." Such an anchoring strategy provides children with a categorization of the same object at different levels, which may help children understand the hierarchical organization.

In a different line of research prompted by recent advances in data science (Landauer and Dumais, 1997; Mikolov et al., 2013), researchers have found that the statistical distribution of basic-level terms in parental speech can lead to a coherent structures at the super-ordinate level (Huebner and Willits, 2018; Fourtassi et al., 2019). To illustrate, children can learn that "horse" and "dog" are part of a higher-level category just by observing that these words co-occur in similar contexts. This cue can be a powerful source of conceptual hierarchy because it does not require the presence of a lexicalized label for the higher-level category; the latter emerges in a bottom-up fashion as a cluster of related words at the lower-level.

Both the anchoring-based cue — which we call here the *explicit* cue (because it requires an explicit marker of the super-ordinate category) and the distributional cue — which we call the *implicit* cue — can be picked up on by children. For example, explicit anchoring cues help 3-year old children interpret the meaning of a novel word at the super-ordinate level (Callanan, 1989). In the case of implicit cues, extensive research in the last couple of decades has shown that children are capable of tracking distributional statistics at different hierarchical levels (Saffran et al., 1996). Besides, children appear to rely on the way words co-occur to make category-based induction (Matlen et al., 2015).

Nevertheless, implicit and explicit cues have been studied using different datasets methods which have made their comparison difficult. For instance, while the implicit cue has been studied using large-scale data, the explicit cue has been studied mainly in the context of small scale experiments. Further, while the implicit cue has been tested on its ability to provide an accurate similarity space for words, the explicit cue has been tested in a less formal fashion; mainly through counting the frequency of a given anchoring construction.

The goal of this work is to make a systematic comparison of explicit vs. implicit cues using comparable methods and the same dataset. Among other things, we compare the accuracy of each cue in providing reliable information relating a large set of basic-level terms to many super-ordinate categories, and we explore the extent to which the cues provide non-redundant conceptual content.

This paper is organized as follows. . . .

Analyses

Data

We constructed a large-scale corpus by aggregated over all English-language transcripts from CHIDLES (MacWhinney, 2000; Sanchez et al., 2019). These transcripts involved the caregivers' speech addressed to children up to three years of age. We had a total of [XXX] transcripts, across [XXX] unique children.

We decided to study the six following super-ordinate categories: "animals", "furniture", "clothes", "food", "toys" and "vehicles" [Why did we choose precisely these categories, what did previous studies use?. . .]. For each of these categories, we used the corresponding basic-level terms available in the Child Developmental Inventory (CDI) containing the list of words that children can produce up to 3 years.

Cue derivation

Explicit cues Following previous research (Callanan, 1985), we first searched for the following expressions of inclusion: "X is a/an Y" and "X is a kind of Y", where Y is a term at the super-ordinate level and X is a term at the basic level of conceptual hierarchy. A preliminary analysis showed these constructions had very low frequency in the corpus and concerned only a subset of the super-ordinate categories. [Here we should make a table with: category, frequency of cue, percentage out of all utterance where the category label appears].

Nevertheless, such grammatical constructions are not the only way parents can hint to the conceptual hierarchy between two concepts in their speech. In fact, an inspection of a few examples showed that parent use a variety of linguistic expressions ("what other animals are with your dog?", [her we should include more examples]. In what follows, we describe two new characterizations of the explicit cue dealing with this diversity.

In **Explicit Cue 1**, we relax rigid grammatical constraints such as "X is a kind of Y", and we keep only the requirement that X and Y should co-occur in the same utterance (or within a fixed window of neighboring utterances). We represent each basic-level term with a vector of length six; corresponding to the six super-ordinate categories. Each entry in the vector corresponds to the frequency with which the basic-level term co-occurs with the super-ordinate term at hand. For the implicit cue to be informative, words from a given super-ordinate category (e.g., "apple") should co-occur more with the label of this category (i.e., "food") than they do with the label of another category (i.e., "toys").

The super-ordinate label is not the only category marker that can cue conceptual hierarchy, especially when this category can be characterized by a function. For example, "food" can be characterized as the category of things we eat and "clothes" as things we wear. Thus, children can learn that some concepts (e.g., "apple" and "bread") are parts of a higher-level category ("things we eat") by observing how these concepts co-vary with a cue of their common function (i.e; the verb "eat").

Explicit Cue 2 expands the first cue by including verbs that encode the function of the super-ordinate category. Unlike the case of a super-ordinate label (noun) anchored with a basic level label (also a noun), here the set of grammatical structures that express the relationship between a concept (noun) and its function (verb) can be reasonably constrained. We chose to keep only the simplest structure, i.e., a verb-complement relationship. For example, after reading the utterance "the bird eats the berries", we increment the "food"-related cell in the vector associated with "berries". We do not increment the vector associated with "bird" because this word is not the complement of the verb "eat".

For each super-ordinate category, we tried to find a single verb that could be used as a function marker for the entire category. We used "eat" for food, "wear" for clothes, "play" for toys, and "ride" for vehicles. The category of furniture has no such obvious function verb. We decided to use the verb "use" because if there were a verb that could fit every member of the category of furniture, it would be that, even though it can also fit things that are not members of the category. For the animal category, we could find no function verb that could categorize the instances, so we continued searching for animals based on co-occurrence of category and instance alone.

Implicit cue Unlike the explicit cues, the implicit cue is not based on an explicit category marker at the super-ordinate level. It is based, instead, on the way basic-level terms are distributed together in speech (the distributional hypothesis; Harris 1957). Following previous research (Fourtassi et al., 2019), we quantified this cue using a word embedding model (Word2Vec, Mikolov, 2013) [What are the parameters of the model (window size, space dimension,..) and how sensitive is the model to these parameters?]. In this model, words are represented as vectors in a high-dimensional space, representing the distribution of these words in a latent semantic structure.

Task and Evaluation

Above, we characterized both explicit and implicit cues in a vectorial framework. This framework allows us to directly compare the cues in terms of how they quantify the similarity between words (defined as the cosine of the angle formed by their vectors). Thus, the task consists in testing the ability of each cue to predict which pairs of words belong to the same superordinate category (e.g., "apple" and "bread") and which pairs of words belong to different categories (e.g., "apple", "horse").

For each category, we first list all pairs of words that contain an instance of this category. Second, we derive the cosine similarity for all these pairs (according to each cue), and finally, we evaluate the ability of the similarity measure to accurately predict the binary classification (into "same" or "different") across various discrimination thresholds. We quantified performance in this task using the standard Area Under the ROC curve (hereafter AUC).

Results

Figure XX shows the AUC scores of the two explicit cues and the implicit cue for all six super-ordinate categories. For explicit cue 1, the accuracy was generally low; only the categories of "toys" and "vehicles" had noticeable scores (above .65). For explicit cue 2 (which takes into account the co-occurrence with a functional marker of the category and not only the label), the scores improved significantly in the cases where we had an obvious functional verb to cue the super-ordinate category, i.e., "food", "clothes", and "vehicles". As for the implicit cue, the scores were generally high, including the categories which had a low explicit score, and which had no obvious functional marker such as "animals" and "furniture". [What happens to Explicit cue 1 when the window size changes from one utterance to k neighboring utterances? could be nice to be able to show a graph with some values of k (till information becomes totally diluted)]

We also explored the extent to which explicit and implicit cues provided complementary vs. redundant information. We fit a logistic regressions, for each category, predicting the correct binary classifications ("1" for pairs of words belonging to the same category, and "0" for pairs belonging to different categories) as a function of Explcict cue 2 (which is the most comprehensive of the tow explicit cues) and the implicit cue. The predictors were centered and scaled. The results of the regressions, summarized in table XX, indicate that each cue remains highly significant when controlling for the other cue, suggesting that the cues provide non-redundant information.

The results we showed concern cues derived from parental speech up to 3 years old, as this is the age when signs of conceptual hierarchy start to emerge in the developmental literature. But we are also interested in how information in these cues may change as children grow older. Results of this analysis, presented in Figure XX, show that both explicit and implicit cues remain stable across development, at least up to 6 years old.

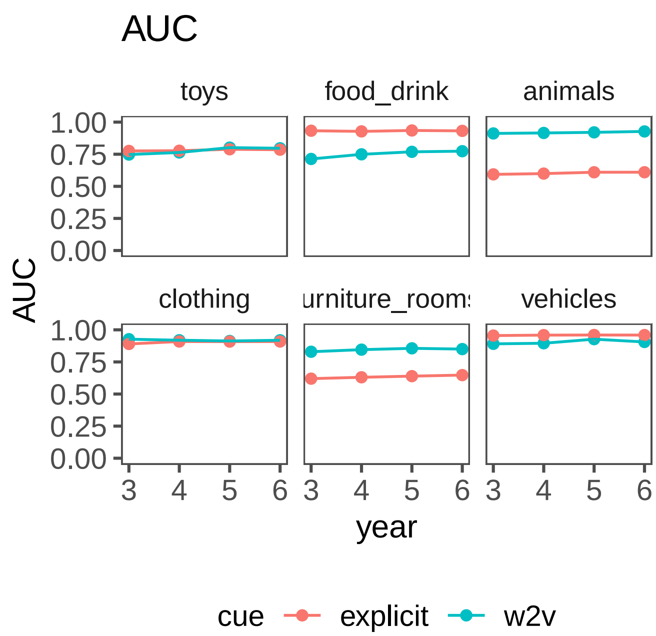

Figure 1: AUC scores....

General Discussion

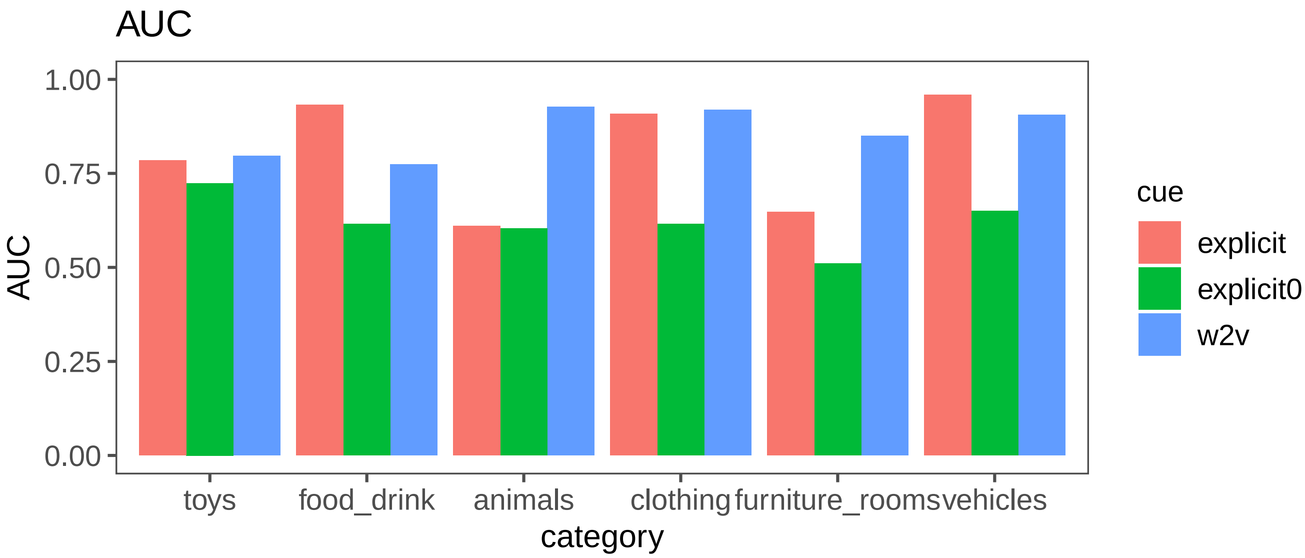

Figure 2: AUC score: chance is 0.5, perfect sccore is 1.

Table 1: Logistic regressions predicting category membership as a function of speech-derived cues.

	Dependent variable:					
	Animals	Furniture	Toys	Food	Clothing	Vehicles
Constant	-2.605^{***}	-3.117^{***}	-3.054^{***}	-2.821^{***}	-2.564^{***}	-4.277^{***}
	(0.070)	(0.115)	(0.119)	(0.095)	(0.102)	(0.277)
explicit	0.092	0.433^{***}	1.032^{***}	2.846^{***}	1.239^{***}	2.380^{***}
	(0.049)	(0.087)	(0.105)	(0.079)	(0.083)	(0.215)
w2v	2.346^{***}	2.028^{***}	1.370^{***}	0.789^{***}	1.940^{***}	1.189^{***}
	(0.068)	(0.115)	(0.118)	(0.047)	(0.112)	(0.169)

Note: *p<0.05; **p<0.01; ***p<0.001