Children's Understanding of Entailment in Conditionals

Irene Canudas-Grabolosa, Elena Pagliarini, Gennaro Chierchia, and Luca L. Bonatti

1. Introduction

The human mind has a unique capacity to represent (objects, events or situations), analyze (abstract regularities, goals or thoughts of other minds), and make predictions based on these representations. How these abilities are developed, as well as their relationship with language, are still deeply controversial questions.

A fundamental requisite for such complex tasks seems to be a robust system that allows handling, connecting and coordinating the flow of representations that knowledge and experience makes us continuously available. Yet, again, its nature has been widely debated but poorly understood. Consensus exists that representations are often connected by associative relations, but also that associations are not sufficient to explain basic properties of language and thought, such as compositionality and the ability to link representations by means of logical relations.

Within this framework, numerous theories converge in attributing a cornerstone role to entailment (Su et al., 2012). Some semanticists even consider it a core property of human languages (Su et al., 2012), given that expressions whose distributional properties are governed by entailment contexts are present in all studied languages (Ladusaw, 1979; Horn, 1989). If such a perspective is true, the possibility exists that entailment has a fundamental role not only language, but also in thought.

Here, we take entailment as a case study for our deeper interest in investigating whether it, as well as in general set operations, could be logical primitives of thought. Our focus will be to explore to what extent children who are still in the process of becoming competent in language are sensitive to entailment relations

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that drive the interpretation of expressions appearing in compositionally built sentences.

1.1. What is entailment?

Entailment is a relationship between two sentences such that if the first is true, the second will necessarily be true (Chierchia and McConnell-Ginet, 2000). The notion, borrowed from standard logic, is easily exemplified in common sentences, as the following examples show:

(1) a. If Mary takes a ball, she plays with a Dalmatian.
    b. If Mary takes a ball, she plays with a dog.

(2) a. If John eats pizza, he gets stains in his t-shirt.
    b. If John eats pizza with olives, he gets stains in his t-shirt.

The first example, (1a), entails (1b), because a *Dalmatian* is a dog breed (a subset, in formal terms), and so every time (1a) is true, (1b) will be true as well. This relationship is not symmetric: (1b) does not entail (1a), as it is not the case that every time Mary plays with a dog, she necessarily plays with a Dalmatian.

In a similar way, (2a) entails (2b), since *pizza with olives* is a type (a subset) of pizza, and hence the fact that John gets stains in his t-shirt when he eats pizza implies that when he is eating pizza with olives the stains will also appear. Again, the relationship is asymmetrical: (2b), does not entail (2a) (i.e- potentially, (2b) could imply that there is something special about *pizza with olives* that makes it the case that John get stains).

Contexts like the antecedent of a conditional, in which the expression entails the truth of the sentence in all its more specific expressions (its subsets), as example (2a) are called Downward Entailing (DE). By contrast, the consequent of a conditional, in which an expression in a sentence entails the truth of that sentence in all its more general expressions (its supersets), as example (1a), are called Upward Entailing contexts (UE) [1].

The existence of entailment and in particular the contrast between UE and DE contexts is of crucial importance for linguistic theory, since they allow theoreticians to state important generalizations and unify several apparently disparate linguistic phenomena (Su et al., 2012). For instance, the interpretation of 'or' as inclusive or exclusive disjunction, as well as the interpretation of other words with logical valence (Chierchia, Crain, et al., 2001), or the licensing of negative polarity items[2], depend on entailment, i.e. on the monotonicity of their local environment.

[1] In this characterization of contexts, we are ignoring non-monotonic expressions (eg. exactly one *X*, more than two *X*, less than 10 *X*).

[2] Negative Polarity Items (NPI) can only appear in DE contexts, -eg. 'any', 'ever', 'anymore', 'yet', 'much' (Linebarger, 1980; Gualmini, 2014).

1.2. Empirical results about entailment

Because of its importance for several linguistic phenomena, empirical research has focused on entailment and, developmentally, on when children come to understand the phenomena that depend on it.

Several cross-linguistic studies showed that 4- and 5-years-olds are sensitive to entailment contexts when interpreting words with logical valence, like 'or' (Chierchia, Crain, et al., 2001; Gualmini, 2014) or numerals (Panizza et al., 2013). Other evidence suggests that by 4 years of age children understand the licensing conditions and interpretation of the English negative polarity item 'any' (O'Leary et al., 1994).

A slightly different approach was taken by Feiman et al. (2019), who investigated how preschoolers understand the mapping of their first numeral words to quantities. They concluded that children understand the entailment relationships that link the numeral words, and use them to advance in their mapping process.

Such studies have marked considerable progress in our comprehension of the development of entailment, but they have a limit: they gather how children understand entailment relationships indirectly, on the bases on how they understand the meaning of certain operators such as 'or', numerals, or NPIs. A direct investigation of children's knowledge of entailment relationships is missing. Understanding when it appears and how it develops is a first fundamental step to understand if we can trace it back to non-linguistic abilities.

1.3. Aim and hypotheses

Here we directly tackle the question of how and when children are sensitive to abstract entailment patterns in UE and DE contexts.

Conditional sentences appear an appropriate linguistic context for testing sensitivity to UE and DE patterns of entailment because they contain a DE context in their antecedent and a UE context in their consequent. Therefore, by using the same linguistic material while inverting the order of antecedent and consequence we can obtain a UE or DE context (see the examples (1) and (2)).

This experimental choice has clear methodological advantages, although it is not innocent, because the DE character of the antecedents of conditionals is questionable (they tend to resist the strengthening of the antecedent or give raise to non monotonic series; see, for example, von Fintel, 2001). Nevertheless, in its favor, it is generally agreed that antecedents are DE across contexts that are sufficiently 'similar' (von Fintel, 2011): furthermore, conditionals seem to be comprehended already by 3 year olds (Scholnick et al., 1995) and, crucially for our long-term projects, under certain assumptions they might be translated into non-verbal scenes (Menzies et al., 2020), accessible even to young children (Jorgensen et al., 1992).

If children are sensitive to entailment, we expect them to be disposed to draw inferences from the set to the superset (that is, from *Dalmatian* to *dog*)

but not vice versa (so, not from *dog* to *Dalmatian*) in UE contexts. In DE contexts predictions are less firm, due to the potential factors mentioned above; however, assuming that the pragmatic context is clear enough to dispel potential non-monotonic interpretations, we expect them to be able to infer from the set to its subsets (that is from *pizza* to *pizza with olives*) but not vice-versa (not from *pizza with olives* to *pizza*).

There are different ways to instantiate entailment relations with lexical materials. It is possible to do it by using lexical concepts, as in *Dog-Dalmatian*, or by creating expressions compositionally, as in *pizza-pizza with olives*. The former requires less operations but more knowledge. With young children as our target participants, to avoid the need to assume knowledge of the correct categorical hierarchies of our reference sets, we tested compositional concepts.

We will first present the results of an experiment with adult participants, whose purpose is to tune the stimuli and set a comparison baseline for the study of children's understanding of UE/DE contexts (experiment 1). Experiment 2 will explore 3-to-6 year-olds' comprehension of such contexts.

2. Experiment 1

2.1. Participants

The data from 34 Catalan speakers (M= 21.55, range= 20-25 years, 21 females) were analyzed for the study. Four additional participants were tested but excluded because they made more than 25% of error in a control question. Participants were recruited from the CBC (Center for Brain and Cognition- UPF, Barcelona) database and received €5 for their participation.

2.2. Methods

We prepared four computerized cartoon-like stories using Apple Keynote, exporting them to QuickTime moves.

All the stories begun by introducing the main character (which could be a boy or a girl, counterbalanced) and then his/her friends. After that, the narrator (a male voice speaking in a child-directed manner) specified the characters' goals, which varied according to the set of objects in the story (pizza, cakes, dogs or trucks), and showed the two friends selecting one of the objects. Then, the narrator informed the participant that it was the main character's turn, and that his/her actions were function of a conditional sentence such as:

(3) If John enters into the tent, he eats pizza with olives. (UE context)

(4) If John eats pizza with olives, he gets stains in his t-shirt. (DE context)

As the example shows, the target set (in that case, *pizza with olives*) could appear in the antecedent or the consequent of the conditional. The behavior of the main character varied depending on the context and condition of the trial. In UE

contexts, s/he always overtly verified the antecedent of the conditional (in that case, John would have gone inside the tent). In DE contexts, participants were informed that the main character either acted on the superset or the subset of the mentioned set (so, in that case they were told that John was eating *pizza* for the Superset Condition, and *pizza with olives* for the Subset Condition). We also included a Control condition, in which we falsified the antecedent of the conditional (e.g. in UE contexts John would stay outside the tent, while for DE Contexts, John would eat pepperoni pizza).

At that point the video would stop and the participant was asked to answer a control question, which required either drawing the inference in UE contexts (in our example, it would ask 'What will John eat?') or recalling the exact object the main character is manipulating ('What is John eating?'). Participants who made more than 25% of error in this question were excluded from analyses (4 participants).

The video resumed with the target child moving to a position such that the consequent of the conditional sentence could be satisfied. However, crucially, s/he was partially hidden, so that participants could never see whether s/he was realizing the action or not. Thus, in the above example, in an UE context John would enter into the tent and move the mouth as it was eating, though participants could not see what he was eating, while in DE contexts John was behind a table, so that participants could not see whether he was getting stains or not.

Following that phase, a new friend (a boy or a girl, also counterbalanced) came into the scene, greeted all the others and asked them about the consequent of the scene. In UE contexts, the new friend asked who was manipulating either the superset or the subset of the mentioned objects (in the above example, the new friend would ask 'who is eating pizza?' in the Superset Condition and 'who is eating pizza with olives and mushrooms?' in the Subset and Control Conditions). In DE Contexts, s/he asked who performed the actions coded in the consequent of the conditional ('who got stains?'). Participants answered the question by selecting the characters who fitted the description. Selection of the target character was the dependent variable.

Figures 1 and 2 display the structure of the trials.

The experiment comprised 20 trials, organized in 4 'blocks' of 5 (4 test conditions [UE-Superset, UE-Subset, DE-Superset, DE-Subset] + 1 control [which could be Upward or Downward, depending on the block], order of the trials randomized within blocks), without any pause between trials. Thus, the complete design crossed 2 Contexts (Upward vs Downward) x 3 Conditions (Subset vs Superset vs Control), generating 16 test trials (4x4) and 4 controls (2 Upward and 2 Downward per participant).

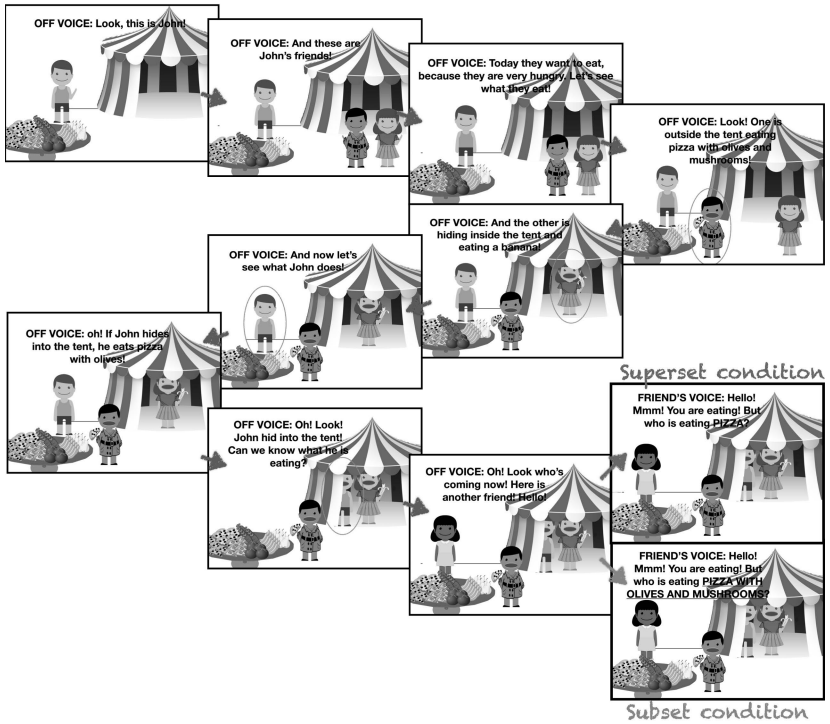

Figure 1: **Example of a test item of an Upward entailing trial**

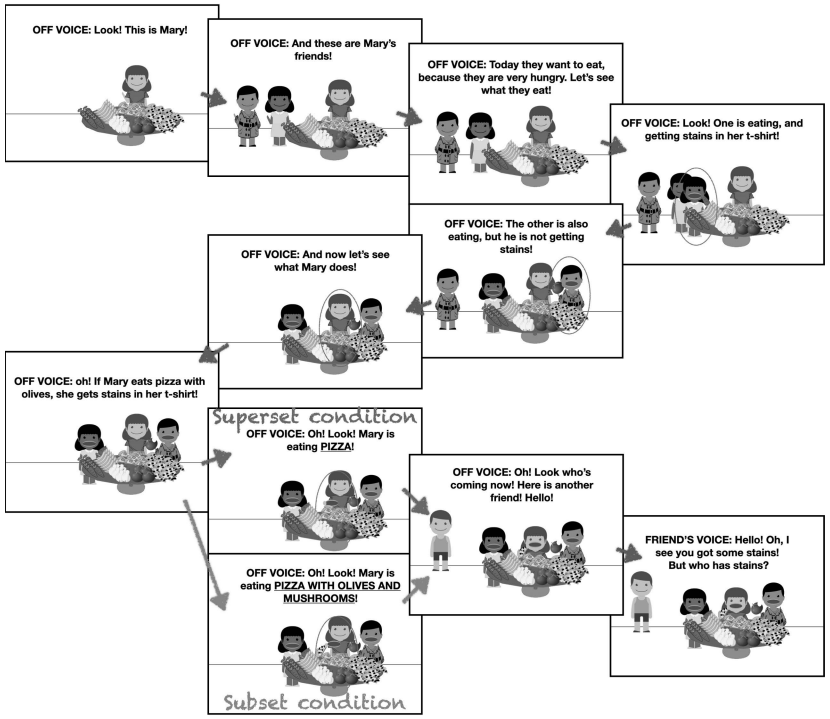

Figure 2: **Example of a test item of a Downward entailing trial**

2.3. Results

Participants selected the target character in the control condition only rarely (DE-control: M = .03; sd= .12; UE-control: M = .0, sd= .0), showing engagement with the logical form of the target question. Turning to the experimental questions, data were analyzed with a Generalized Linear Mixed Model. The maximal converging model included Context (UE vs DE) and Condition (Superset versus Subset) as Fixed effects as well as their interaction. All fixed effects were coded with contrast coding. 'Participant' was included as intercept and by random slope by Context and by Condition; and 'Story' was included as random intercept. There were effects of Context (β = -1.15, se= .32, $\chi^2(1) = 12.16$, p <.001), of Condition (β = -1.25, se= .32, $\chi^2(1) = 13.42$, p <.001), and of their interaction ($\beta = 7.57$, se= .78, $\chi^2(1) = 214.98$, p <.001). Pairwise comparisons using Wilcoxon rank sum test with continuity Bonferroni correction confirmed that invalid inference conditions (that is, UE-subset and DE-superset conditions) were not different from each others (DE-superset: M = .15, sd = .21;UE-subset: M = .15, sd = .22; p=1), but they were different from both UE-superset and DE-subset (all p's<.001). UE-superset and DE-subset (both valid inference conditions) were different from each other (DE-subset: M= .57, sd = .37; UE-superset: M =.89, sd = .24; p=.001).

Figure 3 is a summary of our findings.

While the overall pattern of results was in accord with our predictions, this last result, due to a relatively low level of correct responses in the DE-subset condition, was unexpected. In order to examine whether participants' initial interpretation of the task could account for this result, we further inspected responses in the DE-subset condition. We analyzed potential changes over time of participants' responses by splitting them into four temporal blocks of 5 trials, each of which contained one DE-subset test trial. A trend towards improving correct responses across experiment appeared (Spearman correlation, rank= .29, p=.003).

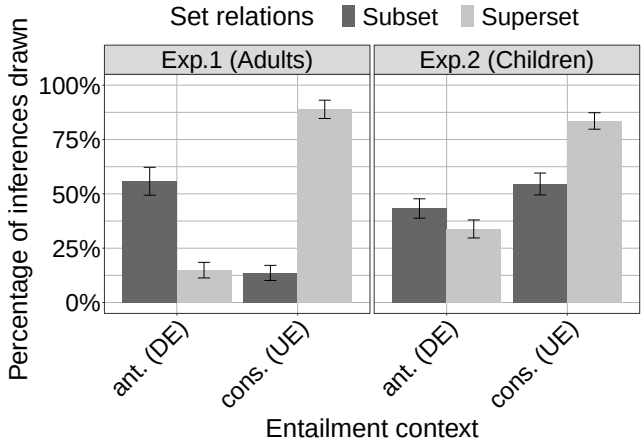

Figure 3: **Mean of target selections as a function of Context and Condition in experiments 1 and 2. Error bars indicate standard error (se). Note that we are not coding *correct* selections, but *all* selections. An ideal responder would select the main character in DE- subset (black) but not superset (grey) and in UE- superset (grey) but not subset (black).**

2.4. Discussion

The aim of this study was to establish a baseline to better evaluate children's responses in situations involving entailment patterns licensed by the same syntactic structures. As expected, participants differentiated conditions in which the invited inference was licensed by the logical context (UE-superset and DE-subset) from the invalid ones, showing that they were sensitive to such entailment patterns. Interestingly, inferences in DE-superset contexts were perceived as less strong than those in DE-subset contexts, even though an a priori theoretical analysis would predict an alike effect. However, such responses revealed a trend to get stronger across blocks, showing that DE deviant responses could depend on an incomplete processing of the task at the first encounter with such contexts.

3. Experiment 2: Children's understanding of entailment

With adults' results as a baseline, we investigated children's understanding of entailment in the same syntactic structures. Participants's age ranged from as young as 3 years, slightly younger than participants in studies where entailment relations were indirectly tested (Chierchia, Crain, et al., 2001; Su et al., 2012; Panizza et al., 2013; Gualmini, 2014) to 6 years, thus extending beyond the age of success in previous studies involving entailment.

3.1. Participants

A sample of 77 Catalan children (39 3-to-4-year-olds and 44 5-to-6-year-olds; M = 4.6; 39 females) were retained for analysis. Other 42 children were tested but were excluded from the sample because of technical problems, because they did not complete enough trials (23 children), or because they made more than 49% of errors in the control question (19 children). They came from Catalonia, most of them from Barcelona and the great Barcelona area (62 children). Thirty-five children were Catalan speakers, 38 were bilingual Catalan-Spanish, one was bilingual Catalan-English, one was bilingual Catalan-French and 3 of them were trilingual (Catalan-Spanish-English). They were recruited among participant families in the Babylab database of the Center for Brain and Cognition, or by direct contacts by the first author. They were tested online and were mailed a small present for their participation.

3.2. Methods

We used the same experimental material and rationale described in Experiment 1 (see section 2.2), with two main differences.

First, the experiment was run online, on the PCIbex Platform (Zehr et al., 2018). So, in order to keep children's attention, we created a video of the experimenter commenting the story. This video was superposed to the experimental material, placed on the right corner of the main video, and did not interfere with it.

Second, we reduced the duration of the experiment, restricting it to 10 trials plus one introduction trial. Trials were organized in blocks of 5 (4 test conditions [UE-superset, UE-subset, DE-superset, DE-subset] + 1 control [which could be UE or DE, depending on the block]), as in experiment 1. The order of the trials was randomized between and within blocks. There were 8 experimental lists.

The experiment lasted for 20-30 minutes (largely depending on the duration of the pause between blocks). All sessions were video-taped using participants webcams and coded offline.

3.3. Results

With these data, as in experiment 1, we performed a Generalized Linear Mixed Model for binomial data, including selection of target child as dependent variable. The maximal converging model included context (UE vs. DE), Condition (Superset vs. Subset) and Age group (3-4 year olds vs. 5-6 year olds), as Fixed effects as well as their interactions. Participant and Story were included as random intercepts. All fixed effects were coded with contrast coding. We found a significant effect for Context (β = -2.002, se= .27, $\chi^2(1) = 70.12$, p <.001;. M=.70, sd=.43 in UE; M=.0.40, sd=.43 in DE), Condition (β = -.66, se= .25, $\chi^2(1) = 7.32$, p <.001; M=.50, sd=.46 for subset; M=.59, sd=.45 for superset), as well as their interaction (β = 2.3, se= .51, $\chi^2(1) = 22.54$, p <.001). There was no effect of age group. Results can be seen in figure 3.

Inspecting the interaction, pairwise comparisons using Wilcoxon rank sum test with continuity Bonferroni correction showed that UE-superset was different from all other conditions, including UE-subset and DE-superset (all p's <.001), thus confirming that children were sensitive to Condition in UE context. However, unlike adults, there was no difference between Conditions (subset vs superset) in DE contexts (p=.94). Interestingly, children showed a tendency (p=.07) to select the target character more in UE-subset than in DE-subset, contrarily to our expectations (UE-subset: M = .56, sd = .47; UE-superset: M =.85, sd = .33; DE-subset: M= .44, sd = .45; DE- superset: M = .36, sd = .41; fig. 3).

3.4. Discussion

Experiment 2 tested children's sensitivity to abstract entailment patterns in UE and DE contexts. We found two main results. First, children's ability to differentiate UE and DE contexts indicates that they were sensitive to the entailment patterns. Importantly, age was not a factor in children's interpretation of these sentences. This result shows that children's sensitivity to entailment relations is more general that previously thought.

However, our second result is that such a sensitivity is strongly attenuated in DE contexts, where children did not differentiate between valid (subset) from invalid (superset) inferences. The asymmetry between DE and UE contexts reminds the findings of experiment 1: there, also adults treated the contexts asymmetrically. Nevertheless, the asymmetry is clearly stronger in children. Barring possible confounds, the preference for drawing valid inferences in UE than in DE contexts seems to be related to children's interpretation of these sentences, and has to be treated as a semantic effect requiring explanation.

4. General Discussion

In the current study, we aimed at investigating children's understanding of entailment relations. Entailment is a crucial notion that (see, for example, Horn,

1989; Chierchia, 2013) can serve as a unifying glue of several disparate linguistic and developmental phenomena, such as the interpretation of words with logical valence, the distribution of negative and positive polarity items (Su et al., 2012), and the acquisition of numerals (Feiman et al., 2019).

We intended to directly test whether children are sensitive to abstract entailment patterns and in particular, given their centrality, we focused on whether they would be willing to draw inferences from a set to the superset in UE contexts and from a set to the subset in DE contexts. We operationalized this question by selecting a fundamental form in which such patterns can be manipulated: their appearance in the antecedent or the consequent of conditional expressions.

Both adults (exp. 1) and children (exp. 2) were found to be sensitive to the entailment context. From a developmental perspective, this result clearly shows that the perception of such relations needs not be triggered by any particular lexical element with logical import, such as a quantifier or a numeral (Chierchia, Crain, et al., 2001; Panizza et al., 2013). Rather, entailment is well within the logical resources of young children, who can look for logical patterns even in arbitrary complex sentences, and are able to flexibly adapt the interpretation of phrases as a function of their position within a frame defined by the overarching logical structure, such as an implication. This result suggests that children may be endowed with a natural sense of entailment relations, possibly common with a general sense of the organization of sets and set relations.

At the same time, both children and adults exhibited a higher predisposition to draw valid inferences in UE than in DE contexts. In children such an asymmetry was more extreme, to the point that there was no significant difference between valid and invalid DE inferences. By contrast, adults' sensitivity improved after some experience with the task.

This asymmetry is open to several interpretations. As we remarked, the DE character of the antecedent of conditionals is controversial, as it is easy to create contexts in which it does not respect downward entailment.It is possible that the contextual information provided in the task was not sufficient to exclude such interpretations and DE-inferences may have appeared as not clearly supported for our participants. This hypothesis deserves a separate investigation.

Alternatively, the lower implication pattens in DE-subset stories could be an effect of the pragmatics of the task. Usually, specification of subsets has a contrastive effect (similar to the classic Piaget's class inclusion question, see Politzer, 2016), so that mentioning a *pizza with olives and mushrooms* induces to think of the complementary set of pizzas with olives and something else (or without mushrooms), as an alternative choice to the pizza with mushroom and olives, as opposed to a subset of pizzas with olives. Children may be particularly sensitive to such invited contrasts. A way to test this interpretation is provided by entailment contexts created with lexical items (*dog - Dalmatian*), in the place of the compositional phrases used in the current experiments (*pizza -pizza with olives*). Such contexts lift the invited contrast and thus may be more open to perceive the differences between subset and superset implications. Interestingly, focus can be

used to bring back the contrastive subset. We plan to extend the current research to test such predictions.

Another (non exclusive) possible interpretation is that DE-subset inferences are less spontaneous and immediate than the UE-superset ones, so that participants may have to overcome resistance to draw inferences towards the DE-subset. That inferences to the subset are inherently more difficult than inferences to the superset has been argued by several authors (Geurts, 2003; Geurts and Der Slik, 2005). Increased difficulty to infer to the subset has been related to general, non-linguistic facts, perhaps present even in nonverbal animals (McGonigle et al., 1996), such as non-human primates.

Finally, a tendency to preferentially encode the superset compared to the subset, which would render UE inferences easier to be drawn, may depend on perception; indeed, a germane phenomenon has been observed in visual tasks, both in adults and children (Zosh et al., 2011). The fact that the asymmetry we found may be due to such phenomena extraneous to language proper, but tied to our general conception of set and set relations, makes it possible to hypothesize that the perception of entailment in language may arise from a natural sense of set and set relations, spanning across perception and reaching into cognition. These considerations may support the idea that entailment and set relations are part of the primitive properties of human inferential and perceptual abilities. A host of further research is needed to properly support this enticing hypothesis.

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