Logical thought and logical words: Developmental links between non-verbal reasoning and language

Introduction How are logical reasoning and language related in development? A core question concerns whether logical reasoning depends on language, or whether it can emerge independently and only later become integrated with linguistic representations[1-3]. Disjunctive reasoning, formalized as $A \vee B$; *exclude* $A \rightarrow B$, is a logical ability thoroughly studied by developmental psychologists. Recent work shows that preverbal infants can draw disjunctive inferences from visual events as evidenced by their sensitivity to violations of such inferences[4,5]. By contrast, from a linguistic perspective, preschoolers do not consistently assign adult-like interpretations to sentences containing the logical connective "or" until later in development[6,7], and its production is rare compared to other connectives such as "and"[8,9]. This raises the question of when children understand the meaning of "or", and how non-verbal abilities relate to the later acquisition of logical language. Specifically, can 3-year-old children use the connective "or" to derive disjunctive inferences? Moreover, can non-verbal disjunctive inferences scaffold children's comprehension of this logical connective?

Objectives and methods To address these questions, we conducted two preregistered experiments with English-speaking 3-year-old children. Our aims were (i) to test whether children at this age can perform disjunctive inferences in non-verbal and linguistic contexts, and (ii) to examine whether prior engagement in non-verbal disjunctive reasoning facilitates children's interpretation of "or". In Experiment 1, 24 children (*M*age = 39 months 10 days; range = 36m12d – 42m22d; 14 boys) first completed a *non-verbal inferential cognitive task* involving only visual information. Two objects sharing an identical top were hidden behind an occluder; a cup scooped one object, revealing only its top; the other object then briefly reappeared from behind the occluder; finally, children were asked which object was in the cup. Success required excluding the visible alternative and inferring the identity of the hidden object (Figure 1A). Children then completed a *linguistic inferential task*, which was structurally identical to the first task but with one key difference: children heard a disjunctive statement (e.g., "The object is the car or the ball") and had to integrate it with visual evidence to identify the correct object (Figure 1C). In Experiment 2, a new group of 24 children (*M*age = 38 months 19 days; range = 36m9d – 42m17d; 11 boys) completed the same linguistic inferential task, but crucially, instead of first completing the inferential cognitive task, they were initially tested on a *non-inferential control task* in which the cup's content was directly revealed, thus not requiring disjunctive inference (Figure 1B). Each task consisted of four trials, and the experiments followed a fully counterbalanced design yielding 16 conditions crossing four factors: target object, order of linguistic disjuncts in the inferential linguistic task, object position on the screen, and trial order.

Results All analyses were conducted using Bayesian one-sample Wilcoxon signed-rank tests (see Figure 1D). Children succeeded in the non-verbal inferential task in Experiment 1, identifying the correct object well above chance (M = 88.19%, SD = 24.32; BF_{10} = 6715). They also succeeded in the non-inferential control task in Experiment 2 (M = 95.49%, SD = 10.42; BF_{10} > 10,000). In the linguistic task, we distinguished two components of disjunctive reasoning. First, we tested whether children interpreted "or" as restricting the set of possible referents to the verbal disjuncts (i.e., from three initial objects to "A or B"). Children in Experiment 1 named one of the disjuncts significantly above chance (M = 88.54%, SD = 22.1; BF_{10} = 45.14), whereas children in Experiment 2 did not (M = 74.65%, SD = 23.38; BF_{10} = 0.542). Second, we tested whether children could exclude one of the two disjuncts based on visual information. Children in both experiments succeeded on this component, reliably selecting the correct alternative once the relevant set was established (Exp1: M = 90.28%, SD = 16.6; BF_{10} >

10,000; Exp2: $M = 89.24\%$, $SD = 18.3$; $BF_{10} > 10{,}000$). A direct comparison confirmed that children in Experiment 1 showed a stronger understanding of "or" as a linguistic cue to define a set of disjunctive alternatives than children in Experiment 2 ($BF_{10} = 2011.87$, $\omega = 0.75$, 95% HDI [0.617, 0.876]; Bayesian Mann-Whitney test).

Discussion Our results have major implications for the development of logical reasoning, the acquisition of verbal disjunction, and the relation between the two. First, we found that at age 3 children are not only highly proficient in deductive reasoning based on visual information but can also generate disjunctive inferences by integrating their comprehension of "or"-phrases with visual information. This suggests that the ability to draw deductive inferences may contribute to the early meaning of "or"[10]. Crucially, we also found that, at the onset of verbal disjunction, even a brief practice with the non-verbal disjunctive inference documented in infants[4,5] improves children's comprehension of verbal disjunction. These findings provide strong support for the proposal that preverbal disjunctive inference functions as a developmental precursor scaffolding the acquisition of the meaning of "or".

(809 words)

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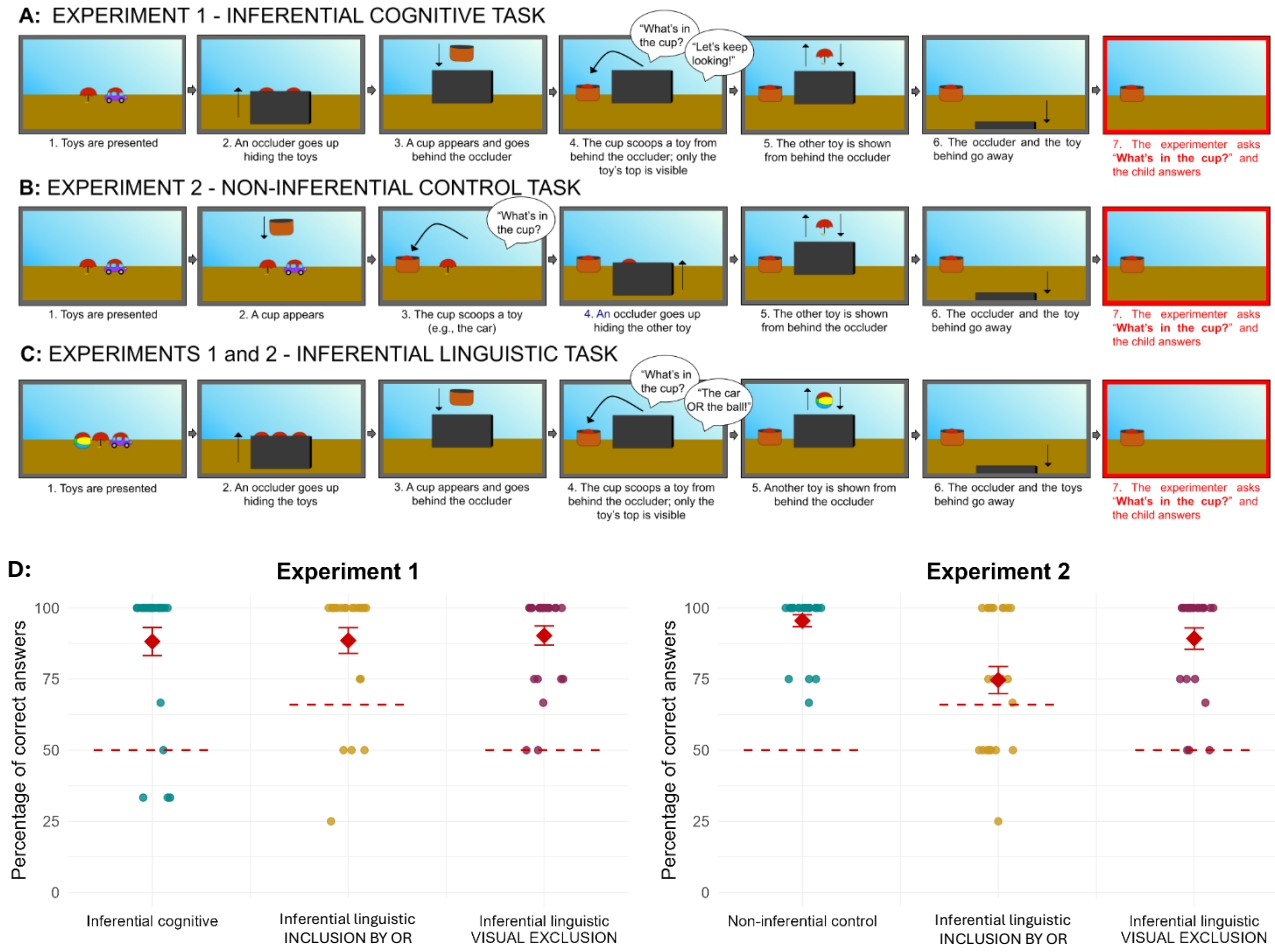

Figure 1: Stimuli and procedure for the three tasks and results across experiments. In the tasks, examples are taken from one of the 16 counterbalanced conditions, which vary target object, order of linguistic disjuncts in the inferential linguistic task, object position on the screen, and trial order. Speech balloons display the prerecorded sentences heard by the child. **A:** *Inferential cognitive task* in Experiment 1: Children can infer the hidden object's identity by reasoning from visual information alone. **B:** *Non-inferential control task* in Experiment 2: Children do not need to infer the identity of the hidden object, as they can directly see which object the cup scoops. **C:** *Inferential linguistic task* in Experiments 1 and 2: Children can infer the hidden object's identity by integrating visual and linguistic information. **D:** The percentage of correct answers across tasks in the two experiments. *Inferential cognitive task*: percentage of trials in which a child named the correct object; *Inferential linguistic task (inclusion by OR)*: percentage of trials in which a child named either verbal disjuncts; *Inferential linguistic task (visual exclusion)*: percentage of trials in which a child named the correct object among the two verbal disjuncts. Dots show participants' scores, red rhombuses the group means, error bars the standard errors, and the dashed red lines the chance level.