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When can young children reason about an exclusive disjunction? A follow up to Mody and Carey (2016)

Shalini Gautam *, Thomas Suddendorf, Jonathan Redshaw

Early Cognitive Development Centre, School of Psychology, The University of Queensland, St. Lucia, Queensland 4072, Australia

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ABSTRACT

Mody and Carey (2016) investigated children's capacity to reason by the disjunctive syllogism by hiding stickers within two pairs of cups (i.e., there is one sticker in cup A or B, and one in cup C or D) and then showing one cup to be empty. They found that children as young as 3 years of age chose the most likely cup (i.e., not A, therefore choose B; and disregard C and D) and suggested that these children were representing the dependent relationship between A and B by applying the logical operator "or". However, it is possible that children succeeded using simpler strategies, such as avoiding the empty cup and choosing within the manipulated pair. We devised a new version of the task in which a sticker was visibly removed from one of the four cups so that 2.5- to 5-year-old children ($N = 100$) would fail if they relied on such strategies. We also included a conceptual replication of Mody and Carey's (2016) original condition. Our results replicated their findings and showed that even younger children, 2.5 years of age, could pass above chance levels. Yet, 2.5-, 3- and 4-year-olds failed the new condition. Only 5-year-old children performed above chance in both conditions and so provided compelling evidence of deductive reasoning from the premise "A or B", where "or" is exclusive. We propose that younger children may instead conceive of the relationship between A and B as *inclusive* "or" across both versions of the task.

1. Introduction

Representing the relationship between two dependent possibilities, "A *or* B", has been suggested to rely on abstract combinatorial thought (Penn, Holyoak, & Povinelli, 2008; Premack, 2007). In particular, it involves understanding the logical operator "or" and allows for subsequent deductive reasoning, as in a disjunctive syllogism: "A or B, not A, therefore B". To reason by disjunctive syllogism, one must *first* represent A and B as two possibilities of which at least one must be true. Then, if A is ruled out, one can logically infer that B is true. The disjunctive syllogism is valid whether the "or" is *inclusive* (A or B, maybe both: Kate is eating cake or ice-cream, but maybe she is eating both) or *exclusive* (A or B, not both: Kate is in Denmark or Australia, but she is not in both). In either case, if one possibility is ruled out, there is *deductive certainty* that the alternative must be true.

Some research has found that even infants and nonverbal animals can succeed at simple tasks designed to measure deductive reasoning (Call, 2004; Hill, Collier-Baker, & Suddendorf, 2011, 2012; Mody & Carey, 2016). A typical study involves a prize or desired object, which is surreptitiously hidden within one of two opaque containers (i.e., "A or B"). One of the containers is then shown to be empty (i.e., "not A"), and thus the logical place to search is the alternative container (i.e., "therefore B"). However, success on these tasks might not necessarily show that animals or infants can represent the dependent relationship "A or B", because the correct choice can be driven by representing 'what is where' or by following a simple rule: *avoid the empty location* (see Call, 2006; Premack & Premack, 1994).

Mody and Carey (2016) aimed to address these alternative explanations in their test of 2.5- to 5-year-old children's capacity for deductive reasoning. They extended Call's (2004) original task by including four opaque cups and two stickers as prizes. The cups were presented in two pairs, and one sticker was hidden within each pair (i.e., the first sticker could be found in cup A or B, and the second sticker in cup C or D). Then, as in the original task, one cup was shown to be empty (i.e., "not A"). Mody and Carey (2016) hypothesised that if children were searching for stickers *without* representing the premise "A or B", or if they were simply avoiding the empty cup, then they should equally choose between any of the three remaining cups that at least *might* contain a sticker (i.e., B, C or D). However, if children understand and remember that one reward is hidden among each pair, and they *can* set up the

* Corresponding author at: School of Psychology, University of Queensland, Brisbane, St. Lucia 4067, Australia.
E-mail address: shalini.gautam@uq.net.au (S. Gautam).

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premise “A or B", then they should preferentially choose the alternative cup within the pair of cups where one was just revealed to be empty (i.e., choose B) and avoid the other pair (i.e., disregard C and D). This is because cup B was guaranteed to contain a sticker whereas both cups C and D were only 50% likely to contain a sticker. The authors found that 3- to 5-year-old children chose cup B significantly more often than a chance level of 33.3%, whereas 2.5 year-old children did not. Taken at face value, this finding implies that at least some 3- to 5-year-olds are capable of reasoning from the premise “A or B" where the “or” is exclusive, i.e., an exclusive disjunction.

We suggest, however, that even in this task many children could be relying on simple cues that encourage them to pick the correct cup. For example, the cups in Mody and Carey’s (2016) task were arranged in pairs, and the stickers were hidden one at a time behind an occluder, which further emphasised these pairs (by covering one pair and then the other). In addition, the experimenter clearly draws the children’s attention to a particular pair by showing them an empty cup. Therefore, children may simply search within that pair and disregard the other pair altogether. This type of responding would result in success without children necessarily understanding the dependent relationship between A and B. In the present study we attempt to rule out these kinds of lower level routes to success. In our *show empty* condition, we conceptually replicate Mody and Carey’s (2016) methodology while also further emphasising the two-pair cup structure: we use same-coloured cups for each pair and introduce a puppet that visits all four cups in pairs without occluders (hiding one sticker in A or B and one sticker in C or D, before showing that A is empty).

Critically, we also include a novel *remove sticker* condition, in which children who simply pick within the emphasised pair of cups will not succeed. In this condition, the puppet also hides two stickers within two pairs of cups (i.e., A or B, and C or D), before a sticker is *removed* from one of the cups (i.e., A *was* correct but is no longer an option). Choosing the alternative cup within that pair (i.e., B) will therefore always lead to no reward, whereas selecting a cup from the other pair (i.e., C or D) has a 50% chance of success. In this condition, as in Mody and Carey’s (2016) study, children will succeed if they can reason from the exclusive disjunction “A or B" (i.e. the sticker is in cup A or cup B, but not in both). Unlike in Mody and Carey’s (2016) study, however, children must apply deductive reasoning to *rule out* the pair of cups that have been emphasised. In this condition, the heightened emphasis of the cup pairings works to our advantage: because there are two correct choices among the three cups, the chance performance level is a rather high 66.7%, and therefore it is important to ensure that children can readily track which cup belongs to which pair.

2. Method

2.1. Participants

The final sample consisted of 100 children: 25 2.5-year-olds (M = 33.04 months, SD = 2.23 months range = 27–35 months, 12 boys), 25 3-year-olds (M = 41.2 months, SD = 2.99 months, range = 36–46 months, 14 boys), 25 4-year-olds (M = 53.44 months, SD = 3.61 months, range = 47–59 months, 10 boys) and 25 5-year-olds (M = 64.6 months, SD = 4.08 months, range = 60–71 months, 10 boys). This sample size was similar to Mody and Carey (2016), who had 96 participants across the same age groups. Children were either tested at the Queensland Museum (n = 88), or at the Early Cognitive Development Centre within the University of Queensland (n = 12). Twenty additional children were excluded for failing to complete all trials due to disengagement with the task (n = 8), because of interference by their caregiver (n = 1), because of experimenter error (n = 7), because of failing the training trials (n = 1) or because the child chose a cup that had just been shown to be empty, or had a sticker removed from it, on any trial (n = 3). All children received a small prize for participating.

2.2. Materials

Four cups were used as the hiding locations, two painted orange and two painted green. A sock puppet introduced as ‘Sally the Snake’ (controlled by the experimenter) hid the stickers.

2.3. Procedure

2.3.1. Training

Prior to the main task, children were given two training trials in which a single sticker was hidden under one of two cups. The puppet ‘Sally the Snake’ picked up and occluded the sticker before she visited both cups and then showed the children that she no longer had the sticker. In the first training trial, one cup was shown to be empty and children were encouraged to search for the sticker. Only one child failed this training trial, and was therefore excluded from the study. In the second training trial, children were told that Sally the Snake also loved stickers, and so she would have a turn finding the next sticker. This sticker was identical to the one the child had just received. Sally proceeded to find the sticker, which was always hidden under the alternate cup to the one it was in during the first training trial. After Sally had removed the sticker, the experimenter tapped the cup next to the one where the sticker had been and stated, *“This cup is empty, isn’t it?”* Following this, children were shown the empty cup to confirm visually that it was in fact empty. The purpose of these training trials was to communicate to the children that there was no “trick” involved in the procedure, and that if the snake had taken a sticker from a pair of cups then there were indeed no more stickers located within those cups.

2.3.2. Test conditions

Following training, all children participated in both test conditions. There were two trials of each condition, and therefore four trials in total. See Fig. 1 for a depiction of the trial sequence.

2.3.3. Show empty condition

Following Mody and Carey (2016), two identical stickers were hidden among four cups: two orange and two green. Sally surreptitiously hid the sticker under one pair of coloured cups (e.g., green), as in the procedure of the training trial. She repeated this with a second sticker and the second pair of coloured cups. Therefore, children could be sure there was a sticker hidden under the green pair of cups *and* the orange pair of cups, but they could not be sure which cup within each pair. Children were then shown an empty cup and, following this, they were given one chance to search for a sticker. There were four ways this procedure differed from that of Mody and Carey (2016): (1) The stickers were hidden by the puppet Sally, rather than directly by the experimenter; (2) No occluders were used when hiding the stickers, as Sally visited each cup with the sticker hidden in her mouth; (3) Sally revealed the empty cup rather than a second experimenter; and (4) the cups within each pair were the same colour.

2.3.4. Remove sticker condition

In this condition, the stickers were hidden in the same manner as in the show empty condition. However, unlike in the *show empty* condition, children were told that this time Sally was going to have a turn to find the sticker. Sally then found one of the stickers, removed it, and the cup was replaced. Children then had the chance to search for the second sticker.

2.3.5. Counterbalancing

See Supplementary Materials for counterbalancing procedures. We found no order effects on children’s performance.

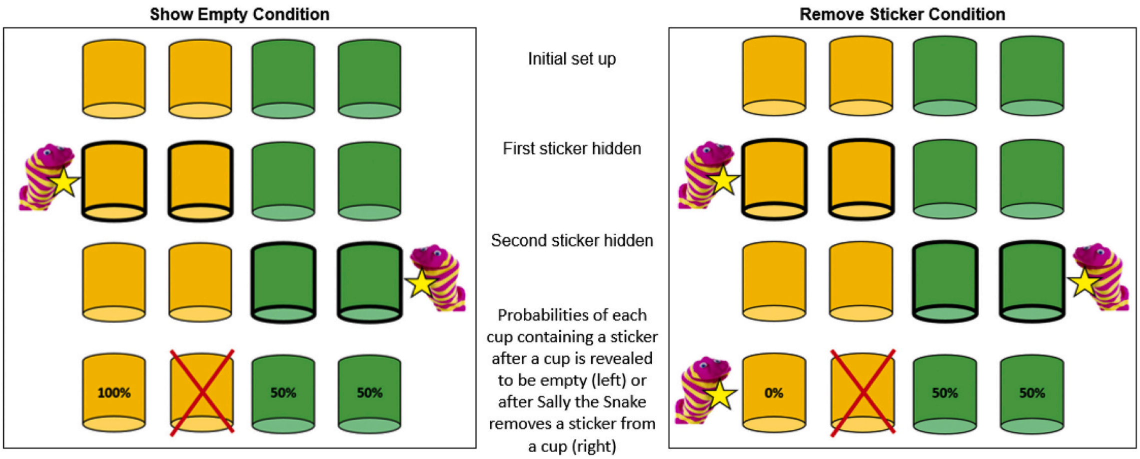

Fig. 1. The arrangement of the *show empty* condition (left) and the *remove sticker* condition (right). The cups that are highlighted by a bolded outline are the locations that Sally the Snake visited when hiding each sticker. The red X represents the cup that is shown to be empty (left, *show empty* condition) or the cup where the sticker is removed by Sally the Snake, and thereby *becomes* empty (right, *remove sticker* condition). Percentages indicate the actual chance of finding the sticker under each cup after one of the cups is revealed to be empty/becomes empty. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Results

3.1. Show empty condition

We followed the analysis plan set out in Mody and Carey (2016). Chance was set at 33.3%, because there were three remaining cups children could choose from after one cup was shown to be empty. No children selected the cup that was shown to be empty in these trials. We used a Bonferroni correction for multiple analyses, resulting in an adjusted alpha of 0.0125. Collapsed across both trials, the 2.5-, 3-, 4- and 5 year olds all chose the target cup significantly more often than chance: 2.5-year-olds on 72% of trials $t(24) = 6.63$, $p < .001$; 3-year-olds on 76% of trials $t(24) = 7.28$, $p < .001$; 4-year-olds on 80% of trials $t(24) = 8.08$, $p < .001$; and 5-year-olds on 82% of trials $t(24) = 7.63$, $p < .001$, (see Fig. 2 for a depiction). There was no evidence of learning over trials (see Table 1).

3.2. Remove sticker condition

For this condition, chance was set at 66.7% because two out of the remaining three cups had a 50% likelihood of containing the sticker and were thus counted as target cups (see Fig. 1). Three children (two 2.5-year olds and one 3-year-old) selected the cup from which the sticker had just been removed and these children were excluded from the final sample. Again we used a Bonferroni correction for multiple analyses resulting in an adjusted alpha of 0.0125. Collapsed across both trials, the

Table 1
Trial-by-trial performance for each condition split by age group.

Age	Show empty condition		Remove sticker condition	
	Trial 1	Trial 2	Trial 1	Trial 2
2.5-year-olds	21/25 (84%)	15/25 (60%)	14/25 (56%)	13/25 (52%)
3-year-olds	20/25 (80%)	18/25 (72%)	16/25 (64%)	14/25 (56%)
4-year-olds	21/25 (84%)	19/25 (76%)	20/25 (80%)	17/25 (68%)
5-year-olds	20/25 (80%)	21/25 (84%)	24/25 (96%)	25/25 (100%)
Total	82/100 (82%)	73/100 (74%)	74/100 (74%)	69/100 (69%)

Note. There were no significant changes in performance across trials for any age group, all $p > .05$.

2.5-, 3- and 4-year olds succeeded at levels no different than chance: 2-year-olds on 54% of trials, $t(24) = -1.80$, $p = .084$; 3-year olds on 60% of trials, $t(24) = -0.94$, $p = .355$; and 4-year-olds on 74% of trials, $t(24) = 1.03$, $p = .315$. The 5-year-olds, by contrast, succeeded significantly more often than chance (98% of trials), $t(24) = 15.67$, $p < .001$, with only one 5-year-old failing one of the two trials (see Fig. 2 for a depiction). There was no evidence of learning between trials in any age group (see Table 1 that depicts the number of children who succeeded in each trial of each condition). One might suggest that younger children were simply appearing to perform at chance at the group level because some individuals were succeeding on both trials and others were succeeding

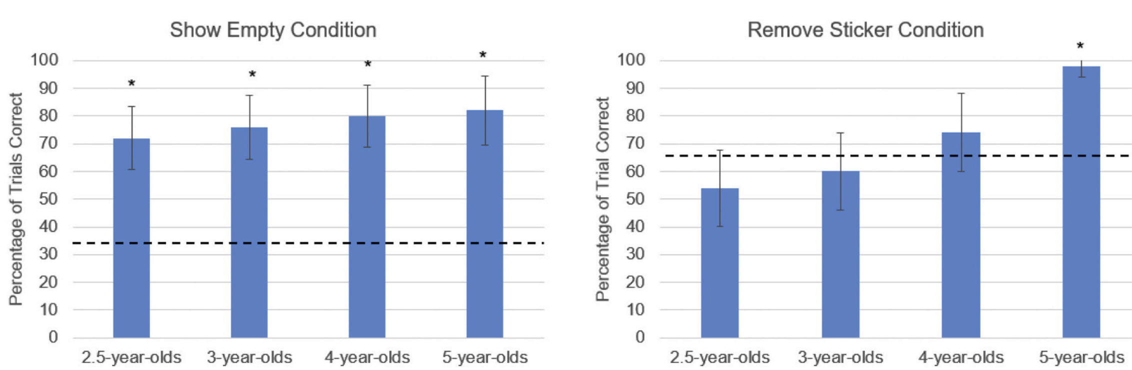

Fig. 2. Percentage of trials correct for each condition by age group. The dotted lines indicate chance level: 33.3% for the *show empty* condition and 66.7% for the *remove sticker* condition. Error bars represent 95% confidence intervals. *Note.* * < 0.001.

on neither. However, there was no evidence of such a pattern (see Table 2).

3.3. Age effects

The effect of age on performance was tested by treating age (in months) as a continuous variable. For the *show empty* condition, the age effect did not reach significance, $r(98) = 0.163$, $p = .106$, whereas age did significantly predict performance in the *remove sticker* condition, $r(98) = 0.495$, $p < .001$. Performance between the conditions was correlated such that success in one predicted success in the other, $r(98) = 0.252$, $p = .011$. A partial correlation revealed that age predicted performance on the *remove sticker* trials even when controlling for performance on the *show empty* trials, $r(97) = 0.475$, $p < .001$. Thus, there were age-related improvements in the *remove sticker* trials above and beyond those seen in the *show empty* trials.

3.4. Post hoc analyses with alternative chance values

We further investigated how children performed compared to a 50% chance level in both conditions. This is because after children were shown an empty cup, or a sticker was removed, they might have been responding by guessing between sides, rather than individual cups. They might have done this because the two colours of the cups may have functioned as cues (e.g., avoid the empty cup [or removed sticker cup] and pick either a green cup or an orange cup). As above, we used a Bonferroni correction for multiple analyses resulting in an adjusted alpha of 0.0125. When the chance value was set at 50%, we found:

In the *show empty* condition, the 2.5-, 3-, 4- and 5-year olds again all chose the target cup significantly more often than chance: 2.5-year-olds, $t(24) = 3.77$, $p = .001$; 3-year-olds, $t(24) = 4.44$, $p < .001$; 4-year-olds, $t(24) = 5.20$, $p < .001$; and 5-year-olds, $t(24) = 5.02$, $p < .001$. This is the first evidence of children younger than 4 years passing significantly above 50% in such a task (cf. Grigoroglou, Chan, & Ganea, 2019; Leahy & Carey, 2020; Mody & Carey, 2016). In the novel *remove sticker* condition, the 2.5- and 3-year-olds again performed at levels no different from chance: 2.5-year-olds, $t(24) = 0.57$, $p = .574$; 3-year-olds, $t(24) = 1.41$, $p = .170$. However, even 4-year-olds chose one of the target cups significantly more often than a 50% chance level, $t(24) = 3.36$, $p = .003$ (as did the 5-year-olds, $t(24) = 24.00$, $p < .001$).

4. Discussion

We investigated when children become able to reason deductively from the exclusive disjunction "A or B", controlling for simpler alternative explanations. We replicated Mody and Carey's (2016) findings that 3- to 5-year-old children can select the appropriate cup (i.e., B) when shown that the other cup within that pair is empty (i.e., not A). Furthermore, we found that even 2.5-year-olds performed above an a priori chance level of 33.3% in this condition, which is consistent with the results of another recent replication study (Grigoroglou et al., 2019). However, in contrast to performance in the *show empty* condition, children of most ages performed poorly in the novel *remove sticker* condition, where they were shown the removal of one of the two hidden stickers (i.e., A) and should therefore infer that the other cup within that pair is empty (i.e., not B). Only the 5-year-olds in our sample succeeded above an a priori chance level of 66.7% in this condition, and correctly selected a cup from the alternative pair (i.e., C or D).

We originally hypothesised that the *show empty* version of the task may not be a valid measure of deductive reasoning from the premise "A or B". That is, children who passed the task might have simply been searching for the stickers within the pair that was emphasised. If this was the case, however, then they should have systematically selected the wrong cup in the *remove sticker* condition. They did not. Contrary to our hypothesis, the 2.5-, 3- and 4-year-olds performed no differently from the a priori chance level of 66.7%. This pattern suggests that they were not simply relying on an "avoid the empty cup and choose the alternative cup within this pair" strategy, but it also fails to substantiate the interpretation that they can reason from the premise "A or B". At face value, it might have been the case that some individual children rely on simple cues, and others are capable of reasoning from the premise "A or B", thus evening out to chance performance at the group level. However, our results do not show a bimodal distribution along these lines, which makes such an interpretation unlikely (see Table 2).

We also considered the possibility that children may have resorted to simply choosing between the two types of coloured cups. That is, if children were not able to reason from the premise "A or B", and they were shown either an empty cup, or a sticker was removed, they may have searched the remaining cups by randomly choosing between the two colours, green or orange. If children were choosing in this manner, then they should have performed no differently from 50% in both conditions (i.e., 50/50 chance of choosing either side). However, although the 2.5- and 3-year-olds performed no differently from 50% in the *remove sticker* condition, they nonetheless performed well above 50% in the *show empty* condition. This strategy therefore cannot explain these children's performances across both conditions. The 4-year-olds performed above 50% in *both* conditions, also suggesting that they were not choosing between sides, but they failed to perform above 66.7% in the *remove sticker* condition and thus failed to demonstrate that they had ruled out the empty cup as an option. Overall, we did not find evidence that the 2.5- to 4-year-olds were *systematically* responding to any simple cues across conditions, but nor did we find evidence that they were consistently reasoning from the premise "A or B". Only the 5-year-olds showed evidence of such deductive reasoning in both conditions.

So what to make of the 2.5- to 4-year-olds' performance? We submit that the most compelling explanation is that these younger children typically conceived of the "or" relationships as inclusive rather than exclusive. If one interprets the relationship between A and B as an inclusive "or" in the *show empty* condition, then one should pass above chance. That is, if one understands that *at least one* of cups A and B contains a sticker and *at least one* of cups C and D contains a sticker, then - when cup A is shown to be empty - one should infer that cup B definitely contains a sticker and therefore choose that cup (as in Grigoroglou et al., 2019; Mody & Carey, 2016). In our novel *remove sticker* condition, by contrast, one would be expected to pass if conceiving of the relationship as exclusive "or", but to perform at chance level only if conceiving of it as inclusive "or". That is, if one imagines that at least one of each pair of cups contains a sticker, and maybe both do (i.e., "A or B, maybe both; C or D, maybe both"), then when the experimenter removes a sticker, all remaining cups are still valid choices (i.e., "A, therefore maybe B; and maybe C, maybe D"). Indeed, this is precisely the pattern of responses shown by our 2.5-, 3-, and 4-year-olds across both conditions. This interpretation parallels findings from linguistics research,

Table 2
Number of children who failed on all trials (none), who were correct on one trial (one) and who were correct on both trials (both).

	Show empty (33.3% chance)			*Remove sticker* (66.7% chance)		
	None	One	Both	None	One	Both
2.5-year-olds	1	12	12	5	13	7
3-year-olds	1	10	14	4	12	9
4-year-olds	1	8	16	3	7	15
5-year-olds	2	5	18	0	1	24

Note. In the remove sticker condition, children received a second chance if they had failed to find the sticker but had searched within the correct pair (e.g. the green cups in Fig. 1). This was to check if they continued to search the correct pair, rather than swapping back to the pair where the sticker could not be (e.g. the orange cups in Fig. 1). Across all children there were 143 successful remove sticker trials, and children required the second chance on 78 trials ($p = .316$, two-tailed binomial test against 50%). Of these 78 trials, only 12 children on 12 trials then reverted to the incorrect side: 2 2.5-year-olds, 3 3-year-olds, 5 4-year-olds and 2 5-year-olds.

which suggest that, in contrast to adults, young children are more likely to interpret verbal "or" utterances as inclusive than exclusive (Braine & Rumain, 1981; Chierchia et al., 2004; Crain & Khlentzos, 2010; Singh, Wexler, Astle-Rahim, Kamawar, & Fox, 2016).

Nonetheless, even if young children's behaviour is consistent with an understanding of inclusive "or" relationships, this need not necessarily imply that they approached the problem as an emerging logician would. It remains possible that they were simply generally uncertain about the contents of each pair of cups after the hiding events, while lacking the awareness that each pair denoted mutually exclusive alternatives with equal probabilities (Redshaw & Suddendorf, 2020). If so, this raises the question of why, in the *show empty* condition, the younger children seemed able to rule out cups C and D as options and select B instead. Why did they not remain generally uncertain about all three options and pick randomly? In the *show empty* condition, children are directly shown the information that negates one possibility (i.e., "the reward might be in A; the reward *is not* in A") but must affirm the alternative possibility themselves (i.e., the reward is in B). In the *remove sticker* condition, by contrast, children are directly shown the information that affirms one possibility (i.e., "the reward might be in A; the reward *is* in A), but must negate the alternative possibility themselves (i.e., the reward is not in B). One potential explanation, therefore, is that children typically become able to affirm before they are able to negate such possibilities (cf. Gautam, Suddendorf, Henry, & Redshaw, 2019). If so, they might be expected to choose B and simply ignore C and D in the *show empty* condition, but choose randomly between B, C, and D in the *remove sticker* condition. Consistent with this explanation, Fabricius, Sophian, and Wellman (1987) found that preschool-aged children were better at making confirmatory inferences (i.e., affirming a possibility) than making disconfirmatory inferences (i.e., negating a possibility) when given incomplete information in a search task. Notably, Grigoroglou et al. (2019) found that 2.5-year-olds also seem able to affirm an exclusive "A or B" possibility when the other possibility is *verbally* negated by an experimenter. Our account would predict these same children to struggle to negate a possibility when the other possibility is verbally affirmed.

In conclusion, we found that even 2.5-, 3- and 4-year-old children showed evidence of deductive reasoning in our conceptual replication of Mody and Carey's (2016) study, but that only 5-year-olds also showed evidence of deductive reasoning in our novel *remove sticker* condition. These findings are consistent with the notion that the 2.5 to 4-year-old children conceived of the relationship between A and B as inclusive "or" rather than exclusive "or", and that children can affirm such possibilities before they can negate them. Nonetheless, more research is needed to pinpoint the precise mechanisms underlying children's early reasoning capacities. As yet, we only have compelling evidence of reasoning from the exclusive disjunction "A or B" by 5 years of age.

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Declarations of interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2020.104507.

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