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Language as a mechanism for reasoning about possibilities

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The ability to entertain and reflect on possibilities is a crucial component of human reasoning. However, the origin of this reasoning—whether it is language-based or not—is highly debated. We contribute to this debate by investigating the relation between language and thought in the domain of possibility from a developmental perspective. Our investigation focuses on disjunctive syllogism, a specific type of possibility reasoning that has been explored extensively in the developmental literature and has clear linguistic correlates. Seeking links between conceptual and linguistic representations, we review evidence on how children reason by the disjunctive syllogism and how they acquire logical and modal language. We sketch a proposal for how language and thought interact during development.

This article is part of the theme issue 'Thinking about possibilities: mechanisms, ontogeny, functions and phylogeny'.

1. Introduction

Humans spend a significant amount of their mental life thinking about possibilities (i.e. non-actual actions, events, states of affairs etc.). For example, we draw logical conclusions based on evidence (e.g. *It must have rained because everything looks wet*), consider consequences of alternative future possibilities (e.g. *If I take the bus instead of the subway, will I make it to the office on time?*) and contemplate how alternative versions of the past could have led to alternative versions of the present (e.g. *What if I had married my college sweetheart?*). These modes of reasoning constitute *modal cognition*, a part of cognition responsible for representing situations as possible or necessary [1,2].

Despite its centrality in human reasoning, the origin and nature of possibility reasoning are highly debated. Currently, there is significant disagreement about whether modal concepts of *possibility* and *necessity* are available to prelinguistic infants and non-human animals or, instead, they can only be represented by linguistically capable reasoners [2–6]. This is part of a broader, venerable debate concerning whether abstract combinatorial thought precedes and can exist in the absence of language [7–9] or, instead, such thought becomes possible with the emergence of natural language in phylogeny and ontogeny [10,11]. Although these ideas have been theoretically debated for centuries, recent advancements in psychology, philosophy and linguistics have provided the tools and methods to seek empirical evidence.

Two main lines of investigation have been pursued to address the debate. The first one investigates logical thought in populations who do not (yet) have language, such as pre-linguistic infants and non-human animals. Evidence for logical thought in these populations would be a clear indication that logic is independent of language. The second line of research examines the development of logical capacities in preschool-aged children. Late emergence of logic would indicate that adult-like logical thought is not part of our innate mental system but rather constructed during childhood. Currently, results from these two lines of investigation appear controversial; findings from studies with infants and non-human animals are interpreted as evidence for successful logical reasoning in

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the absence of language, while findings from studies with preschoolers point to persistent difficulties [5,6,12,13].

In this paper, we contribute to the debate by pursuing a third line of investigation: the comparative examination of children's possibility reasoning with respect to the process of acquiring the language of possibility. So far, for the most part, the studies of cognitive representations of possibility and the acquisition of linguistic meaning have been pursued largely independently, by different research communities and with different methodologies. However, bringing the two lines of research together presents several opportunities for advancing our understanding of the ontogeny of possibility reasoning. First, the comparative examination of *when* linguistic and non-linguistic abilities emerge is a critical piece of evidence in any version of the language and thought debate. Of interest is whether children's ability to represent possibilities precedes the acquisition of the language of possibility, or whether possibility reasoning follows children's linguistic development. Although the former pattern would indicate a standard case of mapping pre-existing modal concepts onto language, the latter would suggest that modal concepts are constructed during development, potentially through language. Second, this type of comparative investigation could provide a more concrete answer to *how* modal concepts develop. Although language acquisition is often proposed as a potential mechanism in the development of modal and logical concepts [5,14], the specifics of how this process works are largely unspecified. By taking a closer look at how children acquire different linguistic constructions related to possibility reasoning (and logical reasoning more broadly) we can gain critical insights into how modal and logical concepts come to exist in our mental world.

(a) Theories of language acquisition and the interaction of language and thought

On classic theories of language acquisition, the process of learning one's native language consists of mapping incoming speech onto pre-existing, universal conceptual categories [15–18]. Such theories make specific assumptions about how mental representations interact with language. Specifically, it is assumed that the mental representation of a concept precedes the emergence of the corresponding linguistic term in child language and, thus, linguistic achievements rely on cognitive achievements, which are assumed to develop in a universally fixed order. The cross-linguistically stable order children learn spatial locatives, which reflects the order they develop the corresponding spatial concepts, is a case in point [19–21].

Although the classic view is widely acknowledged, other accounts suggest that, for specific phenomena, the relation between language and cognition might be reversed to some extent, and language itself might be providing input to cognition [22–27]. On such views, language acts as an 'augmenter' to cognition, whereby linguistic representations combine with nonlinguistic representations to enable performance in tasks that could not be performed with one representation alone [26,28]. Examples of such phenomena include acquiring mental state verb syntax and developing the ability to reason about other people's beliefs [22,29], learning the counting sequence and developing exact representation of large numbers [24,30,31], and using relational language to facilitate relational reasoning [25]. The common denominator in all these phenomena is that they concern highly abstract concepts that are hard to learn from observation alone, while the corresponding linguistic constructions contain clear cues (e.g. special syntactic and semantic properties) that could provide the scaffolding for developing mature conceptual representations.

In this paper, we explore the idea that language might be playing a similar role in the case of possibility reasoning. The domain of possibility is an excellent candidate for studying interactions of language and thought, as possibilities are by definition non-actual (e.g. they may never be materialized) and, thus, not directly observable in the physical world. Instead, a domain of human experience where possibilities can be observed is language, as numerous linguistic expressions exist to mark propositions as possible or necessary [32]. Examples of such expressions include lexical categories such as adverbs (e.g. *Maybe/possibly/probably, Paul is guilty*), nouns (e.g. *There is a strong possibility that Paul is guilty*) and adjectives (e.g. *It is necessary that Paul is guilty*), functional categories such as modal verbs (e.g. *Paul must/should/might/may/could be guilty*), or grammatical constructions such as conditionals (e.g. *If these are Paul's fingerprints, then Paul is guilty*). Although it is often assumed that language might be a critical mechanism for possibility reasoning, we currently lack a detailed account of how linguistic (i.e. semantic) representations and non-linguistic (i.e. conceptual) representations of possibility interact during development. Our goal is to integrate research from both conceptual and linguistic domains to begin shedding light onto such processes.

(b) Empirical focus

Our discussion centres around a specific type of possibility reasoning: reasoning about disjunctive beliefs. Representing disjunctive beliefs requires the representation of two states of affairs as possibly true or possibly false [5,33]. Evidence that young children can reason about disjunctive beliefs has been explored through tasks that target a simple logical inference, the *disjunctive syllogism*: if presented with two possibilities (A or B), and one of them is subsequently excluded (not A), one deduces that the alternative possibility *necessarily* has to hold (therefore B).

This reasoning process was chosen because: (a) in recent years, disjunctive syllogism has been studied extensively with various populations, and (b) it presents clear correlates between conceptual and linguistic representations. At a conceptual level, the syllogism requires the representation of the logical relations of disjunction and negation: the two possibilities need to be represented as dependent on each other, linked by the relation of disjunction (A or B), while the elimination of one of these possibilities should lead to the representation of a negative premise (not A). At the same time, the syllogism requires the representation of the modal concepts of possibility and necessity: the two states of affairs need to be considered simultaneously and be represented as merely possible (*could* be in A or *could* be in B), while, once one of these states of affairs is ruled out, the alternative becomes necessarily true (it is not in A, therefore it *must* be in B). At a linguistic level, these concepts may be encoded in logical connectives and particles such as *or* and *not*, epistemic adverbs such as *possibly, necessarily* or epistemic modal verbs such as *can*/*could*/*may* and *must*/*should*/*have to*. These correspondences facilitate the

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comparative investigation of linguistic and non-linguistic developmental trajectories.

The paper is organized as follows. In §2 and §3, we summarize evidence on how children reason by the disjunctive syllogism and how they acquire the corresponding logical and modal language. In the final section (§4) we sketch a proposal for the interaction of language and thought in the domain of possibility.

2. Reasoning by the disjunctive syllogism

Although the disjunctive syllogism is readily computed by adults [34–36], evidence on children's ability to make this inference appears highly mixed. A widely used paradigm to test disjunctive reasoning in children (and animals) is the reasoning by elimination task. In a typical version of the task, a reward is hidden inside one of two opaque containers (A or B). The experimenter then demonstrates that one of the two containers is empty (not A). Subjects are then asked to search for the reward, with successful performance shown by a search in the alternative container (therefore B). Children as early as age 2, and different animal species are shown to succeed in this task [37–40]. Recent eye-tracking evidence has corroborated these findings by showing that 12-month-old infants can draw disjunctive inferences when tracking the identity of objects on a screen [13,41]. This evidence from non-linguistic (i.e. non-human animals) and pre-linguistic populations (i.e. children who have not yet acquired the linguistic operators of disjunction, negation or epistemic modality) was taken to suggest that some fundamental logical operations required for reasoning by elimination (of a disjunct) develop independently of language and predate the mastery of logical vocabulary.

However, research with toddlers and preschoolers has led to re-evaluation of these findings by suggesting that, in simple (2-location) reasoning by elimination tasks, lower-level (non-deductive) strategies may also lead to success. For instance, when shown that one of two locations is empty, children may engage in an 'avoid empty' strategy and search in the alternative location not because they have reached the logical conclusion that the reward *necessarily* has to be in the alternative location but because it is the only salient hiding location (after avoiding the empty location). Evidently, this strategy does not require the representation of the logical disjunction (*or*) or negation (*not*). Alternatively, children might be engaging in a 'maybe A, maybe B' strategy and, thus, do not represent the two possibilities simultaneously in the same model, but rather represent each of the two possible locations separately. Upon seeing that one location is empty, they eliminate this possibility and search in an alternative location just because it is the only other possible location. In this case, children might be applying logical negation to eliminate A, but they are not applying logical disjunction and do not reach a certain conclusion [5,14].

To eliminate these lower-level strategies, Mody & Carey [14] employed a different search paradigm where participants were presented with four possible hiding locations. In this paradigm, 2.5-, 3-, 4- and 5-year-olds were presented with two pairs of cups (A and B, C and D) and were shown a reward being hidden in one of the two cups in each pair (figure 1). Because the hiding took place behind an occluder, children could not be certain about the exact location of the reward, leading them to represent the cups in each pair as mutually exclusive (A or B, C or D). Then, children were shown that one of the cups was empty (e.g. not A) and were asked to find a reward in the remaining cups. If children do not engage in logical reasoning and use lower-level elimination strategies, they are equally likely to choose among the remaining three cups (B, C, D), as they have never represented each cup within a pair as mutually exclusive possibilities. If, however, children engage in the disjunctive syllogism, they should choose the cup that was paired with the empty cup (i.e. cup B) because it is the only cup that they know *necessarily* holds a reward. Children have insufficient information to make the same deduction for the alternative pair of cups. Results showed that children older than age 3 searched in the location that certainly held a reward (cup B) at levels significantly above chance, but 2.5-year-olds chose randomly among the three remaining cups.

Despite children's success in the 4-cups task at around age 3, these findings are currently interpreted with caution as additional pieces of evidence suggest that children have protracted difficulties managing possibilities [5]. First, children seem to have problems not only with reasoning over uncertainty (as in the 4-location trials described above) but also with reasoning over certainty as well. In multiple studies, children before age 4 performed poorly even in the 3-location trials (A, B or C), where one location (A) was certain to contain a reward, in the absence of any logical inference [14,42,43] (figure 1). Second, success rates in the Mody & Carey 4-cups task demonstrate that although children, beginning from age 3, pass the task, they are not at ceiling even at age 5 (i.e. 5-year-olds choose the target cup 76% of the time) [14]. Interestingly, subsequent experimentation has shown more protracted difficulties with the disjunctive syllogism. In a variation of the 4-cups task (A or B, C or D), where, instead of showing that one location is empty, children saw that one location did contain a reward (A), thus leading children who are reasoning disjunctively to eliminate the other location within the pair (therefore not B) and effectively search in the alternative pair (C or D), only 5-year-olds succeeded [43] (figure 2). This evidence suggests that children before age 5 may not be able to reason by exclusive disjunction (an issue we return to in §3*b*).

Together, these findings demonstrate persistent difficulties with logical and possibility reasoning during preschool years and are in stark contrast with the successful performance of infants and animals in reasoning by elimination search or object identity tasks. To reconcile these contradicting findings, recent theoretical accounts propose that younger children and animals have minimal representations of possibility and can create simulations of single situations (maybe A, maybe B), which they can update in the face of new evidence (not A, maybe B) and add to their current model of reality (B). Crucially, they do not have modal representations of possibility and, thus, cannot represent two mutually exclusive possibilities simultaneously (A or B), a critical component of the disjunctive logical inference [5]. This explanation supports the view that abstract combinatorial thought is not available to infants (and non-linguistic animals) and that children develop mature logical reasoning at a later age, after having acquired the linguistic terms of disjunction and negation, thus raising the possibility that language might be necessary to develop logic-like representations.

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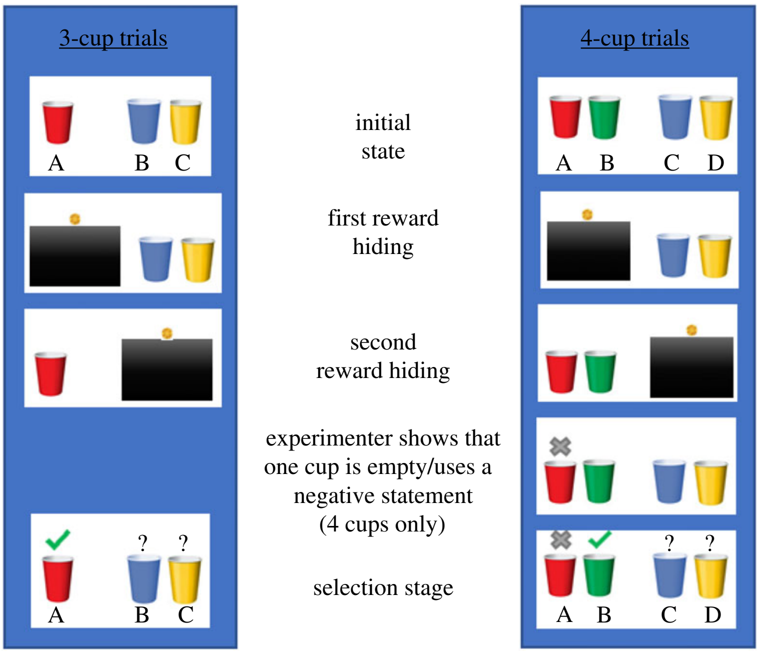

Figure 1. Schematic procedure of the 3- and 4-cup trials used in Mody & Carey [14] and Grigoroglou *et al*. [42]. Children watch a reward hidden behind a screen for each set of cups. In 4-cup trials, children see that the cup with the cross is empty [14] or hear a negative statement (e.g. *There is no coin in the red cup*; [42]). The cup with the tick is certain to contain a reward (100% chance), and the cups with question marks may or may not contain a reward (50% chance for each cup). (Online version in colour.)

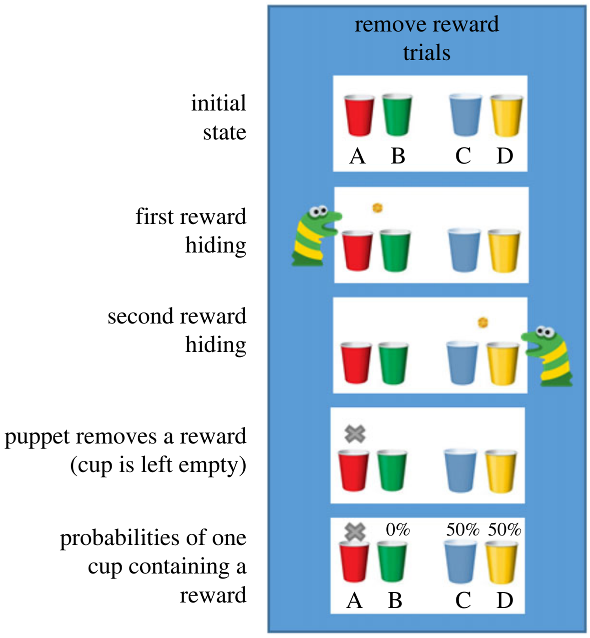

Figure 2. Schematic procedure of *remove reward* trials used in Gautam *et al*. [43]. Children watch a puppet 'visiting' the cups on each side and hiding a reward. The puppet then 'finds' a reward in one of the cups and removes it, leaving the cup empty. The gray X represents the empty cup. Percentages indicate the actual chance of finding a reward inside each cup after one of the cups becomes empty. (Online version in colour.)

3. The acquisition of logical and modal language

The timeline by which children learn logical and modal terms, especially when it is cross-linguistically consistent, can be particularly informative in terms of the age at which logical and modal concepts become available to thought. In this section we discuss evidence from children's production and comprehension of three phenomena involved in the disjunctive syllogism: negation, disjunction and epistemic modals.

(a) Negation

Investigations of children's naturalistic speech across languages have revealed that negation terms are among the earliest terms children produce, emerging, on average, at around 15 months of age [44–47]. However, children's early negation words do not express *denial* (i.e. logical negation), but rather conceptually simpler functions of negation such as *rejection* and *non-existence* [44–46]. Denial negation was found to emerge in children's speech several months later, during their third year of life [44–47].

Comprehension studies with English-speaking children have qualified this timeline by providing more detailed evidence for when children understand denial negation [42,47,48]. In these studies, using variations of the reasoning by elimination paradigm, 2-year-olds searched for a reward between two locations (A or B), after hearing a negative sentence (e.g. *The toy is not in A*). Only after 27 months of age did children understand the negative sentence (as indicated by successful searches in the unmentioned location); 20- and 24-month-olds did not. Importantly, this timeline was replicated even when children were asked to infer the location of the reward in more complex reasoning tasks. As already discussed, success in 2-location paradigms is compatible with the possibility that children do not engage in deductive reasoning but are simply eliminating options [14]. On such interpretations, it is unclear whether children who showed successful understanding of negation in 2-location paradigms interpreted the negative sentence (e.g. *The toy is not in A*) as conveying denial (logical) negation (i.e. not A) or as conveying a less abstract concept of negation, such as non-existence (i.e. A is empty). However, it was shown that 27-month-old children were also successful in search tasks that involved reasoning over three and four locations and required children to combine verbal and visual information to reach a logical conclusion [42]. This flexibility in using negative sentences in logical reasoning suggests that by 27 months of age children interpret

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negation words as having a truth-functional (logical) meaning. Given that this is roughly the age at which children begin to succeed in non-linguistic reasoning by disjunction (which requires the application of a logical concept of negation) [14], the converging evidence from search tasks shows that, in terms of negation, the development of the logical (truth-functional) concept and the acquisition of the corresponding linguistic terms go hand in hand.

Interestingly, recent findings from more diverse experimental paradigms and speakers of languages other than English suggest that children may comprehend negative sentences at an even younger age. For instance, in a recent study using a word-learning eye-tracking paradigm, French-speaking children showed evidence of comprehending negative sentences at 18 months of age [49]. Although this earlier success is most likely due to the lower cognitive demands of the word-learning task (which did not involve logical reasoning but simply matching a sentence with the appropriate referent) rather than the different linguistic background of the children, it is possible that semantic differences in negation constructions across languages may affect acquisition trajectories (e.g. see [50] for evidence that 18-month-old (but not 15-month-old) Hungarian-speaking infants comprehend sentences with both denial and non-existence negation markers in 2-location search tasks). Even though it is not clear whether such paradigms provide definite proof that children possess an understanding of denial negation this early or of a simpler concept, they are in accordance with findings from the non-linguistic domain showing that children can succeed in non-linguistic 2-location search tasks as early as 17 months of age (but not earlier) [51], thus reinforcing our conclusion that, in terms of negation, linguistic and non-linguistic representations develop at a similar pace. Currently, more systematic cross-linguistic investigation with children younger than age 2 and with a variety of paradigms (not just search tasks) is needed to clarify the exact age different types of linguistic and non-linguistic negation become available to human language and thought.

(b) Disjunction

Disjunction in natural language is often expressed as a connective (such as the English *or*), which coordinates two syntactic units of the same type. Disjunction can receive multiple interpretations. For example, the sentence *The woman ordered sushi or pizza*, can have an *inclusive* interpretation (i.e. the woman ordered only sushi, only pizza or both) or an *exclusive* interpretation (i.e. the woman ordered only sushi or only pizza but not both). On standard linguistic accounts, the semantic meaning of *or* is inclusive, and the exclusive interpretation is derived through pragmatic inference [52,53]. For example, if a speaker uses the sentence mentioned above, the speaker typically implies that the woman ordered only sushi or only pizza, because if she had ordered both, then it would be more felicitous to use the stronger connective *and* (i.e. *The woman ordered sushi and pizza*).

The acquisition of disjunction presents a particularly complex puzzle. Studies on children's spontaneous speech demonstrate that *or* emerges in child language at around age 3 [54–57]. However, from production data alone, it is not always clear what meaning of disjunction children have in mind. Some corpus studies have shown that exclusive interpretations are more frequent in both the input that children receive and their own production, thus suggesting that children may have access to the exclusive interpretation very early on [57,58]. Nevertheless, comprehension studies demonstrate that children have persistent difficulties with exclusive interpretation during preschool years [59–64]. For instance, numerous studies demonstrate that although adults reject statements involving disjunction in contexts where the stronger alternative *and* is true (e.g. *Every boy chose a skateboard or a bike*, when the boy chose both objects), thus showing an appreciation of the exclusive interpretation of disjunction, 3- to 6-year-old children tend to accept them [62–64]. These findings are taken to suggest that children are more 'logical' than adults, as they have an appreciation of the inclusive semantics of the logical operator of disjunction, but they have issues with the exclusive inference of disjunction, owing to pragmatic difficulties [65].

In sum, children's acquisition patterns indicate that, although disjunction emerges early in children's speech (at around age 3), mature understanding of disjunction undergoes significant development for years later. Children's persistent problems with the exclusive interpretation of disjunction are in accordance with findings from children's reasoning by the disjunctive syllogism, showing that children—although not at ceiling—pass the task at around age 3 in trials where one location is shown to be empty (not A, therefore B) [14,42] but fail until age 5 in trials where one location is shown to contain a reward and the alternative location also has to be excluded (A, therefore not B) [43]. Although, in principle, in the disjunctive syllogism, the relation 'or' in the premise 'A or B' can be inclusive (at least one of A and B is true) or exclusive (exactly one of A and B is true), search tasks require exclusive disjunction, as only one location contains the reward. When children see that one location is empty (not A), the conclusion that the reward is in the alternative location within the pair (therefore B) is predicted by both an inclusive and an exclusive interpretation of the 'or' relation. However, when children see that one location contains the reward, the conclusion that the alternative location within the pair needs to be excluded (A, therefore not B) is consistent only with an exclusive interpretation of disjunction (figure 2).

(c) Epistemic modals

Epistemic modals express what is possible or necessary given the available evidence [32,66,67]. For example, the sentence *The keys could be on the kitchen table* is used when the available evidence suggests that *it is possible* that the keys are on the kitchen table, while the sentence *The keys have to be on the kitchen table* is used when there is evidence from which *it necessarily follows* that the keys are on the kitchen table.

Research on the acquisition of modal verbs in English has demonstrated that children spontaneously produce modal verbs at around age 2, but these early uses express *root* (i.e. non-epistemic) meanings such as ability or obligation, while epistemic uses of modals arise at around age 3 [68–72]. Different explanations could account for the later emergence of the epistemic meaning of modals. On a conceptual explanation, the later emergence of epistemic modals is due to the complexity and metarepresentational nature of the underlying concepts of possibility and necessity, as well as young children's more general difficulty to reason about the contents

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of other people's minds [69,71,73]. If so, children cannot map modal terms to epistemic meanings, because the related concepts are not yet available to them.

On a grammatical explanation, at least part of children's difficulty with epistemic modals is the fact that they require more elaborate grammatical structure than root modals [72]. If so, the concepts of possibility and necessity may already be in place, but children cannot yet use them because they lack grammatical capacity. This view is supported by the fact that epistemic adverbs such as *maybe* and *probably*, which express epistemic meanings but are semantically and syntactically less complex than modal verbs, emerge in children's speech in adult-like contexts at around age 2, a year earlier than epistemic modals [74–77]. Although such data suggest that some preliminary understanding of possibility might be available to children early on, naturalistic production data do not provide sufficient information about the concepts that children possess.

By contrast, comprehension studies support the conceptual explanation as they demonstrate that before age 7 children have non-adult comprehension of epistemic modals [65,77–81]. An important step in acquiring the meaning of epistemic modals has to do with understanding when possibility and necessity modals are true. In fact, while necessity modals (e.g. *must*/*have to*) are true only in necessity contexts (i.e. when an outcome is not just possible but necessary given the evidence), possibility modals (e.g. *can*, *could*, *may*) are true in both possibility and necessity contexts (i.e. when an outcome is possible or necessary given the evidence). Experimental findings show that children often over-accept necessity modals in possibility contexts [65,78,79,82]. In one demonstration [79], 4- to 5-year-old children were presented with scenarios where animals were hidden in different-coloured boxes and heard statements with necessity or possibility modals (e.g. *X has to/may be in the blue box*). Children were asked if they agreed with the statements or not. Children successfully accepted possibility modals as true in contexts where the location of the animal was uncertain (i.e. when they were presented with two closed boxes), and both possibility and necessity modals in contexts where the location was certain (e.g. when one of two boxes was shown to be empty), in accordance with modal verb semantics. However, children also over-accepted necessity modals in the uncertain context, where the stated location of the animal was simply possible but not necessary. Children seem to have a robust understanding of this semantic distinction at around age 7 [82,83].

These persistent difficulties with processing epistemic modals have been attributed to a broader, conceptual difficulty with maintaining two open possibilities, which children overcome by committing to one outcome, even when there is insufficient evidence to make such a commitment [70,78,79]. Children's protracted difficulties with the meaning of epistemic modals are reminiscent of children's difficulties distinguishing certainty from uncertainty in the search tasks reviewed earlier [14,42,44], and are in accordance with various other developmental findings where children are shown to commit to one outcome when multiple outcomes are possible [6,83,84].

4. Interactions of language and thought

Is the current evidence compatible with theories of acquisition suggesting that language might be providing input to cognition in the domain of possibility? Evidently, such a question is hard to answer in the absence of closely matched linguistic and non-linguistic tasks with the same populations of learners. Furthermore, in the absence of such evidence, it is unclear if language is the single contributing factor to the development of such concepts or one factor among others. Here we consider aspects of the present data suggesting that language acquisition could provide a potential workspace for refining possibility concepts and discuss some preliminary evidence demonstrating that language may be facilitating logical reasoning.

(a) Can language contribute to conceptual change?

Two main aspects of the available evidence are compatible with the view that language might be a contributing factor in the development of logical and possibility concepts. The first concerns irregular acquisition patterns, where the production of a term in adult-like contexts seems to precede mature understanding of the term. Typically, when acquiring language, children comprehend how a word maps onto a concept before they can use this word in speech production. However, a prevalent pattern in the linguistic data we reviewed was that, across phenomena, children produced the different linguistic terms much earlier than the age they understood these terms in comprehension tasks. The acquisition of modal verbs presents a characteristic pattern, with children producing modal verbs with epistemic meanings at around 3 years of age (and epistemic adverbs even earlier) but their semantic understanding of necessity and possibility meanings is non-adult-like until age 7. Such irregular acquisition patterns are puzzling, because, to use a term in speech appropriately, one must understand something about the meaning of the term. Although multiple accounts have been proposed to explain such irregular acquisition patterns [85], it has been suggested that such patterns might be indications of language acquisition contributing to conceptual change [23]. On such accounts, if a specific conceptual distinction is refined by learning the corresponding linguistic (semantic) distinction, then we would expect to see it manifest in children's own language first, while comprehension of the term in someone else's speech would await the full development of the corresponding concept [23]. Under this suggestion, the early emergence of a term in child language and its use in appropriate contexts does not presuppose that the concept is already in place; instead, children who produce a certain term in an adult-like manner may not yet have a fully developed concept but operate on the basis of an immature concept. This view is compatible with classic acquisition theories proposing that children's understanding of linguistic terms may undergo significant conceptual/semantic reorganization [86,87], as well as recent theoretical models of children's possibility reasoning distinguishing early, 'minimal' concepts of possibility from mature, 'modal' concepts of possibility [5]. On such views, irregular acquisition patterns, as in the case of modals, could be explained by suggesting that the early emergence of modal terms in children's speech might be reflecting a 'minimal' understanding of possibility, while the adult-like comprehension of modal verbs might await the development of 'modal' concepts of possibility [75].

A second aspect of the reviewed evidence suggesting that language could contribute to conceptual change has to do with the fact that, across languages, logical and modal terms tend to

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be polysemous and children seem to learn 'easier' (i.e. non-logical, non-epistemic) meanings first. Given that logical and possibility concepts are hard to learn from observation alone, polysemy might be providing the workspace for developing such concepts, through extension of the 'easy' meanings (as some sort of 'conceptual bootstrapping' [88]). Negation is a case in point, as words such as *no* and *not* have multiple meanings, each of which seems to be acquired at different time points. As we saw earlier, children first acquire the meanings of rejection and non-existence, which can plausibly be acquired by observation alone (e.g. by seeing others rejecting things or finding a container to be empty). Once these meanings have been mapped onto negation words, children may notice that the same words are also used when the speaker wants to express denial, and that the mere function of this word is to flip the truth value of a proposition. This observation—which is linguistic in nature—could potentially be contributing to the representation of logical (truth-functional) negation in children's mind.

Similarly, epistemic meanings of modal verbs might be developing from the 'easier', root meanings, which are acquired earlier. In fact, ambiguity between root and epistemic meanings in a single class of modals is a widespread cross-linguistic phenomenon [68,89,90]. Some semantic theories argue that epistemic meanings of modals are related to root meanings through metaphorical extension [91,92]. For example, the root meaning of *may* (e.g. *You may go now*) expresses the existence of a potential but absent barrier in the 'physical world', while its epistemic meaning (e.g. *He may be at work*) expresses a barrier of reasoning in the speaker's 'mental world' [92]. On such views, children may be able to learn root meanings of modals though observation, and then they can extend these meanings to the more abstract, epistemic domain, through metaphorical mapping. Thus, polysemy of logical and modal terms may provide a critical workspace for learning the 'harder', more abstract meanings. This view is in accordance with recent accounts of word learning, demonstrating that polysemy, rather than a barrier, is highly beneficial for language acquisition [93,94], and that knowledge of the 'easy' meaning of a word (i.e. referring to concrete entities/properties/actions) can pave the way for learning its 'harder', more abstract meaning [95].

(b) Does language facilitate logical reasoning?

To our knowledge, one study provides evidence for language effects on thought in logical reasoning during development. In this study by Grigoroglou *et al*. [42], children performed a linguistic version of the Mody & Carey [14] 4-cups paradigm, in which instead of seeing that one cup was empty, 2.5- and 3-year-old children heard a negative statement (e.g. *There is no coin in the red cup*) and were asked to reason about the location of the reward (figure 1). Findings showed that, in this linguistic version of the task, 2.5-year-olds, who were shown to fail in the non-linguistic version, passed the task. This finding indicates that verbal negation somehow facilitated children's logical reasoning. However, the linguistic 4-cups paradigm by Grigoroglou *et al*. involved more than one modification of the non-linguistic Mody & Carey paradigm, making it difficult to isolate the exact manipulation that led to improved performance in 2.5-year-olds. Specifically, in Grigoroglou *et al*., before the test trials, children received two additional training trials, which were a linguistic version of the 2-cups task, where children had to reason about the location of the coin between two cups after hearing a negative sentence. It is possible that 2.5-year-olds' success was due to the additional training in reasoning by exclusion rather than to language.

On-going research directly tests this possibility [96]. In this study, 2.5-, 3- and 4-year-old children perform the non-linguistic version of the 4-cups task, similarly to Mody & Carey [14], but are also provided with additional training trials in the 2-cup paradigm, similarly to Grigoroglou *et al*. [42]. Crucially, in this additional training, children are provided with either a verbal cue (i.e. a negative statement) or a visual cue (i.e. seeing that one cup is empty) indicating emptiness. Results thus far show that only 2.5-year-olds who received the linguistic training passed the disjunctive syllogism task [96]. Although further experimentation is needed to clarify the exact mechanism that drives improved performance, two explanations are possible. On one explanation, the improvement in 2.5-year-olds is due to the modality of the evidence from which children construct the logical representation. Children consider verbal evidence as more reliable than visual evidence [97,98]; therefore, the verbal clue might have increased children's certainty about the premise 'not A' and subsequently the conclusion (therefore B) [42]. Alternatively, hearing logical language could be inviting children to encode logic-like representations in a more detailed way than visual information does, by activating the relevant semantic structure (similarly to findings about how the presence of relational language (e.g. spatial prepositions) facilitates relational reasoning [25]; see also [99] for similar evidence with causal language and causal reasoning). On this view, receiving the negative proposition verbally gave children more direct access to the relevant premise 'not A' compared with when the same premise had to be constructed from visual evidence of 'emptiness', thus providing them with a 'head start' in the inferential process. This view predicts that, given a more complex reasoning task, not just 2.5-year-olds but also older children could benefit from hearing logical language. Furthermore, if the effect of language on logical reasoning is induced by activating the relevant semantic structure that supports logical representations, we would expect to see differences in logical reasoning based on the type of linguistic cue provided to children. Future work could test these predictions.

5. Conclusion

It is often proposed that language acquisition contributes to the development of logical concepts, but explicit evidence for how conceptual and linguistic representations are related is currently lacking. Here we explored specific links between children's ability to reason logically about possibilities and the process of acquiring logical and modal language. The empirical findings reviewed demonstrate that, during development, linguistic and conceptual representations interact in complex ways. Overall, children's conceptual understanding of logical and modal concepts seems to go hand in hand with children's linguistic understanding of logical and modal terms. However, evidence from children's production shows that such terms tend to appear in speech earlier than the age children comprehend these terms and before they show evidence for mature logical and modal reasoning. These

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irregular developmental patterns could be explained by proposing that children have some preliminary conceptual understanding early on, demonstrated in their own production, but the mature comprehension of the linguistic terms awaits the full development of the concept. The polysemy of logical and modal terms could be providing a potential workspace for developing such mature conceptual representations. Finally, we reviewed some findings from recent and on-going research indicating that language facilitates logical reasoning in young children, possibly because logical language invites children to encode logic-like representations by activating the relevant semantic structure. Together, these findings point to a position where language is seen as a tool for cognition. Further investigation is needed to clarify whether, in the domain of logic, language is more intertwined with cognition, similarly to domains like number [24,26,30,31], or the effects of language on thought are more transient, similarly to domains like colour and spatial reasoning [27].

Several issues at the language and cognition interface in the case of logical and possibility reasoning are ripe for further exploration. First, our review clearly highlights that, to test hypotheses about the linguistic basis of cognition, we need further experimentation that will integrate linguistic and cognitive perspectives in a systematic way. Future research should build on the available evidence and create closely matched linguistic and (non-linguistic) cognitive tasks used on the same population of learners, similarly to studies testing different versions of the language and thought debate such as the Whorfian Hypothesis [27,28]. Critically, it should be ensured that cognitive tasks are essentially non-linguistic (i.e. do not use logical or modal language in their prompts) and tap into purely conceptual representations (e.g. see [100]). Second, future work could benefit greatly from integrating a cross-linguistic perspective in the study of logical and modal language, as languages present considerable variability in these constructions, and it is an open question how these differences can affect the development of logical and possibility reasoning. For instance, cross-linguistic investigations on the emergence of modal verbs in children's language have demonstrated that syntactic and semantic differences across languages may affect the acquisition process [72,74]. Furthermore, some languages may possess distinct constructions for certain conceptual categories of negation, thus providing a critical testbed for different theoretical perspectives (e.g. Hungarian uses the form *nincs*/*nincsen* to express non-existence and the general marker *nem* for all other functions including denial [50,101]). Similarly, in some languages, disjunction is not a connective but is expressed through the juxtaposition of two syntactic units, often accompanied by a modal or uncertainty marker (e.g. in Dyirbal 'A or B' is expressed as 'maybe A, maybe B' [102,103]). Whether such linguistic differences also affect the development of logical and possibility concepts remains to be seen. Finally, building on the integrated approach between linguistic and conceptual evidence we attempted here, future work should extend this approach to other phenomena that involve possibility reasoning. For example, conditionals and counterfactuals have been explored extensively in linguistics and psychology, but the two literatures have developed largely independently, and little is known about how linguistic and conceptual representations make contact during development. Investigating these links is an exciting avenue for future research.

Data accessibility. This article has no additional data.

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Both authors gave final approval for publication and agreed to be held accountable for the work performed herein.

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