12-month-olds' reasoning via negation

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Abstract

Abstract combinatorial thought supports adult human reasoning. But it is unknown whether such thought is available to infants who are in the process of acquiring their native language. In a series of three experiments, we ask whether 12-month-old pre-verbal infants have access to a propositional negation operator, as a defining hallmark of abstract combinatorial thought. We examine infants' understanding of disjunctive reasoning problems, taking the insight that some impossible outcomes are supported by negation, while others may not be. We thus introduce a novel use of the Violation of Expectation paradigm, with visual stimuli which build on the Call (2004) cup task by expanding the range of possibilities and testing different kinds of inconsistent outcomes. Results from three experiments do not provide direct support for the view that infants possess a propositional negation operator, but they are more compatible with it than alternatives.

Keywords: negation; disjunctive syllogism; infant reasoning; violation of expectation paradigm; impossibility

Introduction

Abstract combinatorial thought is a distinguishing feature of human cognition, but it is an open issue whether such thought exists independent from language (Descartes, 1964; Fodor, 1975; Davidson, 1999; Bermúdez, 2003; Quilty-Dunn, Porot & Mandelbaum, 2022). In recent years, studies with pre-verbal infants have attempted to push the debate forwards. Under the assumption that pre-verbal infants lack language, evidence for aspects of abstract combinatorial thought could be taken as support for the independence of such thought.

We take a component of a mature system of abstract combinatorial thought to investigate whether it is accessible to pre-verbal infants: negation. Is the reasoning of pre-verbal infants supported by a propositional negation operator? We center the negation operator given that is potentially the least complex logical operator syntactically, while still having considerable semantic import. Negation is an unary operator which takes the truth-value of a proposition as its operand and returns the opposite truth-value. Understanding of this operator is often probed through linguistic stimuli, but the developmental literature provides conflicting results about the age at which children can begin to reason via verbal negation. Some studies suggest that negation is unavailable to children until the third year of life, when they acquire the vocabulary of negation (i.e., *not*; Feiman et al., 2017). Others suggest that negation supports reasoning a year earlier, before most children even produce a word like *not* (de Carvalho et al., 2021; Szabó & Kovács, 2022). But the empirical investigation need not rely on linguistic methods.

There is a significant literature on disjunctive syllogism reasoning in non-verbal populations, starting with Call's (2004) two cups task. In this paradigm, an object is hidden in one of two empty locations, establishing a disjunctive first premise (the object is in location X or the object is in location Y). Participants are then given evidence that one location is empty, to establish a negative second premise (the object is not in location X). If able to perform the disjunctive syllogism, participants should be able to conclude that the object must be in the other remaining location (X OR Y; NOT X; THEREFORE Y). Notice that this requires not only a negation operator but also some way of representing multiple possibilities. Non-verbal populations have been found to succeed at this task by preferentially searching for the object in the remaining location (Hill, Collier-Baker & Suddendorf, 2011; Pepperberg et al., 2013; and many others). While conflicting results are found with pre-verbal human infants in this task (Feiman, Mody & Carey, 2022; Szabó & Kovács, 2022), they succeed at other tasks with structural similarities (Mather & Plunkett, 2011; Cesana-Arlotti et al., 2018; Cesana-Arlotti, Kovács, Téglás, 2020; Ekramnia, Mehler & Dehaene-Lambertz, 2021; Pomiechowska et al., 2021).

Nevertheless, these findings have been controversial in the face of arguments that the basic cups task does not require full modal reasoning (Leahy & Carey, 2020) nor a propositional negation operator (Bohn, Call & Völter, 2020). Arguably, variations on or alternatives to the cups task (Watson et al., 2001; Mody & Carey, 2016; Cesana-Arlotti et al, 2018; and many others) have tended to target leaner interpretations of the possibility component of disjunctive syllogism, due to the nature of the dependent measure or the contrasts tested. Naturally, searching paradigms will better inform representations of possibility given that searching behaviors should only range over possible hiding locations, while not illuminating the mechanisms or representations that underlie elimination of alternatives. Moreover, the tested contrasts foreground possibilities or related phenomena: i.e., possibility vs. impossibility or high vs. low probability.

We wish to cast new empirical light on the negation component of disjunctive syllogism, to adjudicate between the propositional operator hypothesis and competing leaner alternatives, such as proto-negation or avoid-empty, which

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may guide elimination of alternatives but likely have a basis in perception or physical reasoning, and do not require propositional formats or combinatorial procedures (Bermúdez, 2003; Mody & Carey, 2016). These leaner accounts would assume that learning something about the location that is revealed to be empty should not lead to any conclusions about the other location.

We are inspired by the insight that the propositional operator account and the leaner accounts make different predictions about different kinds of impossibilities: (i) those that are never treated as possible and thus do not strictly need to be eliminated (hereafter called Impossible) and (ii) those that were once possible and have been eliminated from consideration due to negative evidence (hereafter called Negated). To clarify the distinction, imagine yourself as the participant in the basic two cups task. You would not search for the hidden object in the cup that is revealed to be empty (Negated location). But neither would you search in the experimenters' coffee mug or the planter in the corner of the testing room (Impossible locations). We assume that representations of Negated options imply a negation operator while representations of Impossible locations would not.

We test pre-verbal infants' understanding of this distinction between impossibilities and eliminated—or negated—possibilities in a Violation of Expectation paradigm. If we find that infants differentiate an Impossible outcome from a Negated one, it would provide initial support for the propositional operator hypothesis. In contrast, lean accounts would predict that infants make no differentiation between such outcomes because there is no difference in their representations of them because neither involves negation.

We have developed a novel paradigm to test this based on the basic two cups task (see Figure 1 for a depiction of the setup). Given 4 boxes (A-D), only 3 are possible hiding locations (A,B,C) while the fourth box is constantly open and not involved in the hiding phase. One of the 3 possible hiding locations is then revealed to be empty (A). Thus, we assume the following reasoning problem: A OR B OR C; NOT A; THEREFORE B OR C). With this framing, we can ask how infants treat Impossible outcomes (D), Negated outcomes (A) and even Possible outcomes (B,C), if a hidden object is revealed in any one of them. Note that this requires representing multiple possibilities, given that the actual hiding location is not known in advance of the outcome reveal. And we crucially assume that a location like D is never represented as a possibility. Understanding of both Impossible and Negated outcomes are supported via physical reasoning (because both locations were previously seen to be empty). But the Negated outcome is further supported by an eliminative mechanism which may be underlain by the negation operator. In other words, the Impossible outcome merely requires understanding of physical (im)possibility, whereas the Negated outcome additionally requires a negation operator and related psychological mechanisms.

Before turning to the experiments, we introduce the comparisons we test and the predicted pattern of results. We plan to test looking to 3 outcomes in pairs: Impossible vs. Possible (Experiment 1), Impossible vs. Negated (Experiment 2) and Negated vs. Possible (Experiment 3). The propositional operator hypothesis predicts a three-way distinction between Impossible, Possible and Negated outcomes, so we should expect to find a positive result in all experiments. Both the Impossible and Negated outcomes are inconsistent with prior events and thus should elicit longer looking times when compared against a Possible outcome.

But this account does not make strong predictions about the direction of the difference between the two inconsistent outcomes, in the absence of other assumptions. On one hand, the Impossible outcome may elicit longer looking than the Negated one, if representing the initial possibility of the Negated option has some faciliatory effect on integrating it as an outcome (Lüdtke et al., 2008). On the other hand, the Negated outcome may elicit longer looking than the Impossible one, if the propositional operator is associated with an inhibitory mechanism which makes it harder to integrate the Negated as outcome (de Vega et al., 2016).

In contrast, lean accounts predict a positive result in only a subset of the Experiments. Under these accounts, infants should be able to distinguish inconsistent outcomes from consistent ones (Impossible vs. Possible, Negated vs. Possible) but they should fail to differentiate between the inconsistent outcomes (Impossible vs. Negated).

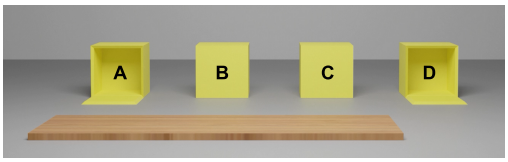

Figure 1: Depiction of the reasoning problem. Wooden occluder reflects position of possible hiding locations. Open boxes have been shown to be empty. A is the Negated location, B and C are Possible, D is Impossible.

Experiment 1

In Experiment 1, we aim to validate our paradigm and determine whether the preconditions are in place for infants to solve reasoning problems with this level of complexity when presented visually. For one, this task shares structural similarities with the Piagetian invisible displacement task, but 12-month-olds have not been found to succeed in that task (Piaget, 1954; Gopnik, 1984). For another, there is much recent debate around infants' modal reasoning abilities and whether they are able to simultaneously entertain multiple possibilities (Leahy & Carey, 2020; Cesana-Arlotti, Varga & Téglás, 2022; Leahy et al., 2022). We thus examined infants' looking behaviors in response to physically impossible vs. possible outcomes, in order to determine whether the above concerns will apply to our test case.

Participants

Twenty-four 12-month-olds contributed data to this experiment (12 boys; mean age = 12;14 months;days, range

= 12;0-12;27). An additional 7 infants failed to contribute at least 2 valid test trials due to fussiness (4), parental interference (1), experimenter error (1), or inattentiveness during crucial portions of stimuli (1). Participants were healthy, full-term infants recruited in Budapest from the database of the Cognitive Development Center. Written informed consent was obtained from caregivers before testing, after approval from the Hungarian United Psychological Research Ethics Committee (EPKEB).

Stimuli

Stimuli were created using Blender animation software (version 2.81a) and Blackmagic Design DaVinci Resolve video editing software (version 16.1.2).

Participants viewed 4 familiarization trials followed by 4 test trials. Familiarization served to introduce the basic structure of the task and equalize the potential of each location as a possible hiding location. Familiarization trials began with 4 open yellow boxes, a wooden screen laying on the ground that would later become an occluder, and a bear holding a red ball. After the occluder raised to cover all 4 boxes, participants would hear the equivalent of "Hi baby! Watch the ball!" in Hungarian. The bear would then toss the ball, before catching it and walking towards the occluder. The bear would then stop at each box behind the occluder (as if to potentially hide the ball there). The bear would then emerge from behind the occluder, with no ball in hand, and the occluder would lower to reveal that all of the boxes that had been occluded were now closed. After the bear exited the screen, participants would see a central attention getter and hear "Where is the ball?" A single box would then open to reveal that the ball was hidden in this location. Across the 4 familiarization trials, each box was revealed as the actual hiding location once (fixed order: CADB).

Test trial events differed from familiarization events in two crucial aspects: First, one of the 4 boxes was not covered by the occluder, and thus not visited by the bear during the hiding phase. We assume that this unoccluded box is never represented as a possible hiding location at test, and thus cannot be eliminated via negation. Second, between hiding phase and outcome reveal, there was an evidence phase where infants were shown that one of the 3 possible hiding locations was empty. See Figure 2 which illustrates trial events as they differ between trial type, condition and experiment.

Across the 4 test trials, the ball was revealed in the Impossible (I) location twice and a Possible (P) location twice (counterbalanced: IPIP vs. PIPI). The order in which the bear visited possible hiding locations was fixed (left to right). The location of the occluder was balanced between subjects (covering ABC vs. BCD), as well as the locations

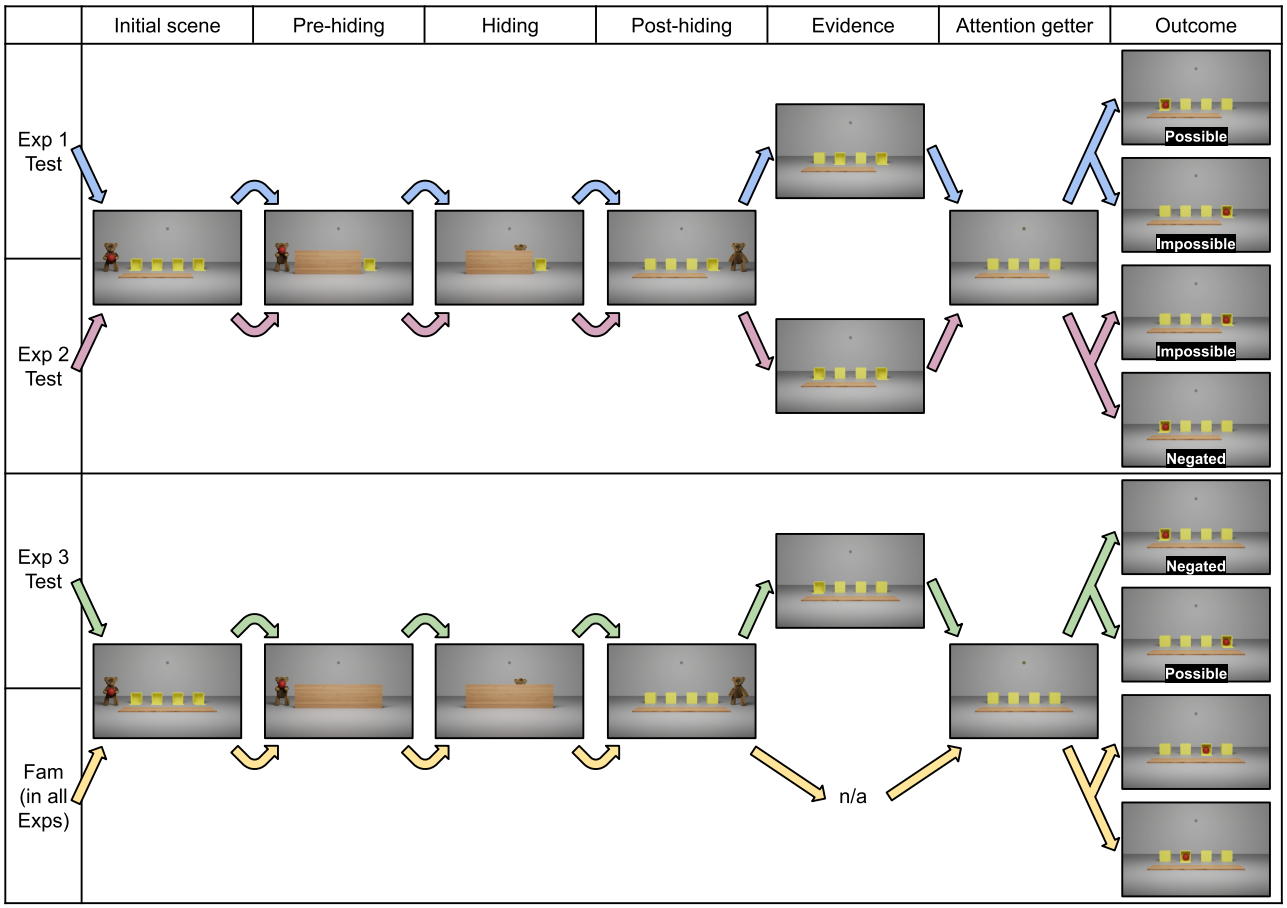

Figure 2: Events by trial type, condition and experiment

of the tested outcomes, given that these were dependent on the occluder location (if ABC were occluded then D remained visible, thus I=D, P=A vs. if BCD were occluded then A remained visible, thus I=A, P=D).

Each familiarization trial was 28s long. The stimuli in test trials were 30s long and their presentation was followed by an infant-controlled measurement period. The measurement period began as soon as the outcome box was fully open and lasted until (I) the participant looked away for 2s consecutively or (II) they looked at the screen for 30s total. The whole experiment lasted about 6 minutes on average.

Procedure

Stimuli were displayed on a 24-inch display (1920 x 1200 resolution) and their presentation was controlled via PsyScope X (Cohen et al., 1993). Infants were seated in their caregiver's lap in a darkened and sound-proofed room, 60 cm from the display. Caregivers were instructed to hold infants by their hips and not impede their ability to disengage from the screen. Caregivers were given opaque glasses to prevent them from seeing the stimuli. A short attention-getting animation played before each trial until participants attended to the display. The experimenter was behind a curtain and coded infants' looking behaviors.

Data Processing

For analysis purposes, infants' looking behaviors were coded offline with PsyCode (Gervain, Bonatti & Filippin, 2009). Individual trials were excluded if infants missed crucial moments in the stimulus, such as the pre-hiding, post-hiding and evidence phases. Trials were also excluded if infants did not look at the display for at least 2000ms during the measurement period. We planned to exclude infants who looked at the display for 30s on >2/4 test trials, but this did not arise in the sample. We also excluded individual trials from the analysis if their looking time was >2 standard deviations from the group's mean in that condition.

Results

Statistical analyses were conducted in R (version 4.2.1) and plots were produced using the ggplot2 package (Wickham, 2009). We conducted a paired samples t-test, with reported p-values two-tailed. See Figure 3 for the results of this Experiment, as well as Experiments 2 and 3.

Infants looked longer when the ball was revealed in the Impossible location (M = 10375 ms, SD = 5733 ms) than when the ball was revealed to be in one of the Possible locations (M = 6978 ms, SD= 2955 ms). This difference was significant: $t(23) = 2.7872$, $p = 0.01047$.

Discussion

The results of Experiment 1 verify that the basic conditions are met for us to be able to test our negation research question using this paradigm and stimuli. When the ball was revealed in a location that infants had only ever seen as empty (Impossible outcome), they looked longer at this outcome than when the ball was revealed to be in a location that the bear had visited behind the occluder (Possible outcome).

This pattern of results is consistent with the interpretation that infants treat the locations that the bear visits as the only possible hiding locations and are thus surprised when the ball is revealed to be elsewhere. If this task is construed as a variant on the traditional invisible displacement task, these results suggest earlier success, perhaps because physical searching is not required of participants (Piaget, 1954; Gopnik 1984). Furthermore, since there are two remaining possible locations when the outcome is revealed, these results also suggest that 12-month-olds can represent both as possible (Cesana-Arlotti et al., 2022), contra minimal theories of modality development (Leahy & Carey, 2020).

Experiment 2

Given the positive result from Experiment 1, we next turn to the crucial contrast for our negation hypothesis. In Experiment 2, we ask whether infants treat negated possibilities differently from non-possibilities. Unless otherwise specified, the method is the same as Experiment 1.

Participants

Twenty-four 12-month-olds contributed data to this experiment (12 boys; mean age = 12;16, range = 12;7-12;27). An additional 18 failed to contribute at least 2 valid test trials due to fussiness (9), sleeping (1), parental interference (1), technical or experimenter error (2), too many outlier trials (2), >2 trials where looking reached 30s (2), or inattentiveness during crucial phases of stimuli (1).

Stimuli

As in Experiment 1, participants viewed 4 familiarization trials followed by 4 test trials. Familiarization trials were identical to Experiment 1. Test trials differed only in the set of outcomes that were tested. The Impossible outcome was contrasted against the Negated outcome, which is the box that is shown to be empty during the evidence phase after the ball is hidden (see Figure 2 for full details).

Results

Infants looked longer when the ball was revealed in the Negated location (M = 9533 ms, SD = 6112 ms) than when the ball was revealed to be in the Impossible location (M = 7988 ms, SD= 3829 ms). This difference was not significant: $t(23) = -1.1225$, $p = 0.2732$.

Discussion

The results of Experiment 2 do not confirm that 12-month-olds differentiate eliminated possibilities from outcomes that were never possible. When the ball was revealed in a location which was initially a possible hiding location that was later revealed to be empty (Negated), infants did not look significantly longer than when the ball was revealed in a location that they had only ever seen as empty (Impossible).

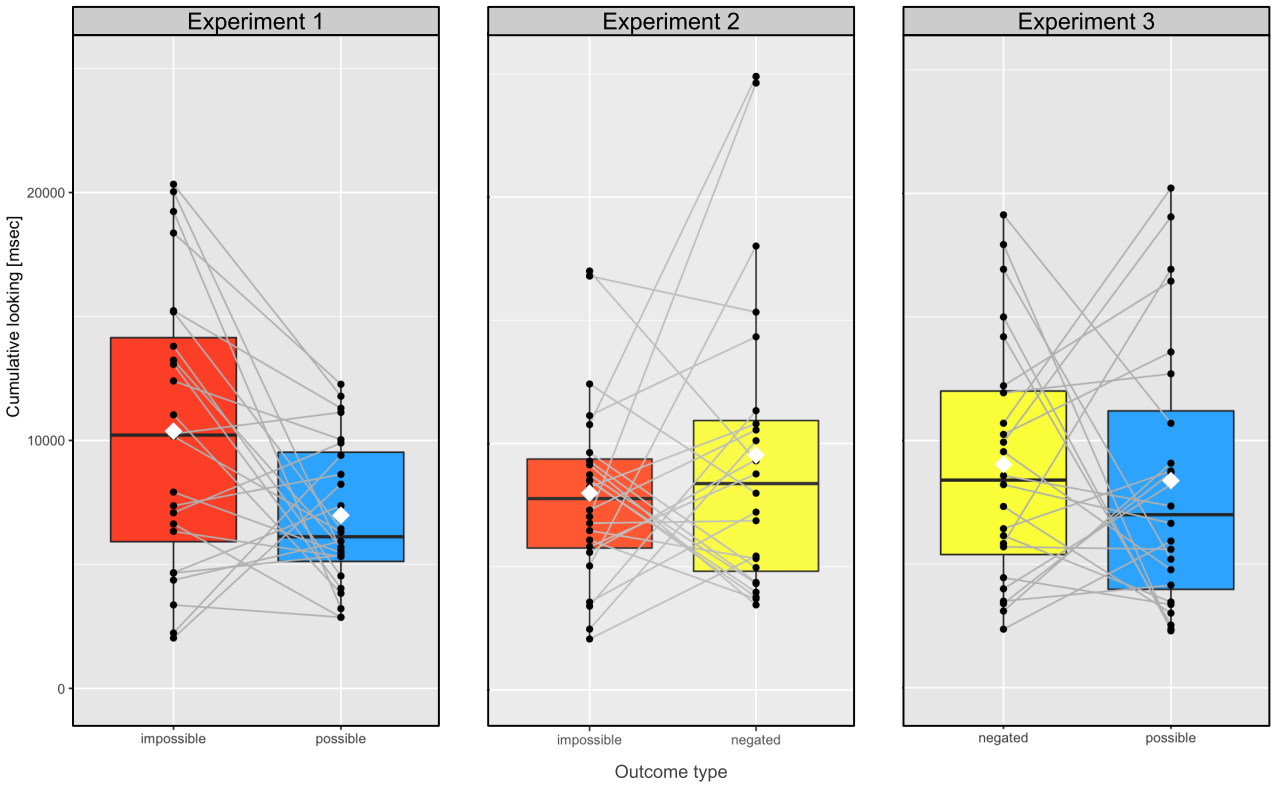

Figure 3: Mean cumulative looking time by Experiment and condition. Red represents data from Impossible conditions, yellow from Negated conditions, blue from Possible conditions. Gray lines connect individual means across conditions. White diamonds indicate means, horizontal lines indicate medians, boxes indicate middle quartiles, whiskers indicate points within 1.5 times the interquartile range from the upper and lower edges of the middle quartiles.

This pattern of results could be taken to support lean accounts such as the proto-negation or avoid-empty accounts, given that they predict no difference between such outcomes. It is also possible that infants' reasoning is indeed supported by a propositional negation operator which can distinguish eliminated possibilities from non-possibilities, but that our manipulation fails to detect the difference. Perhaps infants do not differentially employ their negation operator in understanding the Impossible and Negated outcomes, because both are in fact supported by negation (i.e., all 4 boxes are initially considered possible, the "impossible" box is eliminated during the hiding phase, then "negated" box is eliminated during the evidence phase). Another possibility is that we are not able to detect the difference in looking to the two outcomes (even though there is a true difference in the underlying representations) due to a lack of power or our unconventional use of the Violation of Expectation paradigm (comparing two inconsistent outcomes).

Experiment 3

The results of Experiment 2 do not directly support the propositional operator hypothesis, in the absence of auxiliary assumptions. In fact, they are more compatible with lean accounts like proto-negation or avoid-empty. In Experiment 3, we collect further data on infants' treatment of (im)possibilities in order to distinguish between potential explanations of the null result in Experiment 2. Here, we ask whether infants treat eliminated possibilities differently from possibilities that are still live. Unless otherwise specified, the method is the same as Experiment 1.

Participants

Twenty-four 12-month-olds contributed data to this experiment (12 boys; mean age = 12;15, range = 12;1-12;30). An additional 6 infants failed to contribute at least 2 valid test trials due to fussiness (3), parental interference (1), or inattentiveness during crucial portions of stimuli (2).

Stimuli

There was no Impossible box in this experiment. All four boxes were possible locations before one was eliminated. This Negated outcome was contrasted to a Possible outcome.

Results

Infants looked longer when the ball was revealed in the Negated location (M = 9035 ms, SD = 4927 ms) than when the ball was revealed to be in a Possible location (M = 8379 ms, SD= 5470 ms). This difference was not significant: $t(23) = 0.44147$, $p = 0.663$.

Discussion

The results of Experiment 3 do not confirm that 12-month-olds differentiate eliminated possibilities from possibilities which are still live. When the ball was revealed in a location which was initially a possible hiding location that was later revealed to be empty (Negated outcome), infants did not look significantly longer than when it was revealed in a possible hiding location (Possible outcome).

This pattern of results is predicted neither by the propositional operator account, nor the leaner proto-negation and avoid-empty accounts. On any account, the outcome that is still a live possibility is consistent with prior events, and should thus elicit shorter looking time than the eliminated possibility, which is inconsistent with prior events. Given that we do find a positive result in Experiment 1, where we test another contrast based in physical reasoning about (im)possibilities, we should also expect to find it here.

However, there is a difference between Experiments 1 and 3 with respect to the number of possibilities that must be tracked: In Experiment 1, 3 boxes are initially occluded and are thus possible hiding locations. In Experiment 3, all four boxes are initially occluded and are thus possible hiding locations. Note that tracking four possibilities likely goes beyond the working memory capacity of 12-month-olds (Feigenson & Carey, 2003). If so, infants could fail to represent all boxes as possible and then they may treat the so-called "possible" outcome as an unexpected appearance (Kaufman, Csibra & Johnson, 2003). We are currently running a follow-up to explore this. We anticipate that infants will differentiate the negated and possible outcomes when the range of possibilities falls within their working memory capacity, compatible with the propositional operator account.

General Discussion

We set out to test whether pre-verbal infants, aged 12 months, can solve a disjunctive reasoning problem by appealing to a propositional negation operator. We were inspired by the insight that non-actual outcomes could have different psychological histories: either they may be considered as possibilities and then eliminated from the set of live alternatives, or they may not be considered as possibilities at all and thus never require elimination. This insight provides a wedge into current theoretical debates on negation in non-verbal populations. Rich accounts would assume that elimination of possibilities implies a propositional negation operator, which would not be required unless elimination occurs. In contrast, lean accounts would run different kinds of impossibility together, because they rely on implicit eliminative mechanisms which are sensitive to the current status of some option, and not its history.

In order to examine whether infants distinguish between kinds of non-actual outcomes, we use a variation of the Violation of Expectation paradigm that is new to this literature. In contrast to studies which test infants' understanding of consistent vs. inconsistent (e.g., possible vs. impossible) outcomes, we asked whether their looking times could distinguish two kinds of inconsistent outcomes (e.g., eliminated possibilities vs. non-possibilities). This would be a high evidentiary threshold, given the linking assumptions between underlying representations and looking time; violations of expectations supported by different representations do not necessarily elicit different looking times. But if an eliminated possibility is associated with specific psychological mechanisms, then we might expect to see responses to it differing from responses to other kinds of inconsistent outcomes. On the one hand, we might expect that its history as a possible alternative is associated with a facilitative effect. On the other hand, we might expect that a negation operator is associated with a suppressive or inhibitory effect (see Tian & Breheny, 2019 for discussion from the adult psycholinguistics literature).

In our line of experiments, we test two sets of consistent vs. inconsistent contrasts (Impossible vs. Possible; Negated vs. Possible) and one inconsistent vs. inconsistent contrast (Impossible vs. Negated). While these contrasts are tested pairwise, we can infer relative rankings of overall difficulty in integrating the outcomes: Either (i) Negated is easier to integrate than Impossible, but harder than Possible (looking time prediction: Impossible > Negated > Possible). Or (ii) Negated is harder to integrate than Impossible, which is in turn harder than Possible (looking time prediction: Negated > Impossible > Possible). In contrast, lean accounts would make the prediction that (iii) Impossible and Negated are not treated differently and that both elicit longer looking times than Possible (looking time prediction: Impossible = Negated > Possible). We find that infants look longer to Impossible outcomes than Possible ones (Experiment 1), but we do not find a significant difference in infants' looking to Negated outcomes in neither the contrast with Impossible outcomes (Experiment 2) nor Possible outcomes (Experiment 3). These results do not directly support lean accounts: given the positive result in Experiment 1, we would also expect a positive result in Experiment 3.

With respect to the rich propositional negation operator account, this set of results does not provide direct support either. But it may be that aspects of the experimental design have obscured differences in infants' responses to the different outcomes. As one possibility, our choice of the Violation of Expectation paradigm and comparison between two inconsistent outcomes may not reveal differences in infants' understanding of the two outcomes. As another possibility, we may not have the power needed to detect the targeted effects. While we find the Impossible vs. Possible difference, we might not expect the differences between Negated vs. Impossible or Negated vs. Possible to be as big. Especially if we assume the pattern described above in (i) where Negated has some intermediate status compared to the others. And this would not be altogether surprising, considering that eliminated possibilities have characteristics of both possibilities and impossibilities. Future work will pursue some of these open questions, along with related ones in the literature on pre-verbal infants' reasoning.

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References

Blackmagic Design. (2019). *Davinci Resolve (version 16.1.2)*.

Bermúdez, J. L. (2003). *Thinking without words*. Oxford University Press.

Bohn, M., Call, J., & Völter, C. J. (2020). Evolutionary precursors of negation in non-human reasoning. In *The Oxford Handbook of Negation*. Oxford University Press.

Call, J. (2004). Inferences about the location of food in the great apes (Pan paniscus, Pan troglodytes, Gorilla gorilla, and Pongo pygmaeus). *Journal of Comparative Psychology*, 118(2), 232.

Cesana-Arlotti, N., Kovács, Á. M., & Téglás, E. (2020). Infants recruit logic to learn about the social world. *Nature communications*, 11(1), 5999.

Cesana-Arlotti, N., Martín, A., Téglás, E., Vorobyova, L., Cetnarski, R., & Bonatti, L. L. (2018). Precursors of logical reasoning in preverbal human infants. *Science*, 359(6381), 1263-1266.

Cesana-Arlotti, N., Varga, B., & Téglás, E. (2022). The pupillometry of the possible: an investigation of infants' representation of alternative possibilities. *Philosophical Transactions of the Royal Society B*, 377(1866), 20210343.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: An interactive graphic system for designing and controlling experiments in the psychology laboratory using Macintosh computers. *Behavior Research Methods, Instruments & Computers*, 25(2), 257–271.

de Carvalho, A., Crimon, C., Barrault, A., Trueswell, J., & Christophe, A. (2021). "Look! It is not a bamoule!": 18- and 24-month-olds can use negative sentences to constrain their interpretation of novel word meanings. *Developmental Science*, 24(4), e13085.

de Vega, M., Morera, Y., León, I., Beltrán, D., Casado, P., & Martín-Loeches, M. (2016). Sentential negation might share neurophysiological mechanisms with action inhibition. Evidence from frontal theta rhythm. *Journal of Neuroscience*, 36(22), 6002-6010.

Davidson, D. (1999). The emergence of thought. *Erkenntnis*, 51(1), 511-521.

Descartes, R. (1964). *Les passions de l'ame*, Amsterdam, Lodewijk Elsevier, and Paris, Henry le Gras. Adam & Tannery (1964-74), 11.

Ekramnia, M., Mehler, J., & Dehaene-Lambertz, G. (2021). Disjunctive inference in preverbal infants. *Iscience*, 24(10), 103203.

Feigenson, L., & Carey, S. (2003). Tracking individuals via object-files: evidence from infants' manual search. *Developmental Science*, *6*(5), 568-584.

Feiman, R., Mody, S., & Carey, S. (2022). The development of reasoning by exclusion in infancy. *Cognitive Psychology*, 135, 101473.

Feiman, R., Mody, S., Sanborn, S., & Carey, S. (2017). What do you mean, no? Toddlers' comprehension of logical "no" and "not". *Language Learning and Development*, 13(4), 430-450.

Fodor, J. A. (1975). *The language of thought* (Vol. 5). Harvard university press.

Gervain, J., Bonatti, L., & Filippin, L. (2009). *The PsyCode Software Manual*. http://psy.ns.sissa.it/

Gopnik, A. (1984). The acquisition of gone and the development of the object concept. *Journal of Child Language*, 11(2), 273-292.

Hill, A., Collier-Baker, E., & Suddendorf, T. (2011). Inferential reasoning by exclusion in great apes, lesser apes, and spider monkeys. *Journal of Comparative Psychology*, 125(1), 91.

Kaufman, J., Csibra, G., & Johnson, M. H. (2003). Representing occluded objects in the human infant brain. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *270*(suppl_2), S140-S143.

Leahy, B. P., & Carey, S. E. (2020). The acquisition of modal concepts. *Trends in Cognitive Sciences*, 24(1), 65-78.

Leahy, B., Huemer, M., Steele, M., Alderete, S., & Carey, S. (2022). Minimal representations of possibility at age 3. *Proceedings of the National Academy of Sciences*, 119(52), e2207499119.

Lüdtke, J., Friedrich, C. K., De Filippis, M., & Kaup, B. (2008). Event-related potential correlates of negation in a sentence–picture verification paradigm. *Journal of cognitive neuroscience*, 20(8), 1355-1370.

Mather, E., & Plunkett, K. (2011). Mutual exclusivity and phonological novelty constrain word learning at 16 months. *Journal of Child Language*, 38(5), 933-950.

Mody, S., & Carey, S. (2016). The emergence of reasoning by the disjunctive syllogism in early childhood. *Cognition*, 154, 40-48.

Pepperberg, I.M., Koepke, A., Livingson, P., Girard, M. & Hartsfied, L.A. (2013). Reasoning by inference: further studies on exclusion in Grey parrots (Psittacus erithacus). *Journal of Comparative Psychology*, 127: 272-281

Piaget, J. (1954). *The construction of reality in the child*. Routledge.

Pomiechowska, B., Bródy, G., Csibra, G., & Gliga, T. (2021). Twelve-month-olds disambiguate new words using mutual-exclusivity inferences. *Cognition*, 213, 104691.a

Quilty-Dunn, J., Porot, N., & Mandelbaum, E. (2022). The best game in town: The re-emergence of the language of thought hypothesis across the cognitive sciences. *Behavioral and Brain Sciences*, 1-55.

R Core Team (2022). R*: A language and environment for statistical computing* (version 4.2.1). R Foundation for Statistical Computing, Vienna, Austria.

Stichting Blender Foundation (2018). *Blender (version 2.81a).*

Szabó, E., & Kovács, Á. M. (2022). *Infants' early understanding of different forms of negation*. Manuscript at Central European University.

Tian, Y., and Breheny, R. (2019). Negation, in Chris Cummins, and Napoleon Katsos (eds), *The Oxford Handbook of Experimental Semantics and Pragmatics*, Oxford Handbooks.

Watson, J. S., Gergely, G., Csanyi, V., Topal, J., Gacsi, M., & Sarkozi, Z. (2001). Distinguishing logic from association in the solution of an invisible displacement task by children (Homo sapiens) and dogs (Canis familiaris): using negation of disjunction. *Journal of Comparative Psychology*, 115(3), 219.

Wickham, H. (2009). *Ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag.