Reversing how to think about ambiguous figure reversals:
Spontaneous alternating by uninformed observers

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Ambiguous figures are a special class of images that can give rise to multiple interpretations. Traditionally, switching between the possible interpretations of an ambiguous figure, or reversing one’s interpretation, has been attributed to either top-down or bottom-up processes (e.g., either attributed to having knowledge of the nature of the ambiguity or attributed to a form of neuronal fatigue). However, here we present evidence that is incompatible with both forms of explanations. Five to nine year-old observers can reverse ambiguous figures when uninformed about the ambiguity, negating purely top-down explanations. Further, those children who make these ‘spontaneous’ reversals are more likely to succeed on a high-order theory of mind task, negating purely bottom-up explanations.

1 Introduction
Every view of our visual world gives rise to an infinite number of interpretations. Only through a series of inferential processes do we perceive a consistent and stable world. These inferences occur so smoothly that they are rarely noticed. However, certain stimuli, such as ambiguous figures, can create problems for the visual system and in so doing allow for a glimpse into the inferential processes. In these cases, a single image gives rise to multiple interpretations. As an example, stare at figure 1a and your percept should occasionally reverse - alternating between a ‘duck’ and a ‘rabbit.’ There are two competing theories of how one’s interpretation of an ambiguous figure reverses, but this issue remains, at best, ambiguous.

According to a satiation theory ambiguous figure reversals occur through a process analogous to neuronal fatigue when perceiving color afterimages (e.g., Köhler, 1940; Long & Toppino, 1981). If you stare at a yellow color patch, and then shift your gaze to a white patch, you will perceive blue. The initial exposure to yellow fatigues the firing “yellow neurons” and when you shift to the white patch, the “blue neurons,” which are not fatigued, dominate. Following the analogy, perceiving a duck in figure 1a will eventually fatigue the neurons that represent the duck interpretation, giving way to the percept of a rabbit. Alternatively, a cognitive theory suggests that a reversal can only occur if a) an observer knows the figure is ambiguous, b) knows the two specific interpretations of the figure, and c) has the intent to reverse (e.g., Girgus, Rock, & Egatz, 1977; Rock & Mitchener, 1992; Rock, Gopnik, & Hall, 1994; Rock, Hall, & Davis, 1994).

These competing theories map onto a ‘bottom-up’ versus ‘top-down’ debate and they can be pitted against one another through a simple experiment - show observers an unfamiliar ambiguous figure (without telling them of its ambiguity) and ask tell them to look at it. Will they spontaneously perceive both interpretations? The satiation theory predicts that observers will spontaneously reverse between the possible percepts and the cognitive theory predicts they will not. Unfortunately, implementing this experiment has produced mixed results. When high-school students were shown ambiguous figures and told that they were ambiguous (but not informed of the possible alternatives), approximately one-half made a spontaneous reversal (Girgus et al, 1977). When college students were shown ambiguous figures and not informed in any way about the ambiguity, approximately one-third spontaneously reversed (Rock & Mitchener, 1992). These results are damning for both theories - reversing cannot be purely bottom-up if only a subset of observers spontaneously do so; reversing cannot be purely top-down if any observers spontaneously reverse. In light of these results, Rock and his colleagues suggested that those who spontaneously reverse might not be naïve - any prior experience with such figures, combined with an...
intent (possibly born from the experimental setting) could lead to what would appear to be spontaneous reversals. They hypothesized that “some, perhaps all, of the few reversals that occurred under the uninformed condition resulted from prior knowledge about reversible figures” (Rock & Mitchener, 1992, p 44) and that “if a still younger and therefore more naïve sample had been used, the percentage of spontaneous reversals would have been even lower” (Girgus et al., 1977, p.555).

To test this hypothesis, young children were shown ambiguous figures and not informed of the ambiguity (Rock, Gopnik, & Hall, 1994; Gopnik & Rosati, 2001). No 3- to 5-year-old observer spontaneously reversed, but once informed of the ambiguous nature and of the possible interpretations, a subset of children did perceive both interpretations of the figure. The ability to make such ‘informed’ reversals correlated with success on a theory of mind task1, suggesting that the ability to reserve an ambiguous figure is related to specific cognitive abilities (Gopnik & Rosati, 2001). Although this confirms the assumption that younger observers would fail to spontaneously reverse, and suggests that cognitive abilities might play a role in the mechanisms that underlie reversals, it does not necessarily validate the cognitive theory of reversals. A large age range remains untested; it is possible that older children may spontaneously reversal these figures. If older (yet still naïve) children are shown ambiguous figures and not informed in any way, will any of them spontaneously reverse?

In the current study, we presented 5- to 9-year-old observers with an ambiguous figure and examined whether they would reverse the figure spontaneously. Given that younger children’s informed reversals were related to their theory of mind abilities (Gopnik & Rosati, 2001), we also examined such relations with spontaneous reversals (if present). In particular, the difference between perceiving two interpretations of an ambiguous figure when told of its ambiguity and recognizing those two interpretations exist spontaneously is not representational but one of interpretation. On a cognitive level, spontaneous reversals require a particular skepticism about one’s percepts. Such a metacognitive stance might be related to other metacognitive abilities the child develops – such as their knowledge about other mental states. As an investigation, we used a ‘metacognitive’ theory of mind task, in which children had to reason about what another thought about what they were thinking (Perner & Wimmer, 1985). Finding a relationship between these two abilities would suggest a potential role of higher order cognition in complex visual processing.

2 Methods
Each child participated in four tasks: Gopnik and Rosati’s (2001) ambiguous figure interview, Taylor’s (1988) representational change “droodle” theory of mind task, Perner and Wimmer’s (1985) metacognitive “ice cream” theory of mind task, and a Piagetian number conservation task, which was used as a measure of general cognitive abilities.

2.1 Participants
Thirty-seven children were recruited from two preschools and a YMCA after school program in Berkeley, CA. Data were eliminated from three children; two due to previous experience with ambiguous figures and one due to a failure to pass a control question (see below). The remaining 34 children (18 male, 16 female) ranged in age from 61 to 107 months (Mean = 84 months).

2.2 Materials
We used two sets of line drawings for the ambiguous figure task - versions of the ‘duck/rabbit’ and of the ‘vase/faces’ figures. The figures were approximately 12 x 12 cm in length and were drawn with black ink on white paper. Each set consisted of one ambiguous figure and two unambiguous pictures (see figure 1). For the droodle task we used a black line drawing of a sunflower measuring approximately 15 x 23 cm, on standard white paper. A manila folder with a circle (diameter = 4 cm) cut out of it covered the drawing, leaving only the center of the sunflower visible; this center simply looked like angular

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1Theory of mind tasks involve understanding how mental states relate to the world around us. The tasks used by Gopnik and Rosati (2001) involved representational change. Children were asked about their beliefs about the world (e.g., about the contents of a crayon box) and evidence was presented that differed from those beliefs (e.g., that there were candles in the crayon box). Children were asked what another person would think was in the box, and what they themselves had previously thought was in the box. The latter question in particular measures children’s ability to keep track of their own first-person phenomenology (Gopnik, 1993; Gopnik & Astington, 1988). Perceiving both interpretations of an ambiguous figure requires similar access to one’s own mental states.
lines. For the “ice cream” task, we created a model village on a wooden board approximately 30 x 53 cm. There was the ‘park’ in one corner, the ‘church’ in the opposite corner, and ‘Mary’s house’ halfway in between. The park was an area painted green with five small wooden trees, the church and Mary’s house were made of wood, the ice cream truck was a small metal toy, and ‘John’ and ‘Mary’ were wooden dolls about 2 cm tall. Finally, twelve 2 cm washers were used for the number conservation task.

2.3 Procedure
Each child was tested individually. The four tasks were presented in a random order for each child. Testing sessions took approximately 15 minutes and were audio taped.

Figure 1. A) The ambiguous duck/rabbit figure used in the experiment. B) The unambiguous versions of the duck/rabbit figure used to teach the children the possible interpretations.

2.3.1 Ambiguous Figures
Each child was shown one of the two ambiguous figures and received an interview similar to that of Gopnik and Rosati (2001). The child was asked to report what they saw immediately, after 15 seconds, and after 30 seconds. If the child generated both interpretations, they were asked to point to specific parts (e.g., the rabbit’s ears and the duck’s bill). If they did not generate both interpretations, the experimenter used unambiguous versions of the figure (see figure 1b) to inform the child of the ambiguity and the alternative interpretations. Once the child was fully informed, the experimenter again showed the child the ambiguous figure and asked what the child saw immediately, after 15 and after 30 seconds. If the child reported seeing both interpretations before being informed, they were coded as making a spontaneous reversal. If they only reported reversing after being informed, they were coded as making an informed reversal.

2.3.2 Ice Cream Task
For the ‘ice cream’ task, the experimenter introduced the child to the town model and identified the relevant components. The child was asked clarifying questions and was provided with feedback when needed. The experimenter then used the model and components to act out a story based on that of Perner and Wimmer (1985; see Appendix). The child was then asked the test and control questions. One child failed the final control question and his data were eliminated from all analyses. Children were scored as passing if they correctly answered the test question (stating that John thinks that Mary is at the park; see Appendix) and justified this response using an explanation that appealed to mental states.

2.3.3 Droodle task
Each child received an interview similar to that of Taylor (1988). The experimenter placed a mostly-occluded picture with only a set of angular lines visible in front of the child and asked, ‘What do you think this is a picture of?’ After they responded, the experimenter uncovered the picture to reveal the drawing of a sunflower. With the picture fully exposed, the experimenter asked, “What is this really a picture of?” After the child had identified the flower, the experimenter re-covered the drawing and asked, “Do you remember what you thought this was a picture of before we uncovered it?” and “Let’s say that [classmate’s name] came in here now. What would [classmate’s name] think this was a picture of, if he could only see it all covered up like this?” Children were scored as passing if they stated that they did not know the picture was a flower before it was uncovered and that another child would also not know.

2.3.4 Number Conservation
The children were shown twelve washers placed in two evenly spaced lines of six each. The experimenter labeled the line closest to the child as “your line” and the line closest to him as “my line” and asked, “Does your line have more, less, or the same as my line?” The experimenter then spread out the washers in the child’s line such that they were further apart than the washers in the experimenter’s line and again asked, “Does your line have less, more, or the same as my line?” The ordering of the words ‘more,’ ‘less’ and ‘same’ was changed between children and between the two questions for the same child. If the children were scored as passing if they
stated there was the same number of washers for each question.

3 Results
12 of the 34 (35.3%) children spontaneously reversed the ambiguous figure (8 had seen the vase/faces). Twenty of the remaining 22 children reversed the figure after they were informed of the ambiguity and 2 failed to make any reversal (see figure 2). Those who made a spontaneous reversal were more likely to pass the ice cream task (10 of 12) than those who did not (6 of 22; Fisher Exact Test: \( p = .003 \)) and spontaneously reversing correlated with passing the ice cream task \( (r^2 = .288, p < .001) \). There was no significant correlation between children’s spontaneous reversals and age \( (r^2 = .036, ns.) \) or the number conservation task \( (r^2 = .005, ns.) \) and when these two factors were accounted for through a hierarchical regression, performance on the ice cream task continued to predict a significant amount of the variance in spontaneous reversals \( (\Delta r^2 = .259, F(3, 30) = 4.19, p < .014) \). Unlike previous findings (Gopnik & Rosati, 2001), there was no relationship between informed reversals and the droodle task, however, performance on the droodle task was near ceiling (see figure 2) so the lack of a significant finding is not surprising.

4 Discussion
Five- to 9-year-old children can reverse ambiguous figures when uninformed and their ability to do so is linked to their developing theory of mind capabilities. These findings are problematic for the current theories of ambiguous figure reversals; the satiation theory, a purely bottom-up explanation, cannot account for two thirds of the observers failing to spontaneously reverse and the cognitive theory, a top-down explanation, cannot account for any observers spontaneously reversing.

![Figure 2](image)

Figure 2. Performance on the ambiguous figure task by type of reversal on the left and success rates for the ‘droodle,’ ‘ice cream,’ and number conservation tasks on the right.

In light of the current data, we offer an alternative explanation for how ambiguous figures are perceived and reversed. Similar to the cognitive theory, this proposal involves top-down processes, but rather than requiring prior knowledge, it requires specific cognitive abilities. First, to reverse an ambiguous figure, informed or otherwise, observers need certain mental representational capacities. Without understanding that a single image can have multiple percepts, observers will perseverate on a single interpretation (as seen in young children). Second, to spontaneously reverse, observers need more complex representational capabilities. Without the ability to reason about multiple representations in a metacognitive manner, it is unlikely that observers will a) infer the ambiguity, b) infer the potential percepts, and then c) discover the bi-stability of ambiguous figures. While we have shown a relationship between second order theory of mind and spontaneous reversals, second order theory of mind might not be the necessary cognitive ability. In that some of our observers failed the ice cream task but nonetheless spontaneously reversed an ambiguous figure (two children), second order theory of mind is likely one of a number of tasks representative of such higher order representational capacities. Finally, given these necessary requirements, spontaneous reversals can occur with additional top-down influences (e.g., intent) or bottom-up influences (e.g., happening to focus attention on certain parts or locations of the image). This final and critical point explains why not all adults, who presumably have complex representational

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2 All p-values are 2-tailed.

3 Although two observers’ data were removed due to prior experience with ambiguous figures, this result supports the claim that the remaining observers were in fact naive. The correlation between spontaneous reversals and the ice cream task cannot be explained in terms of prior knowledge — there is no reason why the children who have these specific cognitive abilities would also be the children who have previously seen ambiguous figures (when age and general cognitive abilities are accounted for). Further, anecdotally, the children’s phenomenological experiences revealed that they were honestly surprised that a single figure could suddenly change percepts. The children showed amazement when they saw the other interpretation, whether they did so on their own or when informed.
capabilities, spontaneous reverse ambiguous figures (e.g., Girgus, et al., 1977; Rock & Mitchener, 1992).

5 Conclusions
The finding that young children can spontaneous reverse an ambiguous figure provides a much-needed piece to an unsolved puzzle. Whereas before the very existence of spontaneous reversals was under debate, now discussions can focus more on what ambiguous figures can tell us about visual perception and cognition. For example, ambiguous figures were recently used to explore whether autistic children's social limitations may stem from broader cognitive limitations (Sobel, Capps, & Gopnik, in press). The existence of spontaneous reversals raises new questions about the connections between visual perception and high-order cognition and through further exploration the process of visual perception promises to become less and less ambiguous.

References
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Appendix
The following are the script and questions used for the ‘ice cream’ task, which are modeled after Perner and Wimmer (1985):

“While at the park, John and Mary notice the ice cream man. Mary says she would like ice cream but has left her money at home. ‘Don’t worry,’ says the ice cream man, ‘you can go home and get your money. I’ll be here in the park all afternoon.’ ‘Oh good,’ Mary says, ‘I’m going home to get my money and then I’ll come back.’ Mary leaves for home.”

Clarifying question 1: “Where did the ice-cream man tell Mary he would be all day?”

“A little after Mary leaves, the ice cream man starts to leave. John sees this and asks the ice cream man where he is going. The ice cream man tells John, ‘there are no kids to buy my ice cream at the park so I am going to the church.’ So off he drives to the church. Along the way, he sees Mary. He says to Mary, ‘Oh I am glad I saw you, when you want ice cream later today, I will be at the church.”

Clarifying question 2: “Where did the ice-cream man tell Mary he was going”?

Clarifying question 3: “Did John know that the ice-cream man talked to Mary?”

“So Mary goes home and the ice cream man goes to the church. Later that day, Mary feels like ice cream and goes to get some at the church. A little later, John goes to see if Mary is home. He knocks on the door and Mary’s mother answers. John asks, ‘Is Mary here?’ ‘No’ says her mother. ‘She’s gone to get ice cream.’

Test question: “Where does John think Mary has gone to buy ice cream?”

Control question 1: “Where did Mary really go to buy ice cream?”

Control question 2: “Where was the ice cream man in the beginning?”