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

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Stephen R Mitroff, David M Sobel¶, Alison Gopnik§

Center for Cognitive Neuroscience and Department of Psychological and Brain Sciences, Duke University, Box 90999, Durham, NC 27708, USA; e-mail: mitroff@duke.edu; ¶ Department of Cognitive and Linguistic Sciences, Brown University, Providence, RI 02912, USA;

§ Department of Psychology, University of California at Berkeley, Berkeley, CA 94720, USA

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**Abstract.** 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 either to top–down or to bottom–up processes (eg attributed to having knowledge of the nature of the ambiguity, or to a form of neuronal fatigue). Here we present evidence that is incompatible with both forms of explanations. Observers aged 5–9 years 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 environment. These inferences occur so smoothly that they are rarely noticed. However, certain stimuli can create problems for the visual system, and in so doing allow for a glimpse into the inferential processes. One such class of stimuli is ambiguous figures—single images that can give rise to multiple interpretations. For example, if you look at figure 1a, your percept should occasionally reverse, alternating between a 'duck' and a 'rabbit' (Jastrow 1899). Traditionally there have been two competing theories of how one's interpretation of an ambiguous figure reverses (for a recent review see Toppino and Long 2005), 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 (eg Köhler 1940; Long and Toppino 1981). If you stare at a green color patch, and then shift your gaze to a white patch, you will perceive red. The initial exposure to green fatigues the firing 'green neurons' and when you shift to the white patch, the 'red neurons', which are not fatigued, dominate. Extending this 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 occur only if an observer (a) knows the figure is ambiguous, (b) knows the two specific interpretations of the figure, and (c) has the intent to reverse (eg Gergus et al 1977; Rock and Mitchener 1992; Rock et al 1994a, 1994b).

These competing theories map onto a 'bottom–up' versus 'top–down' debate, and they can be pitted against one another experimentally—simply showing observers an unfamiliar ambiguous figure without telling them of its ambiguity. 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 reversible (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 and 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 naive—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 and Mitchener 1992, page 44) and that if a “younger and therefore more naive sample had been used, the percentage of spontaneous reversals would have been even lower” (Girgus et al 1977, page 555).

In a test of this hypothesis, young children were shown ambiguous figures and not informed of the ambiguity (Rock et al 1994a; Gopnik and Rosati 2001). No 3–5-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 developed between the ages of 3 and 5 years, and correlated with success on a theory-of-mind task,<sup>(1)</sup> suggesting that the ability to reverse an ambiguous figure is related to specific cognitive abilities (Gopnik and 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 could spontaneously reverse an ambiguous figure. If older (yet still naive) children are shown ambiguous figures and not informed in any way, will any spontaneously reverse?

In the current study, we presented observers aged 5–9 years with an ambiguous figure and examined their ability to produce spontaneous reversals. Theoretically, there is an important difference between perceiving two interpretations of an ambiguous figure when told of its ambiguity (ie making an informed reversal) and recognizing on one’s own that two interpretations exist (ie making a spontaneous reversal)—spontaneous reversals require a particular skepticism about one’s own percepts. Such skepticism might be related to ‘metacognitive’ abilities that develop over childhood—such as the knowledge about others’ mental states. To investigate this issue, in addition to the ambiguous-figures task, we also presented the children with a particular ‘metacognitive’ theory-of-mind task, in which they had to reason about what another thought about what they were thinking (eg Perner and Wimmer 1985). In particular, success on this theory-of-mind task indicates that the children can move beyond recognizing that other persons have representational capacities that differ from their own and can raise into question the validity of their own representations. A liberal interpretation would be that success indicates that the child could be skeptical of his/her own representations. A more conservative suggestion that we wish to articulate, however, is that finding a relationship between spontaneous reversals and metacognitive theory-of-mind abilities would suggest a role of higher-order cognition in complex visual processing.

<sup>(1)</sup>Theory-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 (eg about the contents of a crayon box) and evidence was presented that differed from those beliefs (eg 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 and Astington 1988; Gopnik 1993). Perceiving both interpretations of an ambiguous figure requires similar access to one’s own mental states.

## 2 Methods

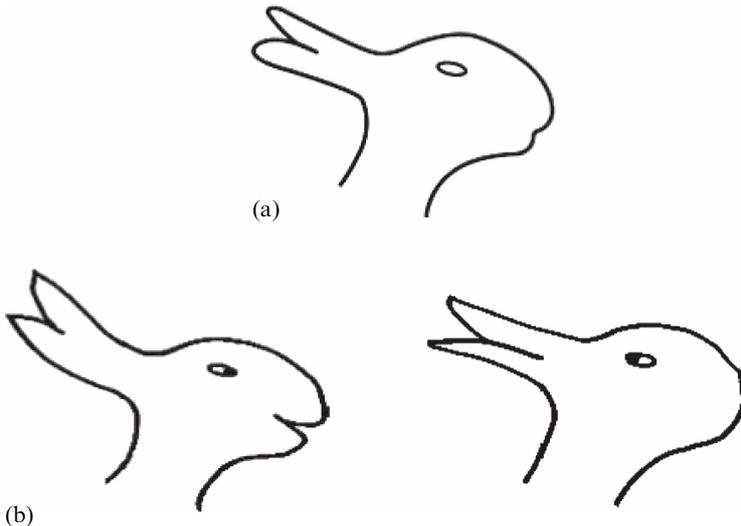
Each child participated in four tasks: Gopnik and Rosati's (2001) ambiguous-figure interview, Taylor's (1988) representational change 'doodle' theory-of-mind task, Perner and Wimmer's (1985) metacognitive 'ice-cream' theory-of-mind task, and a Piagetian number-conservation task, which was used as a measure 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 owing to previous experience with ambiguous figures, and one owing to a failure to pass a control question (see below). The remaining thirty-four children (eighteen male, sixteen female) ranged in age from 61 to 107 months ( $M = 84$  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 cm × 12 cm and drawn with black ink on white paper. Each set consisted of one ambiguous figure and two unambiguous pictures (see figure 1). For the 'doodle' task we used a black line drawing of a sunflower, measuring approximately 15 cm × 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 lines. For the 'ice-cream' task, we created a model village on a wooden board approximately 30 cm × 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 approximately 2 cm tall. Twelve 2 cm washers were used for the number-conservation task.



**Figure 1.** (a) The ambiguous duck/rabbit figure. (b) The unambiguous versions of the duck/rabbit figure used to teach the children the possible interpretations.

### 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 min and were audio taped.

**2.3.1 Ambiguous figures.** The child was shown one of the two ambiguous figures and received an interview similar to that of Gopnik and Rosati (2001). The children were

asked to report what they saw immediately, after 15 s, and after 30 s. If they generated both interpretations, they were asked to point to specific parts (eg 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 displayed the ambiguous figure and asked what the child saw immediately, after 15 s, and after 30 s. If the child reported seeing both interpretations before being informed, he/she was coded as making a *spontaneous* reversal. If the child reported reversing only after being informed, he/she was 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 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.

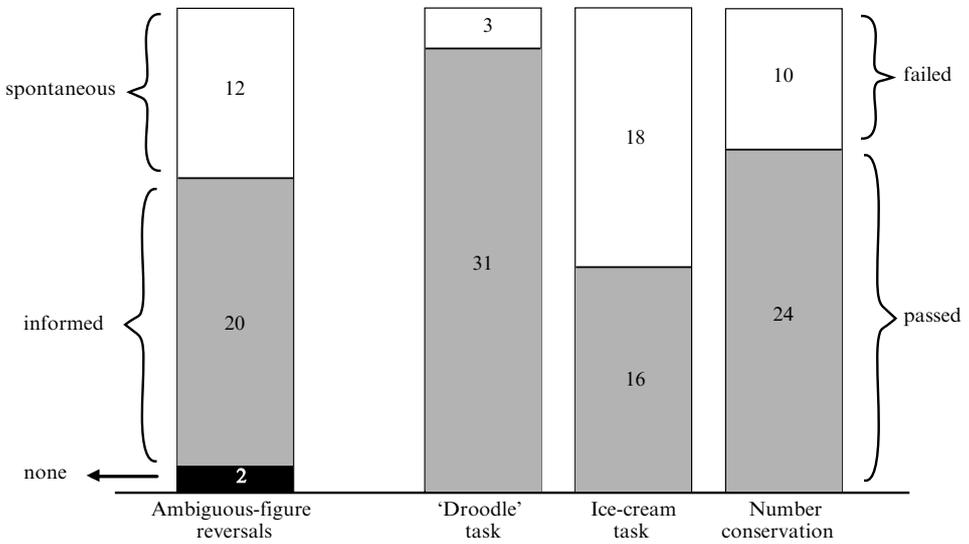
**2.3.3 'Doodle' task.** Each child received an interview similar to that of Taylor (1988). The experimenter placed a mostly occluded picture with only a set of angular lines visible in front of the child and asked, "What do you think this is a picture of?" After the child responded, the experimenter 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?" The 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 child was 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. The child was scored as passing if he/she stated there was the same number of washers for each question.

### 3 Results

Twelve of the thirty-four (35.3%) children spontaneously reversed the ambiguous figure (eight saw the vase/faces figure and four saw the duck/rabbit figure). Twenty of the remaining twenty-two children reversed the figure after they were informed of the ambiguity and two failed to make any reversal (see figure 2). Those who made a spontaneous reversal were more likely to pass the 'ice-cream' task (ten of twelve) than those who did not (six of twenty-two; Fisher exact test:  $p = 0.003$ )<sup>(2)</sup> and spontaneously reversing correlated with passing the 'ice-cream' task ( $r^2 = 0.288$ ,  $p < 0.001$ ).

<sup>(2)</sup> All  $p$ -values are two-tailed.



**Figure 2.** Performance on the ambiguous-figure task by type of reversal on the left and success rates for the 'doodle', 'ice-cream', and number-conservation tasks on the right. The numbers indicate the number of cases.

There was no significant correlation between children's spontaneous reversals and age ( $r^2 = 0.036$ , ns) or the number-conservation task ( $r^2 = 0.005$ , 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 ( $\Delta r^2 = 0.259$ ,  $F_{3,30} = 4.19$ ,  $p < 0.014$ ).<sup>(3)</sup> Unlike previous findings (Gopnik and Rosati 2001), there was no relationship between informed reversals and the 'doodle' task; however, performance on the 'doodle' task was near ceiling (see figure 2), so the lack of a significant finding is not surprising.

#### 4 Discussion

Children aged 5–9 years 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 both purely bottom-up and top-down 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. Only a hybrid model that incorporates both bottom-up and top-down contributions (eg Long and Toppino 2004) can account for these findings.

How are ambiguous figures perceived and reversed? To date this question remains unanswered (for a detailed review of this issue see Toppino and Long 2005) but the current findings help narrow the realm of possibilities. While more research is needed before we can know unequivocally how ambiguous figures are reversed, here we offer one possible theory. First, to reverse an ambiguous figure, observers—informed or

<sup>(3)</sup> Although data of two observers were removed owing 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.

not—need to possess certain mental representational capacities. Without understanding that a single image can have multiple percepts, observers will persevere with a single interpretation (as seen in young children). Second, to reverse a figure spontaneously, observers must possess additional capabilities, above and beyond understanding that a single image can have more than one percept. Without the ability to reason about multiple representations in a more complex, or ‘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. Here we have shown a relationship between second-order theory-of-mind and spontaneous reversals; yet this does not necessarily suggest that metacognitive theory-of-mind abilities are *the* cognitive abilities needed for spontaneous reversals. This is especially relevant, given that some of our observers failed the ‘ice-cream’ task yet, 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 that may be required for spontaneous reversals.

Finally, given these hypothetical necessary requirements, spontaneous reversals *can* then occur with either additional top–down influences (eg intent) or additional bottom–up influences (eg happening to focus attention on certain parts or locations of the image). This final and critical element can explain why not all adults, who presumably have complex representational capabilities, spontaneously reverse ambiguous figures. This hypothesized theory is by no means proven by the current findings, but it offers a framework in which the nature of ambiguous figures can be further explored.

## 5 Conclusions

The finding that young children can spontaneously reverse an ambiguous figure provides a much-needed piece to an unsolved puzzle. Whereas previously the very existence of spontaneous reversals was under debate, now discussions can focus on what ambiguous figures can tell us about visual perception and cognition (eg Long and Toppino 2004; Toppino and Long 2005). For example, ambiguous figures were recently used to explore whether social limitations of autistic children stem from broader cognitive limitations (Sobel et al 2005). Here, we offer the first unequivocal evidence for spontaneous reversals and what will hopefully be the start of a deeper exploration into the connections between visual perception and higher-order cognition.

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## Appendix

The ‘ice-cream’ task script and questions, modeled after Perner and Wimmer (1985):

“While at the park, John and Mary notice the ice cream man. Mary says she would like to buy an 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 day’. ‘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?”



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