Striking Deficiency in Top-Down Perceptual Reorganization of Two-Tone Images in Preschool Children

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***Abstract* - Two-tone images (black and white transformations of gray-scale photographs) can be difficult for adult observers to recognize. However, following a brief presentation of the original photograph from which the two-tone image was created, adults experience rapid and long-lasting perceptual reorganization, such that after the initial presentation, the two-tone image becomes immediately and easily recognizable. Following a previously reported observation [1], we present evidence that, in contrast to the effortless recognition seen in adults, preschool-aged children are generally unable to recognize two-tone images even when the photograph is simultaneously available. When asked to draw corresponding parts of the photo and two-tone images, children often marked correct regions of the photo and nonsensical regions of the two-tone image. A control experiment showed that children are fully able to mark corresponding parts of two identical photographs. These results point to a dramatic lack of cue-driven perceptual reorganization in young children under conditions that trigger instant recognition in adults. We suggest that this robust phenomenon may provide a window into the development of top-down mechanisms of perceptual learning and consider interventions (e.g., [2-4]) that may improve young children's ability to use one image to reorganize another.**

Index Terms – Development, Perceptual Reorganization, Preschool Children, Two-Tone Images.

INTRODUCTION

Figure 1 shows a two-tone image often seen in perception textbooks that illustrates how information not derived directly from the image can be used to guide perceptual organization. In this case, naïve observers often fail to see the Dalmatian dog in the snow and instead perceive a disorganized smattering of black and white patches. However, when instructed to look for a Dalmatian, viewers find the image suddenly and vividly transformed into a coherent percept [5, 6]. Moreover, following reorganization, it is difficult if not impossible to see the image as a meaningless array of patches. This serves as a powerful demonstration of the ability of top-down information to drive perceptual reorganization.

Other cues, such as a single presentation of the photo from which the two-tone image was derived, can also trigger immediate perceptual reorganization of the corresponding two-tone image in human and non-human adult primates. Long-lasting recognition for the two-tone image obtains without further need for the cue, resulting in enhanced responsivity in neurons in the inferior temporal cortex [7] as well as increased functional connectivity between temporal and frontal cortical regions [8] when viewing previously cued two-tone images in comparison to equivalent uncued and unrecognised images. That an extrinsic cue can trigger perceptual reorganization following a single presentation suggests the influence of a process high in the visual hierarchy driving a top-down reinterpretation of an otherwise unchanged stimulus.

Fig. 1 Dalmatian dog two-tone image (hint: head is on the left).

Kovacs and Eisenberg [1] suggested that this ability might only develop over time. They presented two-tone images and their corresponding photos to 4-5 year-old children. None of the eight children observed were able to verbally identify the two-tone images, even with simultaneous presentation of the corresponding photo. This phenomenon is striking in that children appear to not just be slower or less accurate; rather, when viewing the two-tone images and photos side-by-side, they fail to see what adults see automatically. The experiments reported below document our efforts to probe the robustness of Kovacs and Eisenberg's observations, develop a measure that allows children to show us how well they can or cannot perceive the correspondence between a two-tone image and its cue, and to quantify the

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difference between children and adults in two-tone image recognition.

EXPERIMENT 1

Following Kovacs and Eisenberg [1], we showed preschool children seven two-tone images and the corresponding photos from which the two-tone images were derived. We recorded the children's spontaneous remarks about the similarity between the two-tone and photo image pairs. In cases where children claimed that the two-tone image was the same as the photo, we asked the children to draw corresponding parts of the two images. The seven test trial image pairs were preceded by two practice image pairs using the same procedure. For those two-tone images that children failed to recognize at initial presentation, we were interested in how often children would report perceptual re-organization when shown the photo, and how well they would be able to draw corresponding parts of the two-tone and photo images.

Participants

Twelve preschool children (3y3m – 4y11m, average 4y6m) from Bing Nursery School participated in the study. Three children were excluded as a result of the child not finishing the study (n=1) or experimenter error (n=2).

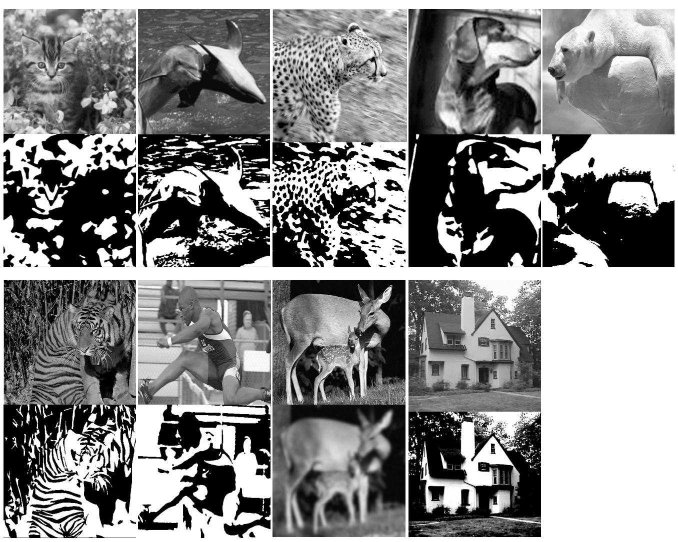

Fig. 2 Seven two-tone / photo pairs and two practice items (bottom right).

Stimuli

Two-tone images were created by thresholding gray-scale photographs of a kitten, dolphins (the example image used in the Kovacs & Eisenberg, 2004), a cheetah, a dog, a polar bear, a tiger, and an athlete (Fig. 2). Each trial included a two-tone image paired with the original gray-scale photograph from which it was derived. Two additional practice image pairs were created using simpler image transformations. A photograph of a deer was paired with a blurred version of the same photograph and a house was paired with a higher contrast version of the same image. Each image was printed onto a 12 x 12 cm card.

Procedure

The experimenter sat across from the child at a small table and explained the procedure to the child by saying, "In this game, I'm going to show you some pictures. You just tell me what you think is in this picture. Sometimes, the pictures will be very clear and sometimes they will look all fuzzy and blurry." Each trial consisted of at least three stages: (1) uncued two-tone identification, (2) photo identification, and (3) cued two-tone identification. An optional fourth stage occurred depending on the outcome of the third stage: (4) drawing corresponding parts of two-tone and photo images.

In stage (1), uncued two-tone identification, the experimenter placed a two-tone image card before the child and asked, "What do you think this pictures is?" If children did not provide an identifying label, the experimenter asked them to make their best guess, but did not offer suggestions.

In stage (2), photo cue identification, the experimenter moved the two-tone image card to one side, and then placed a photo card before the child and asked, "What about this picture? What do you see?" The photo card was always the one that corresponded to the two-tone image card that the child saw in stage (1).

In stage (3), cued two-tone identification, the experimenter placed the two-tone card from stage (1) next to the photo card and pointed to the two-tone image card, saying, "Let's look at this picture again. Does it look different to you? Do you see anything new in this picture?"

Drawing

When children gave the same label for the two-tone and photo cards or otherwise indicated that the two were the same, the trial continued to stage (4) and they were then invited to draw corresponding parts of the two-tone and photo image. The experimenter picked two or three features of the named image and asked, "Can you draw for me where the [feature] is in this picture?", pointing to the photo. Then the experimenter asked, "Can you draw for me where the same [feature] is in this picture?", pointing to the two-tone image. The experimenter gave positive feedback no matter what the child drew, "Wow, that looks great! Thank you."

For each trial, drawings on the paired two-tone and photo images were then given a single score of 0, 0.5 or 1. Drawings earned a score of 1 if all parts drawn on the two-tone image corresponded correctly to the parts drawn on the two-tone image. Drawings earned a score of 0.5 if at least one part (e.g., nose) drawn on the two-tone image corresponded exactly with the part drawn on the two-tone image, but some remaining drawn parts did not correspond. Drawings received a score of 0 if no parts drawn on the two-tone image corresponded to the same parts drawn on the photo.

Results and discussion

Performance on the practice items demonstrated that children understood the task. Every participant recognized both practice items correctly without the photo cue (the blurred deer and the high contrast house). Participants also successfully drew corresponding parts between the practice items and photos (mean score of 0.94, SD = 0.11).

In contrast, participants recognized only 19% of two-tone images without a cue (SD = 14%). Moreover, on 40% of test trials (SD = 43%), participants did not claim to perceive a correspondence between the two-tone and photo image pairs. On these trials, the participants gave different labels for the paired two-tone and photo images, and at stage (3), cued two-tone identification, either said that they did not see anything new or different about the two-tone image after seeing the photo, or offered a new incorrect label for the two-tone image. Incorrect labels for the two-tone images were often highly descriptive and fanciful (e.g., “the whole sky and earth”, “lines in the water”, “a moose walking in trees”, “really deep grass”).

On the remaining 41% of test trials, the participants first gave an incorrect label to the uncued two-tone image during stage (1) and then identified the cued two-tone image at stage (3) using the same label used to identify the photo. The children often explicitly indicated that they had changed their mind and that the two-tone image was the same as the photo (e.g., “Instead of that’s a bat, that’s a dolphin”, “I mean that’s a puppy dog”, “Oh, I know! This is a polar bear and this is a polar bear, too”).

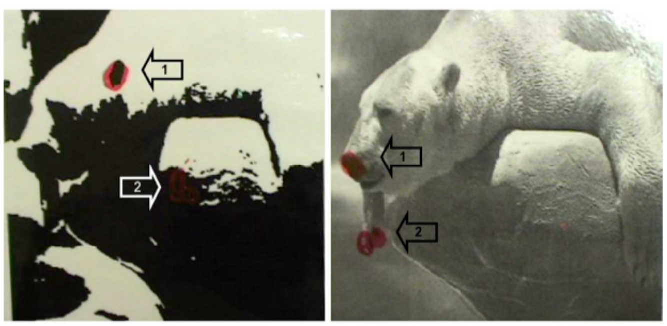

Fig. 3 An example in which the child indicated a match but could not draw corresponding parts. In red, a 4-year-old has drawn the nose (arrow 1) and claws (arrow 2) of the bear in the photo, and what she claims are the same parts in the two-tone image of the bear.

Curiously, on these trials in which the child verbally indicated that the photo cue had reorganized their perception of the two-tone image, the average drawing scores across children was only 0.22 (SD = 0.19), indicating that their drawings had few if any correctly corresponding parts and largely earned scores of only 0 or 0.5. This is much lower than the average of 0.94 on the practice items ($P < .001$, two-tailed paired t-test), suggesting that neither lack of task understanding nor poor drawing skills were responsible for the inability to draw corresponding parts. The drawing score was about the same when children had first recognized the two-tone image uncued (mean = 0.23, SD = .22), although this was only a small number of trials (a mean of 1.0 per child). The only items recognized uncued by more than one child were the tiger and the cheetah. The fact that they did not draw corresponding parts on these items well perhaps suggests that they identified them by features such as stripes or spots but did not clearly see the figures.

EXPERIMENT 2

In experiment 1, the drawing measure was contingent on successful recognition; if the child gave the photo and the two-tone image different labels, then s/he was not asked to draw corresponding parts. Furthermore, we found that even when the child did assert that the photo matched the two-tone image, the drawings (as in Fig. 3) suggested that they did not in fact see the match. To further explore the robustness of the phenomenon, we tested another group of children with a modified procedure. During side-by-side presentation in Experiment 2, the experimenter explicitly told children that the two-tone and photo images were the same. We were interested in whether drawing scores would improve under these conditions, particularly in “candidate perceptual reorganization trials”, the subset of trials in which children did not initially recognize the two-tone image (prior to the photo cue). In addition, we were able to collect drawing scores on every trial for every child with this design, rather than only on about 60% of trials as in Experiment 1.

Participants

Eleven preschool children from Bing Nursery School (3y10m – 5y0m, average 4y8m) participated in the study. None had participated in previous versions of the experiment. Two children were excluded as a result of the child not finishing the study (n=1) or experimenter error (n=1).

Stimuli

The same seven two-tone and photo test trial pairs were used as in Experiment 1. The same two practice trial image pairs were also used.

Procedure

The procedure was highly similar to that described in Experiment 1. Stage (1), uncued two-tone identification, and stage (2), photo cue identification, were exactly the same.

The procedure differed in stages (3) and (4). In stage (3), cued two-tone identification, the experimenter placed the two-tone and photo images side-by-side, pointed back at the two-tone image and said, “Let’s look at this picture again.” She then explicitly told children that the two-tone and photo images were the same. If the child had given the incorrect label for the uncued two-tone image, the experimenter pointed to the images in turn and said, “Actually, this is a picture of the same thing as this. So there is a [name of object] in this picture and in this picture” If the child had already provided the correct label for the uncued two-tone image, the experimenter still explicitly stated the two images were the same, saying, “Okay! You said this is a picture of the same thing as this. So there is a [name of object] in this picture and in this picture.”

Because stage (3), cued two-tone identification, always resulted in the child deciding or being told that the two-tone and photo images corresponded, all trials concluded with stage (4), drawing, which was described in the procedure for Experiment 1 and conducted in the same way.

Results and discussion

On 16% of the test trials (SD = 0.15), participants labelled the uncued two-tone image during stage (1) correctly. On the remaining 84% of test trials, participants first gave an incorrect label to the uncued two-tone image during stage (1). However, at stage (3) the cued two-tone image was identified using the same label used to identify the photo.

On these candidate perceptual reorganization trials, the average drawing score was 0.33 (SD = 0.44). This score was much lower than the average drawing score on practice trials (0.89, SD = 0.13; $t(8) = 10.3$, $p < .001$, paired two-tailed t-test), but did not differ from the average drawing score on candidate perceptual reorganization trials in Experiment 1 (0.24, SD = 0.19; $t(14) = 0.99$; $p = 0.34$, unpaired two-tailed t-test) when children were not explicitly told about the correspondence between two-tone and photo image pairs. In Figure 4, the drawing scores are plotted for all experiments, collapsed across trials in which the two-tone image was successfully recognized uncued and those trials in which it was not successfully recognized uncued since these two trial types did not differ from each other.

Deficient perceptual reorganization of two-tone images as revealed by inability to draw corresponding parts was therefore replicated in Experiment 2. In addition, the deficit was found to be robust, persisting in the face of explicit instruction from a knowledgeable experimenter about the identity between the two-tone and photo images.

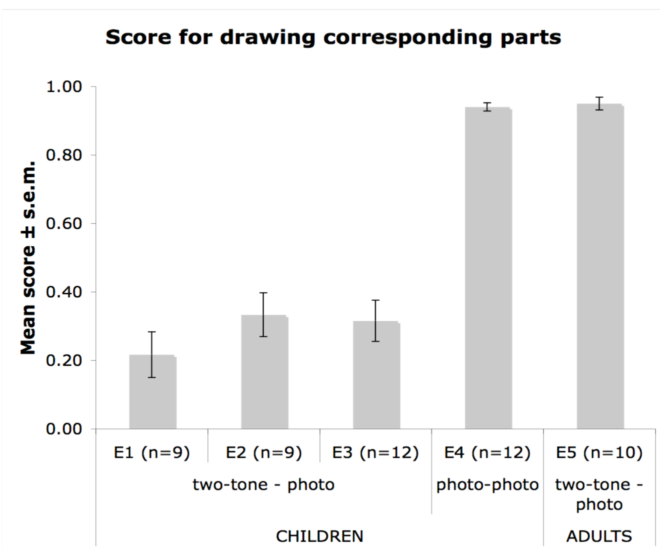

Fig. 4 Performance in drawing corresponding parts on image pairs. Data are combined from trials when the two-tone image was or was not successfully recognized without first seeing the photo-cue. Children are significantly worse at drawing corresponding parts of two-tone and photo image pairs (Experiments 1-3) compared to adults and compared to children drawing on two identical photographs. Neither instruction about the identity between the two-tone and photo images (Experiment 2) nor reducing perceptual interference (Experiment 3) helped to improve drawing scores significantly.

EXPERIMENT 3

When children fail to recognize the uncued two-tone image, their incorrect initial interpretation may interfere with the formation of a new interpretation upon presentation of the original image (e.g., [3]). The incorrect perceptual hypothesis formed when children are asked to identify the uncued two-tone image might be what is blocking the top-down reorganization of the two-tone image that is triggered by the corresponding photo cue. Although such "perceptual interference" has been found in both adults and children [2, 3], it is thought to be more pronounced in children and may have contributed to their difficulty in reinterpreting two-tone images in the previous experiments, since they were first asked to evaluate the two-tones prior to seeing the cue. We therefore removed the uncued two-tone presentation in order to reduce perceptual interference, first showing children the photograph, and then the corresponding two-tone image, thus eliminating the chance to make a cue-free, incorrect perceptual hypothesis about the two-tone image. If perceptual interference is at all responsible for children's low drawing scores, this manipulation should result in improved drawing scores, reflecting increased perceptual reorganization.

Participants

Twelve preschool children from Bing Nursery School (4y2m – 5y1m, average 4y7m) participated in the study. None had participated in previous versions of the experiment. None were excluded.

Stimuli

The same seven test trial photos (kitten, dolphins, cheetah, dog, polar bear, tiger, athlete) and two practice photos (house, deer) were used as in Experiments 1-2.

Procedure

The procedure was a similar but truncated version of the procedure described in Experiment 2. Instead of beginning each trial with stage (1), uncued two-tone identification, all trials instead began at stage (2) photo identification and proceeded identically through stages (3) and (4) as in Experiment 2. The procedure reduced possible perceptual interference by omitting stage (1), uncued two-tone identification.

Results and discussion

The average drawing scores on all test trials was 0.32 (SD = 0.21) (Fig. 4). This score was much lower than the average drawing score on practice trials (0.83, SD = 0.12; $t(11) = 10.73$, $p < .001$, paired two-tailed t-test), but not significantly different from the average drawing score on all test trials in Experiment 2 (0.33, SD = 0.19; $t(19) = .20$; $p = 0.84$, unpaired two-tailed t-test), when children were explicitly told about the correspondence between two-tone and photo image pairs but asked to identify the two-tone image prior to seeing the corresponding photo.

Reducing perceptual interference did not result in significant improvement in perceptual reorganization (as indexed by the drawing measure) in our task. It is possible that a different task or more fine-grained scoring metric would detect an improvement, but this improvement is likely small and subtle. While we cannot rule out the possibility that perceptual interference may hinder cue-driven perceptual reorganization, or results suggest that some other, more powerful barriers remain.

EXPERIMENT 4

Because the drawing score deficit on experimental versus practice trials persisted in Experiments 2 and 3 in the face of clear information from the experimenter about the relationship between the two-tone and photo image pairs, we conducted a control experiment to confirm the sensitivity of the drawing measure. In Experiment 4, children were asked to draw corresponding parts of identical gray-scale photographs. The procedure was otherwise unchanged from Experiment 2.

Participants

Ten preschool children from Bing Nursery School (3y9m – 4y11m, average 4y7m) participated in the study. None had participated in previous versions of the experiment. None were excluded.

Stimuli

The same seven test trial photos (kitten, dolphins, cheetah, dog, polar bear, tiger, athlete) and two practice photos (house, deer) were used as in Experiments 1-3. However, image pairs for practice and test trials were identical gray-scale photographs.

Procedure

Aside from the change in stimuli, the procedure from Experiment 2 was duplicated.

Results and discussion

Average drawing scores were 0.94 (SD = 0.04) (Fig. 4). Drawing scores for Experiment 4 were much higher than those obtained through experimental trials in Experiments 1-3 and were even marginally higher than those obtained through practice trials in Experiments 1-3 ($F(3,38)=2.76$, $p=0.06$, one-way ANOVA across four groups). These results support our contention that the drawing measure employed in Experiments 1-3 is indeed sensitive and that the low scores obtained in those experiments cannot be attributed to children's generalized inability to correctly draw corresponding parts on image pairs.

EXPERIMENT 5

Although we had informal evidence from adults that two-tone images were trivial to recognize when placed side-by-side with the corresponding photo cue, we wanted to quantify the difference between children and adults in perceptual reorganization using the same drawing measure used in Experiments 1-4. We therefore tested adults using the same procedure as Experiment 2 in order to obtain a drawing measure for each trial.

Participants

Ten undergraduates from Stanford University participated in the study. None were excluded.

Stimuli

The same practice and test image pairs were used as in Experiments 1-3.

Procedure

The procedure from Experiment 2 was duplicated exactly.

Results and discussion

On 66% of the test trials (SD = 0.22), adult participants labelled the uncued two-tone image during stage (1) correctly. On the remaining 34% of test trials, participants first gave an incorrect label to the uncued two-tone image during stage (1). At stage (3) the experimenter identified the two-tone image with the same label used to identify the photo. However, when adults failed to identify the uncued image correctly, they always spontaneously indicated that they could re-organize the two-tone image before the experimenter provided the label. For example, when a subject guessed that the two-tone polar bear was "a car", upon presentation of the photo the subject spontaneously added "I mean a polar bear".

Adults had significantly fewer candidate perceptual reorganization trials than the children in Experiment 2 (2.4 per adult vs 5.7 per child; $t(8) = 6.5$, $p < .001$), due to adults' superior recognition for uncued two-tone images.

Average drawing scores for adults on all trials was 0.95 (SD = .06). Adults were equally good on the candidate perceptual reorganization trials, with an average score of 0.98 (SD = 0.05).

DISCUSSION

In these experiments, we have documented preschool children's robust and dramatic deficit in perceptual reorganization by asking them to draw corresponding parts of two-tone and photo images. We found that even when children spontaneously claimed the two-tone and photo images were the same, or were explicitly instructed that the two-tone and photo images corresponded to each other, the deficit remained unchanged. Children were able to draw corresponding parts in practice trials with blurred and contrast-altered practice images, and in a control task with identical image pairs, showing that neither deficiencies in drawing ability nor lack of task understanding or motivation were responsible for the effect. Finally, the use of simultaneous side-by-side presentation of the photo and cue make it possible for children to 'cheat' if they wanted to, and yet their drawing scores are strikingly low.

The effortless success of adults in Experiment 5 is in striking contrast to children's failure. Even when they did not recognize a two-tone image on its initial, uncued presentation, adults often felt that it was impossible not to recognize a two-tone image with simultaneous presentation of the photo cue.

How does the mechanism that allows top-down information to influence perceptual reorganization develop and why is it so dramatically different in adults and children? One possibility is the late maturation of top-down control of perceptual processes, perhaps in the ability to inhibit interference from alternative, cue-independent organizations of the two-tone image. Reducing such perceptual interference by relieving children from the requirement to report one of these alternative organizations (Experiment 3), however, did not lead to a measurable improvement in their ability to draw corresponding parts. Difficulty inhibiting an initial cue-free and possibly incorrect perceptual hypothesis about the two-tone image therefore does not appear to be the primary mechanism blocking perceptual reorganization.

Another possible explanation for children's deficient perceptual reorganization is that in order to use the photograph as a cue for successful reorganization of the corresponding two-tone image, young children must appreciate the dual nature of the photograph as both a concrete object in and of itself, and a transformed representation of something other than itself—the two-tone image. That is, children may not be able to simultaneously keep in mind the two-tone image and photo as images in and of themselves, as well as representations of one another that are mutually informative. This difficulty in achieving dual representation may be what prevents children from understanding that the photograph corresponds to the two-tone image and from capitalizing on this understanding to use the photo as a cue to help interpret the two-tone image. Eliminating the need to achieve dual representation has been shown to aid young children's use of symbolic objects such as scale models. For example, DeLoache and colleagues [9] have demonstrated that children fail to find a hidden toy when shown its location in a scale model, but succeed if they are convinced that the model is in fact the large room put through a shrinking machine. To explore this possibility, we plan to test whether eliminating the need for dual representations will rescue children's performance. We will show children photos that are transformed by a special "blurring machine" so that children believe that the two-tone images are in fact the photos, only transformed.

A third possibility is that the photo cues in fact do trigger perceptual reorganization of two-tone images in children when they report that it does, but that the very act of drawing somehow destroys the fragile reorganization that exists. For example, the child who claimed to see the polar bear in the two-tone image shown in Figure 3 may have in fact seen it correctly, but upon attempting to draw the paw and nose became distracted by salient features in the two-tone image that encourage a photo-discrepant organization. If children do in fact reorganize the two-tone images, but their reorganizations are somehow more fragile or incomplete than adults', then more sensitive measures like eye-tracking could reveal implicit consequences of the perceptual reorganizational capacities present from much earlier in development than supposed here.

A final consideration is that there are fundamental differences in basic perceptual processing and/or neural maturation between children and adults and that cognitive interventions such as those discussed above will not improve children's ability to see the figures hidden in two-tone images. For example, long-range connections between retinotopic visual areas required for low-level visuospatial integration are thought to continue maturing through early adolescence [10]. Such long-range connections may be especially crucial in organizing two-tone images, since figures are often comprised of distinct contours spatially separated from one another. Other candidate perceptual mechanisms required for successful recognition of two-tone images include figure-ground segmentation and Gestalt grouping. These possibilities can be tested by looking for concurrent improvements in a candidate perceptual process and in uncued recognition of two-tone images, as the developmental trajectory of uncued two-tone image organization should follow closely the maturation of the required perceptual mechanism.

We look forward to further exploring these possibilities in future work.

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