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The interplay between perceptual organization and categorization in the representation of complex visual patterns by young infants

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Abstract

The relation between perceptual organization and categorization processes in 3- and 4-month-olds was explored. The question was whether an invariant part abstracted during category learning could interfere with Gestalt organizational processes. A 2003 study by Quinn and Schyns had reported that an initial category familiarization experience in which infants were presented with visual patterns consisting of a pacman shape and a complex polygon could interfere with infants' subsequent good continuation-based parsing of a circle from visual patterns consisting of a circle and a complex polygon. However, an alternative noninterference explanation for the results was possible because the pacman had been presented with greater frequency and duration than had the circle. The current study repeated Quinn and Schyns's procedure but provided an equivalent number of familiarization trials and duration of study time for the infants to process the pacman during initial familiarization and the circle during subsequent familiarization. The results replicated the previous findings of Quinn and Schyns. The data are consistent with the interference account and suggest that a cognitive system of adaptable feature creation can take precedence over organizational principles with which a perceptual system comes preequipped.

Keywords: Category learning; Perceptual organization; Infant cognition

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Introduction

Perceptual organization occurs when the elements of a visual pattern are grouped into larger perceptual units or perceptual wholes (e.g., Kimchi, Hadad, Behrmann, & Palmer, 2005). Perceptual categorization occurs when objects from a common class are grouped into a category representation (e.g., Hampton, Estes, & Simmons, 2005). Although the topics of perceptual organization and categorization traditionally have been considered in separate literatures, there have been recent efforts directed at understanding how perceptual and more conceptual representations for objects can be understood within a common framework (Goldstone & Barsalou, 1998; Palmeri & Gauthier, 2004). A point of departure for these efforts has been to highlight the difficulties associated with achieving a complete accounting for object representation with one or another fixed featural vocabulary (Goldstone, 2003). As an alternative, Schyns, Goldstone, and Thibaut (1998) proposed a flexible system of perceptual unit formation where the features that come to represent objects are developed during the task of concept learning. An individual's history of concept formation and the concepts possessed by that individual at a particular moment in development affect subsequent perceptual organization processes. Concepts develop based on perceptual experiences, but perceptual experiences are also affected by developing concepts.

The interplay between processes of perceptual organization and categorization is of particular interest and importance for developmentalists (e.g., Quinn & Bhatt, 2005b). Through studies of the object representation abilities of young infants (who have a minimum of experience and acquired knowledge of objects and object kinds), one can (a) learn how the formation of emergent perceptual features is constrained by Gestalt grouping principles and (b) observe whether such grouping principles can at times be overridden if a feature that might be nonnatural in the Gestalt sense is diagnostic of a concept that an infant has been asked to learn. To this end, Quinn and Schyns (2003) undertook a set of experiments to better understand the relation between adherence to Gestalt organizational principles and flexible feature creation in young infants. The experiments were designed to answer the following question: Will organizations of scenes into objects that are natural by Gestalt principles be "overlooked" by young infants if alternative means of perceptual organization are "suggested" by presenting the infants with a category of objects in which the features uniting the objects are not those predicted by adherence to Gestalt organizational principles? In the first experiment, 3- and 4-month-olds were familiarized with a number of complex figures, examples of which are shown in the top portion of Fig. 1. Subsequently, during a novelty preference test, infants were presented with the pacman shape paired with the circle shown in the bottom portion of Fig. 1. Infants were found to recognize the circle as familiar, as evidenced by their preference for looking at the pacman shape, a preference that was not attributable to a spontaneous preference for the pacman shape over the circle shape given that a null preference is observed for the two shapes when there is no familiarization (Quinn, Brown, & Streppa, 1997). This result suggests that infants had parsed the circle from the complex figures in accord with good continuation, a finding that is consistent with other reports that infants in this age range can use the Gestalt principle of good continuation when processing visual pattern information (Quinn & Bhatt, 2005a; Quinn et al., 1997).

In a second experiment, Quinn and Schyns (2003) asked whether an invariant part abstracted during category learning would interfere with the perceptual organization

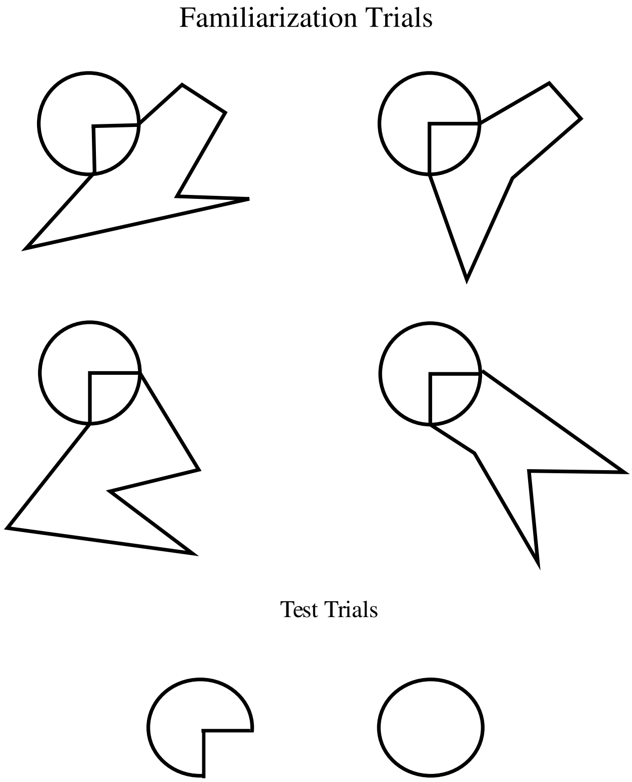

Fig. 1. Examples of the familiarization stimuli and test stimuli used in Quinn and Schyns (2003, first experiment and Part 2 of second and third experiments) and in Part 2 of the current study.

achieved by adherence to good continuation. The experiment made use of a two-part sequential learning procedure (Mareschal, Quinn, & French, 2002). In Part 1, the infants were familiarized with multiple exemplars, each marked by an invariant pacman shape, and subsequently were administered a novelty preference test that paired the pacman shape with the circle shape. Examples of the stimuli are shown in Fig. 2. The pacman shape was recognized as familiar, as evidenced by a preference for looking at the circle shape. Part 2 of the procedure was then administered and followed the design of the initial experiment, including both the familiarization and test trials shown in Fig. 1. The expectation was that if the category learning from Part 1 of the procedure, particularly the representation of the invariant pacman shape, could interfere with the Gestalt-based perceptual organization that was observed in the first experiment, then infants would interpret the ambiguous forms during the familiarization trials in Fig. 1 as containing pacman shapes rather than circles. If this occurred, then the novelty-based preference for the pacman shape that was observed in the original experiment no longer would be predicted. Consistent with this prediction, a null preference was recorded.

Although the results of the second experiment of Quinn and Schyns (2003) could be interpreted as evidence that the invariant pacman shape that was recognized as familiar on the basis of the Part 1 category familiarization experience interfered with the good

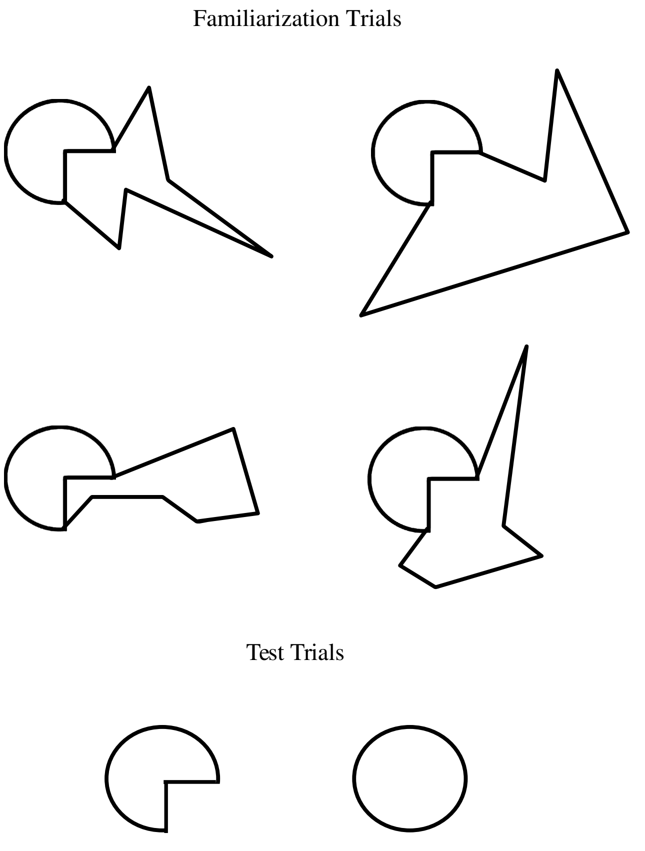

Fig. 2. Examples of the familiarization stimuli and test stimuli used in Quinn and Schyns (2003, Part 1 of second and third experiments) and Part 1 of the current study.

continuation-based process of parsing the circle from the stimuli presented in Part 2, there is an alternative noninterference account of the data: When the infants were shown the pacman shapes in Part 1, they extracted the pacman. In Part 2, when the infants subsequently were shown the ambiguous circle/pacman shapes, they did exactly what the infants in the first experiment did and represented these shapes as circles. When given a choice between a pacman and a circle during the preference test trials of Part 2, the infants did not look reliably at one more than the other because both the pacman (from Part 1) and the circle (from Part 2) had been presented with equal frequency and duration (i.e., four 15-s familiarization trials).

In an effort to defeat the alternative explanation, Quinn and Schyns (2003) carried out a third experiment that was a replication of the second experiment except that infants were given two additional familiarization trials in Part 1 that presented four new stimuli depicting the invariant pacman shape. The reasoning was that this additional familiarization experience would allow infants to form a stronger representation of the pacman shape in Part 1 that would carry over more robustly into Part 2 and produce a positive result rather than a null result, that is, a preference for the circle. This positive result was observed and suggests that perceptual units formed during concept acquisition can be entered into a perceptual system's working "featural" vocabulary and be used for subsequent object segmentation. There is plasticity to the bias set by the Gestalt principle of good continuation. More generally, an individual's history of category learning can affect his or her subsequent object parsing abilities.

Despite the positive results observed in both parts of the third experiment conducted by Quinn and Schyns (2003), the alternative noninterference account still was not ruled out definitively. Specifically, infants in Part 1 could have encoded the pacman and in Part 2 may have encoded the circle (without interference from the pacman from Part 1), but because the pacman during the Part 1 familiarization was shown more frequently and with greater duration than was the circle during the Part 2 familiarization, infants looked more to the circle during the Part 2 test trials.

The current experiment was performed to determine more decisively whether exposure to a shape simply primes that shape or actively inhibits segmentations of ambiguous forms that are perceptually natural but do not involve the shape. In particular, the experiment was a replication of the third experiment of Quinn and Schyns (2003) but included two additional Part 2 familiarization trials, thereby providing equivalent presentation frequencies and durations for the pacman and circle shapes. The interference account would predict a continuing preference for the circle shape, whereas the alternative noninterference account would predict a no-preference result.

Method

Participants

The participants were 32 3- and 4-month-olds (14 girls and 18 boys, mean age = 109.16 days, $SD = 7.81$). An additional 9 infants were tested, but 7 failed to complete the procedure due to fussiness and 2 were excluded from the data analysis due to either position preference or failure to compare the test stimuli. The participants were predominantly Caucasian and from middle-class backgrounds.

Stimuli

The familiarization and test stimuli for Part 1 were the same as those used in Part 1 of the third experiment of Quinn and Schyns (2003). Each of the 12 stimuli presented during the Part 1 familiarization trials was composed of a pacman shape and a complex polygon. The thickness of contour for all shapes was 3 mm. Examples of the familiarization stimuli are shown in the top portion of Fig. 2. The test stimuli for Part 1, shown in the bottom portion of Fig. 2, consisted of the circle and a pacman shape that was composed of three fourths of the circle contour and was closed by the horizontal and vertical contours forming a right angle contour at the center of the circle.

The familiarization stimuli for Part 2 were the same as those used in Part 2 of the second and third experiments of Quinn and Schyns (2003) and four additional stimuli that were constructed for the current study. Each of the 12 stimuli presented during the Part 2 familiarization trials was composed of a circle shape (5.6 cm in diameter) and a complex polygon. Each of the stimuli could also be interpreted as containing a pacman shape. The thickness of contour for all of the shapes was 3 mm. Examples of the familiarization stimuli are shown in the top portion of Fig. 1. The test stimuli for Part 2 were identical to those used during the test trials of Quinn and Schyns (2003) and were the same as the test stimuli for Part 1 of the current study. They are shown in the bottom portion of Fig. 1.

Apparatus

All infants were tested in a visual preference apparatus modeled after the one described by Fagan (1970). The apparatus is a large, three-sided gray viewing chamber that is on wheels. It has a hinged, gray display panel onto which two compartments were attached to hold the poster board stimuli. The stimuli were illuminated by a fluorescent lamp that was shielded from the infant's view. The center-to-center distance between compartments was 30.5 cm, and on all trials the display panel was situated approximately 30.5 cm in front of the infant. A 0.62-cm peephole located midway between the two display compartments permitted an observer to record the infant's visual fixations. A second peephole, 0.90 cm in diameter, was located directly below the first peephole and permitted a Pro Video CVC-120PH pinhole camera and a JVC video recorder to record the infant's gaze duration.

Procedure

All infants underwent the following general procedure. Each infant was brought to the laboratory by a parent and was seated in a reclining position on the parent's lap. There were two experimenters, both of whom were naive to the hypotheses under investigation. The first experimenter positioned the apparatus so that the midline of the infant's head was aligned with the midline of the display panel. When the display panel was open, the infant could see the experimenter from the midsection upward in addition to a portion of the room that was a light background color. The experimenter selected the appropriate stimuli and loaded them into the compartments of the display panel from a nearby table. The experimenter then elicited the infant's attention and closed the panel, thereby exposing the stimuli to the infant. The parent was unable to see the stimuli.

During each trial, the first experimenter observed the infant through the small peephole and recorded visual fixations to the left and right stimuli by means of two 605 XE Accusplit electronic stopwatches, one of which was held in each hand. Between trials, the experimenter opened the panel, recorded the infant's looking times, changed the stimuli, reobtained the infant's attention, recentered the infant's gaze, and closed the panel. The first and second experimenters changed places for the test trials. The experimenter who presented stimuli and measured infant fixations during familiarization now measured trial duration and signaled the end of each test trial, whereas the second experimenter presented the test stimuli and measured infant fixations. The second experimenter always was naive with respect to the familiar stimuli. The two experimenters changed roles across infants.

Interobserver agreement, as determined by comparing the looking times measured by the experimenter using the center peephole and an additional naive observer measuring looking times offline from videotape records, was calculated for the preference test trials of eight randomly selected infants. Average level of agreement was 98.42% ($SD = 2.09$).

In Part 1, the infant was familiarized with 12 complex shapes, each containing an invariant pacman shape, during the course of six 15-s familiarization trials (2 shapes/trial). Immediately after familiarization, the infant was presented with the pacman and circle shapes for two 10-s test trials. Directly following Part 1, the infant was administered Part 2 of the procedure. In Part 2, the infant was familiarized with 12 complex shapes, each marked by an ambiguous circle/pacman shape, during the course of six 15-s familiarization trials (2 shapes/trial). Immediately after familiarization, the infant was presented with the pacman and circle shapes for two 10-s test trials. For both sets of familiarization trials, the order of presentation of the shapes was randomized for each infant. For both sets of test trials, the left–right positioning of the stimuli was counterbalanced across infants on the first test trial and reversed on the second test trial.

Results

Part 1 familiarization trials

Individual looking times were summed over the left and right stimuli presented on each trial and then averaged across the first three and last three trials. The infants displayed a reliable decrement in looking time from the first half to the second half of familiarization: Trials 1 to 3, $M = 9.78$ s, $SD = 2.82$; Trials 4 to 6, $M = 8.42$ s, $SD = 3.20$; $t(31) = 3.37$, $p < .01$. This decrement provides evidence of a decline in responsiveness with repetitive stimulation that is consistent with the presence of habituation (Cohen & Gelber, 1975).

Part 1 preference test trials

Each infant's looking time to the circle shape was divided by the total looking time to both test stimuli and then converted to a percentage score. The mean preference for the circle shape was determined to be significantly higher than the chance preference of 50%, $M = 56.22\%$, $SD = 15.06$, $t(31) = 2.34$, $p < .05$. This result indicates that after familiarization with the complex shapes, infants extracted the invariant pacman shape and recognized the pacman shape as more familiar than the circle. The results are consistent with those of Quinn and Schyns (2003).

Part 2 familiarization trials

Infants showed a significant decline in looking time from the first three trials ($M = 7.27$ s, $SD = 2.84$) to the last three trials ($M = 5.94$ s, $SD = 3.55$), $t(31) = 3.71$, $p < .001$. This reliable decrement in looking time from the first half to the second half of familiarization is consistent with that observed in Part 1 and indicates that the infants again habituated to the familiar stimuli. In addition, the mean decrement in looking time from the first half to the second half of familiarization was not different for Part 1 ($M = 1.36$ s, $SD = 2.29$) versus Part 2 ($M = 1.26$ s, $SD = 1.92$), $t(31) = 0.18$, $p > .20$. This latter result implies that the preference test outcomes from Part 1 and Part 2 cannot be attributed to differential learning rates occurring within the two familiarization periods.

A planned comparison between the mean looking time for the last three trials of Part 1 and the first three trials of Part 2 is also instructive. By the interference account, if the invariant pacman shape that was recognized as familiar on the basis of the Part 1 familiarization experience continues to be represented in Part 2, then one would expect a continued decline in responsiveness (i.e., looking time) from the last three trials of Part 1 familiarization to the first three trials of Part 2 familiarization. In contrast, by the noninterference account, if the infants had been engaged in extraction of the invariant pacman in Part 1 and deployed a Gestalt-based grouping process to represent the circle in Part 2, then the representation of the novel circle relative to the familiar pacman should have resulted in some increment in responsiveness (i.e., looking time) during the first three trials of the Part 2 familiarization subsequent to the decrement in looking time that was observed during the last three trials of the Part 1 familiarization. The planned comparison in question revealed a significant decrement in the mean looking time from the second half of Part 1 familiarization to the first half of Part 2 familiarization, $t(31) = 2.92$, $p < .01$, a finding that supports the interference-based explanation of performance.

Part 2 preference test trials

The mean preference for the circle shape was significantly different from chance, $M = 58.11\%$, $SD = 16.47$, $t(31) = 2.79$, $p < .01$. This result is consistent with what was observed in Part 2 of the third experiment of Quinn and Schyns (2003) and indicates again that the invariant pacman shape that was learned during the Part 1 category familiarization task continued to be represented, biasing the interpretation of the ambiguous pacman/circle forms in the Part 2 category familiarization task. These ambiguous forms apparently were interpreted in terms of familiarized pacman forms, with the consequence that a novelty preference was observed for the circle shape.

Discussion

Previous research was consistent with the possibility that 3- and 4-month-olds could parse a circle in accord with good continuation from multipart visual patterns consisting of a circle and a complex polygon, a Gestalt-based parsing process that could be interfered with by a category familiarization experience in which infants were presented with a set of visual patterns, each one consisting of a pacman shape and a complex polygon (Quinn & Schyns, 2003). However, the prior findings were also consistent with an alternative noninterference account in which infants in Part 1 encoded the pacman and in Part 2 encoded the circle (without interference from the pacman from Part 1). This alternative account was possible because infants in the third experiment of Quinn and Schyns (2003) were presented with the pacman shape in Part 1 for two additional 15-s familiarization trials relative to the circle shape in Part 2. Thus, the Part 2 preference results could have reflected this difference in presentation frequency and duration rather than interference.

In the current study, the third experiment of Quinn and Schyns (2003) was repeated, but in this case the pacman shape of Part 1 and the circle shape of Part 2 were presented for the same number of equal-duration familiarization trials. The infants displayed reliable decrements in looking time from the first half to the second half of familiarization in both Part 1 and Part 2 of the procedure. If the infants were extracting the pacman from Part 1 and the circle from Part 2 in accord with the noninterference account, then a null preference should have been observed in the Part 2 preference test trials, just as it was in the Part 2 preference test trials of the second experiment of Quinn and Schyns (2003), a task context in which there were four Part 1 and four Part 2 familiarization trials of equivalent duration. Or, if one assumes decay to memories, then the more recent Part 2 familiarization trials would be expected to influence preference more than would the earlier Part 1 familiarization trials. According to a noninterference account combined with memory decay, a preference for the pacman shape would be expected. However, in the current study, neither a null preference nor a pacman preference was observed; rather, infants in Part 2 preferred the circle. The results provide evidence that supports the interference account more conclusively, namely that the representation of the pacman shape in Part 1 blocked the subsequent good continuation-based parsing of the circle in Part 2.

One still might attempt to defend the noninterference account by pointing not to the equivalent presentation frequency and durations across the two familiarization sequences in the study but rather to differences in exposure times, where looking times were lower during Part 2 familiarization than during Part 1 familiarization. However, this appeal loses force when one factors in that looking times from the Part 2 familiarization were also lower than those from the Part 1 familiarization in the second experiment of Quinn and Schyns (2003), when infants demonstrated a null preference between the pacman and circle shapes during the Part 2 test trials. Thus, the noninterference account runs into difficulty when attempting to explain the pattern of outcomes observed across experiments.

The findings from the current study, as well as those from previous investigations of both perceptual organization and categorization in infants, are relevant to the issue of how infants begin to decompose a complex configuration of visual pattern information into elements that can be used as building blocks (i.e., units of processing) for purposes of representing objects. Although previous investigations have documented that young infants may be constrained to follow organizational principles such as lightness similarity (Quinn & Bhatt, in press; Quinn, Burke, & Rush, 1993), good continuation (Quinn & Bhatt, 2005a; Quinn et al., 1997; Quinn & Schyns, 2003), common movement (Johnson & Aslin, 1995; Kellman & Spelke, 1983), and uniform connectedness (Hayden, Bhatt, & Quinn, in press), a majority of these experimental demonstrations have used simple two- and three-dimensional displays (e.g., rows and columns of elements, a rod and box display) and one may question whether the perceptual units formed by adherence to Gestalt organizational principles would be sufficient to provide the full range of functional features necessary to support an object representation system that receives enormously variable input. There is evidence that infants can perceptually categorize complex and realistic images (Mareschal & Quinn, 2001), and the current results suggest that features that are learned as being diagnostic of category distinctions, even if they are not “good” Gestalts, may become functional units in the memory codes that influence subsequent acts of object recognition.

A recent study suggested that the dividing line between processes of perceptual organization and categorization can be blurred even further (Quinn & Bhatt, 2005b). The study showed that some organizational principles may be learned rather than innately available (see also Spelke, 1982) and that the way such principles are learned is in the context of concept formation. In particular, 3- and 4-month-olds were shown to organize visual patterns via form similarity, but only if they were provided with varied examples with which to abstract the invariant arrangement of the elements (e.g., presentation of X–O, square–diamond, and H–I patterns depicting a common row vs. column arrangement within the same familiarization period). That form similarity was learned through experience with multiple patterns depicting a common arrangement (i.e., in the context of a concept formation task), rather than apprehended immediately in an individual pattern, suggests that some classic Gestalt principles that once were believed to be innately available (e.g., Kohler, 1929) might actually be acquired through a process of flexible feature creation (Schyns et al., 1998). This way of thinking is consistent with how the shape bias (or whole object assumption) in object naming, once thought to be a natural constraint on word learning (Markman, 1989), may also be the product of a developmental period of category learning (Gershkoff-Stowe & Smith, 2004). Both sets of findings underscore the dynamic relation between perception and learning during early developmental processes that produce knowledge acquisition (Goldstone, 2003).

Acknowledgments

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