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What goes up may come down: perceptual process and knowledge access in the organization of complex visual patterns by young infants

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Abstract

The relationship between perceptual categorization and organization processes in 3- to 4-month-old infants was explored. The question was whether an invariant part abstracted during category learning could interfere with Gestalt organizational processes. Experiment 1 showed that the infants could parse a circle in accord with good continuation from visual patterns consisting of a circle and a complex polygon. In Experiments 2 and 3, however, this parsing was interfered with by a prior category familiarization experience in which infants were presented with visual patterns consisting of a pacman shape and a complex polygon. Part 1 of Experiments 2 and 3 showed that the infants recognized the pacman as familiar, and Part 2 demonstrated that the representation of the pacman blocked the subsequent parsing of the circle. The results suggest that a cognitive system of flexible feature creation can override organizational principles with which a perceptual system may come pre-equipped.

Keywords: Category learning; Perceptual organization; Infant cognition

1. Introduction

An important event in the development of visual cognition is the organization of the environment into coherent entities, that is, into bounded objects, events, and patterns. The writings

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of both the early Gestalt psychologists and more modern cognitive scientists suggest that the grouping of edge fragments and surface contours into unified structures begins early in life, and is aided by powerful constraints (Kohler, 1929; Quinn & Bhatt, 2001). These constraints or organizational principles help to solve the nontrivial problem of how a child with little or no formal tuition arrives at an adult like view of the world, despite there being an indefinite number of ways to organize the flux of contiguous and partially overlapping surfaces arriving at the visual sensorium.

Gestalt psychologists have argued that our perceptual systems come pre-constructed to follow certain principles, e.g., closure, common movement, good continuation, proximity, and similarity (Helson, 1933; Wertheimer, 1923/1958). Such principles specify how surface fragments of a visual display should be spontaneously grouped into more complex structures (i.e., units of processing) that serve as the basis for object recognition. Recent evidence indicates that young infants adhere to at least some of these principles when organizing visual pattern information (Johnson & Aslin, 1996; Kellman & Spelke, 1983; Quinn, Burke, & Rush, 1993; Quinn, Brown, & Streppa, 1997). Current debate centers on the issue of whether sensitivity to all organizing principles is present early in life or whether sensitivity to different principles develops at different rates and according to different factors, i.e., maturation versus experience (Quinn, Bhatt, Brush, Grimes, & Sharpnack, 2002). In addition, there is discussion of whether some principles consistently take precedence over others, thereby suggesting a hierarchy of rule use in the development of perceptual organization (Needham & Kaufman, 1997) or whether a set of equally weighted principles sum together in a threshold model of perceptual unit formation (Johnson & Aslin, 1995, 1996). In the latter case, when multiple cues are detected from the same display (e.g., common motion, similarity, good continuation), these cues will add together to determine whether the stimulus configuration is above threshold for unit formation.

There has also been the recognition in the literature on the early development of perceptual organization that object perception is likely to be assisted by top-down contributions, inclusive of physical knowledge of support and solidity relations, and experiential knowledge of objects and object kinds (Needham, Baillargeon, & Kaufman, 1997; Peterson, 1994; Spelke, 1982; Carey & Williams, 2001). A general framework for thinking about the roles of perceptual process and knowledge access in perceptual organization has been offered by Schyns, Goldstone, and Thibaut (1998). Schyns et al. argue for a flexible system of perceptual unit formation, one in which the features that come to define objects are extracted during the task of category learning. In support of this idea, there is both empirical and computational evidence that an individual's history of categorization (i.e., the category representations possessed by an individual at a specific point in time) will affect their subsequent object parsing processes (Schyns & Rodet, 1997; Goldstone, 2000).

The present experiments were undertaken to better understand the interplay between adherence to Gestalt organizational principles and flexible feature creation. In particular, they ask the question: Will features that are specified as functional by Gestalt principles be "overlooked" by young infants if alternative means of object parsing are "suggested" by presenting a category of objects in which the features uniting the objects are "non-natural" in the Gestalt sense?

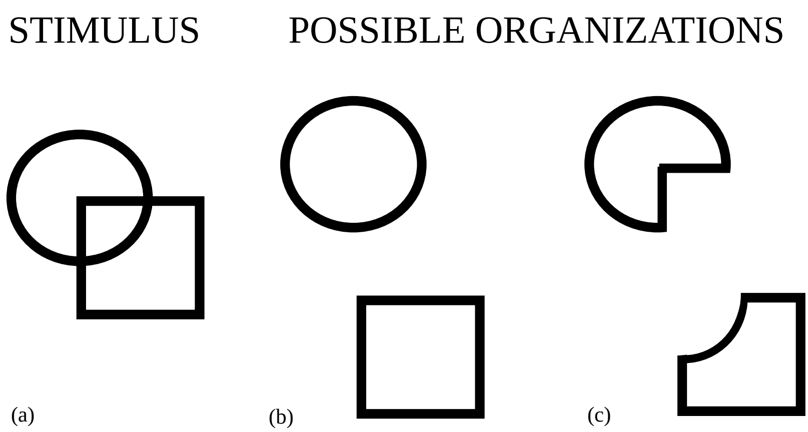

Fig. 1. Intersecting circle–square stimulus in (a), and two possible organizations in (b) and (c), from Quinn et al. (1997).

2. Experiment 1

Experiment 1 utilizes an embedded figure procedure that was previously employed by Quinn et al. (1997) to determine whether 3- and 4-month-olds could organize visual pattern information in accord with the Gestalt principle of good continuation. In Quinn et al. (1997), the infants were presented with the overlapping square–circle configuration presented in Fig. 1a. Adults tend to parse and organize this pattern into the square and circle shapes shown in Fig. 1b rather than the pacman P1 and P2 shapes depicted in Fig. 1c. To determine how infants represent the pattern, immediately following familiarization, two novelty preference tests were presented: one paired the circle with P1, and the other paired the square with P2 (depicted in Fig. 1b and c). If infants parse the pattern and organize its contours into the circle and square in accord with good continuation, then the circle and square shapes should be recognized as familiar, and the P1 and P2 shapes should be preferred. However, if infants do not parse the unitary configuration, and the outcome representation is that of an unparsed whole, or if infants parse the configuration into more than one whole, but not the wholes predicted by adherence to good continuation, then one would not expect a consistent preference for the pacman shapes. The results were that the infants preferred P1 to the circle and P2 to the square, preferences that control experiments revealed could not be attributed to a priori preferences for the pacman shapes. This pattern of outcomes provides evidence that infants in the age range from 3 to 4 months can utilize good continuation information to organize a configuration of overlapping contours.

In Experiment 1, we used the familiarization/novelty-preference methodology to ask whether 3- and 4-month-olds could achieve perceptual organization in accord with good continuation for visual patterns that were more complex than those used in Quinn et al. (1997). The infants were familiarized with eight complex figures, examples of which are shown in the top portion of Fig. 2. Subsequently, during a novelty preference test, the infants were presented with the pacman shape paired with the circle shown in the bottom portion of Fig. 2. If the infants parse

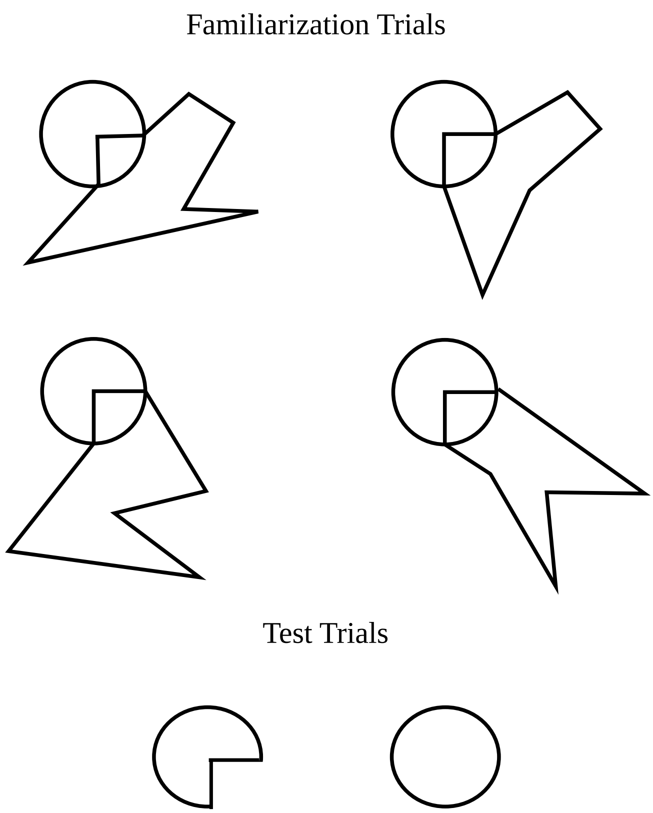

Fig. 2. Examples of the familiarization stimuli and test stimuli used in Experiment 1.

the circle from the complex figures, then they should recognize it as familiar and prefer the pacman shape. This rationale is contingent on there being no spontaneous preference for the pacman shape over the circle shape when there is no familiarization, a finding which was reported in Quinn et al. (1997).

2.1. Method

2.1.1. Participants

The participants were 16 3- to 4-month-old infants (6 females, 10 males) with a mean age = 108.75 days, *SD* = 11.25 days. Four additional infants were tested, but were excluded from the data analysis because of position preference ($n = 1$), failure to compare the test stimuli ($n = 2$), and experimenter error ($n = 1$). The participants in both experiments were predominantly Caucasian and from middle-class backgrounds.

2.1.2. Stimuli

Each of the eight stimuli presented during familiarization was composed of a circle shape (5.6 cm in diameter) along with a complex polygon. The thickness of contour for all the shapes was 3 mm. Examples of the familiarization stimuli are shown in the top portion of Fig. 2. The test stimuli, shown in the bottom portion of Fig. 2, consisted of the circle and a pacman shape that was composed of 3/4 of the circle contour, and was closed by the horizontal and vertical contours forming a right angle contour at the center of the circle.

2.1.3. Apparatus

All infants in each experiment were tested in a visual preference apparatus described in detail in Quinn et al. (1993, 1997).

2.1.4. Procedure

All infants in each experiment underwent a general procedure in which looking times to familiarization and test stimuli were recorded by trained observers who were naive to the hypotheses under investigation. The particulars of this procedure are described in Quinn et al. (1993, 1997).

Each infant was familiarized with eight complex shapes during the course of four, 15-s familiarization trials (two shapes per trial). The order of presentation of the shapes was randomized for each infant. Immediately after familiarization, the infants were presented with the pacman and circle shapes for two, 10-s 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.

2.2. Results

2.2.1. Familiarization trials

Individual looking times were summed over the left and right stimuli presented on each trial, and then averaged across the first two and last two trials. The infants displayed a reliable decrement in looking time from the first to the last half of familiarization: Trials 1 and 2, $M = 7.82$ s, $SD = 2.24$; Trials 3 and 4, $M = 5.71$ s, $SD = 2.00$; $t(15) = 4.34$, $p < .0005$, one-tailed. Although there are differences in the literature concerning how to operationally define habituation with some studies defining habituation in terms of a preset decrement in looking (e.g., a decrease to half of the original level), the most basic operational definition is a decline in responsiveness with repeated stimulation (e.g., Cohen & Gelber, 1975). By applying this latter criterion for inferring habituation, the reliable decrement in looking time observed across familiarization trials indicates that the infants habituated to the stimuli.

2.2.2. Preference test trials

Each infant's looking time to the pacman shape was divided by the total looking time to both test stimuli and then converted to a percentage score. Table 1 displays the mean preference for the pacman shape, which was determined to be significantly higher than the chance preference of 50%. This result indicates that after familiarization with the complex shapes, infants recognized the circle as more familiar than the pacman shape. The results are consistent with those of Quinn et al. (1997), and indicate that infants segregated the contours making up the circle from the familiar stimuli and organized those contours in accordance with the Gestalt principle of good continuation.

Table 1
Mean preference scores (percentages) for the pacman shape during the preference test trials for Experiments 1–3

Experiment	Preference					
	Part 1			Part 2		
	M	*SD*	t[a]	*M*	*SD*	t[a]
1	61.33	21.97	2.06*			
2	42.46	15.65	−1.93*	46.63	12.65	−1.06
3	36.32	17.86	−3.06***	38.03	20.30	−2.36**

[a] For mean vs. chance.
* $p < .05$, one-tailed.
** $p < .025$, one-tailed.
*** $p < .005$, one-tailed.

3. Experiment 2

In Experiment 2, we asked whether an invariant part abstracted during category learning would interfere with perceptual organization achieved by adherence to good continuation. The experiment consisted of two parts. In Part 1, infants were familiarized with eight exemplars, each marked by an invariant pacman shape. To insure that the pacman shape was parsed and represented, the infants were administered a novelty preference test that paired the pacman shape with a circle shape. If the pacman shape is recognized as familiar, then the circle shape should be preferred. Part 2 of the experiment was a replication of Experiment 1. The expectation is that if the category learning from Part 1 of the procedure, in particular, the representation of the invariant pacman shape, can interfere with the Gestalt-based perceptual organization that was observed in Experiment 1, then the preference for the pacman shape should no longer be observed. Part 1 of the procedure is described as a category familiarization experience because it requires infants to extract the commonality from the various exemplars (e.g., the pacman shape) in order to display a preference for the circle shape.

3.1. Method

3.1.1. Participants

The participants were 16 3- to 4-month-old infants (9 females, 7 males) with a mean age = 104.75 days, *SD* = 9.36 days. Five additional infants were tested, but three failed to complete the procedure due to fussiness, and two were excluded from the data analysis because of failure to compare the test stimuli.

3.1.2. Stimuli

Each of the eight stimuli presented during the Part 1 familiarization were composed of a pacman shape along with 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. 3. The test stimuli, shown in the bottom portion of Fig. 3, were the same as those used in Experiment 1. The Part 2 familiarization and test stimuli were the same as those used in Experiment 1.

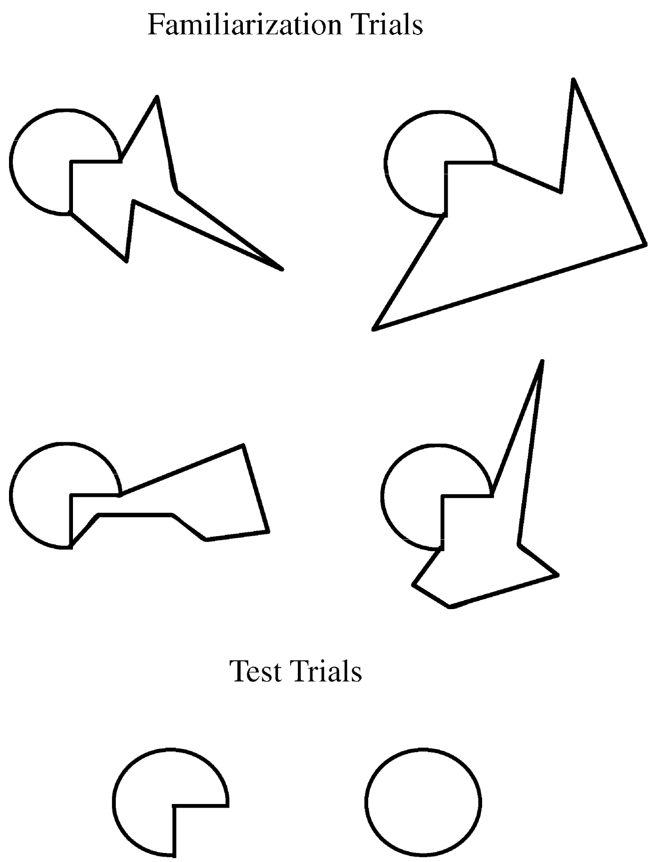

Fig. 3. Examples of the familiarization stimuli and test stimuli used in Part 1 of Experiments 2 and 3.

3.1.3. *Procedure*

In Part 1, each infant was familiarized with eight complex shapes, each marked by an invariant pacman shape, during the course of four, 15-s familiarization trials (two shapes per trial). The order of presentation of the shapes was randomized for each infant. Immediately after familiarization, the infants were presented with the pacman and circle shapes for two, 10-s 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. Immediately following Part 1, the infants were administered Part 2, which was a replication of the procedure used in Experiment 1.

3.2. *Results*

3.2.1. *Part 1: Familiarization trials*

The infants displayed a reliable decrement in looking time from the first two trials ($M = 8.08$, $SD = 2.82$) to the last two trials ($M = 6.85$, $SD = 3.14$), $t(15) = 1.91$, $p < .05$, one-tailed. This significant decline in looking time from the first to the last half of familiarization indicates that the infants habituated to the familiar stimuli.

3.2.2. Part 1: Preference test trials

The mean preference for the pacman shape is displayed in Table 1. It was found to be significantly lower than chance. This result indicates that the invariant pacman shape was learned during the category familiarization task, and recognized as familiar, with the consequence that a novelty preference was observed for the circle shape, $M = 57.54\%$, $SD = 15.65$, $t(15) = 1.93$, $p < .05$, one-tailed.

3.2.3. Part 2: Familiarization trials

The infants showed a significant decline in looking time from the first two trials ($M = 6.63$, $SD = 2.07$) to the last two trials ($M = 5.40$, $SD = 2.43$), $t(15) = 2.17$, $p < .025$, one-tailed. This reliable decrement in looking time from the first to the last half of familiarization is consistent with that observed in Experiment 1 and indicates that the infants again habituated to the familiar stimuli.

3.2.4. Part 2: Preference test trials

The mean preference for the pacman shape, shown in Table 1, was not significantly different from chance. This result indicates that the circle shape was not successfully parsed and represented as it was in Experiment 1. The difference between the mean preference for the pacman shape in Experiments 1 and 2 was reliable, $t(30) = 3.27$, $p < .01$, two-tailed. It is also important to mention that an analysis of variance performed on the looking times from the familiarization trials of Experiment 1 and Part 2 of Experiment 2, with Experiment (1 vs. 2) as a between-subjects factor and Trials (1 and 2 vs. 3 and 4) as a within-subjects factor, revealed only a reliable effect of trials, $F(1, 30) = 19.96$, $p < .001$. Neither the effect of experiment nor the interaction between Experiment and Trials were significant, $F(1, 30) < 1.37$, $p > .20$, in both cases. Because the effect of experiment was not significant in this analysis, one cannot attribute the differential results in the preference test trials of Experiment 1 and Part 2 of Experiment 2 to be the outcome of a general fatigue effect operating in Experiment 2. The combined results from the two experiments suggest that the invariant pacman shape that was recognized as familiar on the basis of the Part 1 category familiarization experience interfered with the good continuation-based process of parsing the circle from the stimuli presented in Part 2.

4. Experiment 3

A concern with the interpretation of Experiment 2 is that it rests on a null effect of equal looking to the pacman and circle. At least two alternative accounts can be advanced to explain the null findings. First, it could be that any Part 1 experience (i.e., not just one based on familiarization with a pacman shape) would cause infants not to show a preference for the pacman or circle in Part 2. Second, it could be that the infants in Part 1 encoded the pacman and the infants in Part 2 encoded the circle (without interference from the pacman from Part 1), and the null result is an outcome of the infants being familiar with both the pacman (from Part 1) and the circle (from Part 2). To provide empirical data that would speak against these alternative explanations of Experiment 2, we undertook Experiment 3. Experiment 3 was a replication of Experiment 2, except that in Part 1 the infants were presented with two additional familiarization trials depicting four new stimuli displaying the invariant pacman shape along with a variable polygon shape. Our reasoning was that the additional familiarization should result in a stronger representation of the pacman shape, one that would carry over from Part 1 to Part 2 more robustly, thereby resulting in a novelty preference for the circle shape in Part 2. A positive result in Part 2 in the form of a preference for the circle would be unlikely to result from a non-specific Part 1 interference experience or the representation of the two different shapes from the different parts of the procedure.

4.1. Method

4.1.1. Participants

The participants were 16 3- to 4-month-old infants (10 females, 6 males) with a mean age = 109 days, *SD* = 10.30 days. Six additional 3- to 4-month-olds were tested, but three failed to complete the procedure due to fussiness, and three were excluded from the data analysis because of failure to compare the test stimuli ($n = 2$) or because of position preference, i.e., greater than 95% of looking to one side of the display ($n = 1$).

4.1.2. Stimuli

The stimuli were the same ones used in Experiment 2, with the exception that four additional stimuli, each composed of a pacman shape and a complex polygon, were presented during Part 1.

4.1.3. Procedure

The procedure was the same as in Experiment 2, except that 12 shapes were presented during the course of six, 15-s familiarization trials in Part 1.

4.2. Results

4.2.1. Part 1: Familiarization trials

The infants displayed a reliable decrement in looking time from the first two trials ($M = 7.25$, $SD = 3.66$) to the last two trials ($M = 6.32$, $SD = 3.21$), $t(15) = 1.89$, $p < .05$, one-tailed. This significant decline in looking time from the first to the last half of familiarization indicates that the infants habituated to the familiar stimuli.

4.2.2. Part 1: Preference test trials

The mean preference for the pacman shape as revealed in Table 1 was significantly lower than chance. This result is consistent with what was observed in Part 1 of Experiment 2 and indicates again that the invariant pacman shape was learned during the category familiarization task, and recognized as familiar, with the consequence that a novelty preference was observed for the circle shape, $M = 63.68\%$, $SD = 17.86$, $t(15) = 3.06$, $p < .005$, one-tailed.

4.2.3. Part 2: Familiarization trials

The infants showed a marginally significant decline in looking time from the first two trials ($M = 6.07$, $SD = 3.86$) to the last two trials ($M = 5.21$, $SD = 3.31$), $t(15) = 1.45$, $p < .10$, one-tailed. This marginally reliable decrement in looking time from the first to the last half of familiarization is once more consistent with the idea that the infants habituated to the familiar stimuli.

4.2.4. Part 2: Preference test trials

The mean preference for the pacman shape as shown in Table 1 was significantly lower than chance. This result indicates that the circle shape was not successfully parsed and represented as it was in Experiment 1. In fact, the outcome supports the idea that the representation of the pacman shape had carried over from Part 1 to Part 2. The difference between the mean preference for the pacman shape in Experiments 1 and 3 was reliable, $t(30) = 3.12$, $p < .01$, two-tailed. The combined results from Experiments 1 and 3 suggest that the invariant pacman shape that was recognized as familiar on the basis of the Part 1 category familiarization experience continued to be represented in Part 2, and consequently interfered with the good continuation-based process of parsing the circle from the stimuli presented in Part 2.

5. General discussion

Previous research has established that young infants can use the good continuation principle to organize visual-pattern displays consisting of an overlapping circle and square (Quinn et al., 1997). Experiment 1 extended this finding by showing that 3- to 4-month-olds could parse a circle in accord with good continuation from multipart visual patterns consisting of a circle and a complex polygon. In Experiment 2 and 3, however, this Gestalt-based parsing process was 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. Part 1 of Experiments 2 and 3 showed that the infants recognized the pacman shape as familiar, and Part 2 of Experiments 2 and 3 demonstrated that the representation of the pacman shape blocked the subsequent parsing of the circle in accord with good continuation. In Part 2 of Experiment 2, a null preference between the pacman and the circle was observed, whereas in Experiment 3, with additional familiarization with the pacman shape during Part 1, a preference for the circle over the pacman was in evidence.

The hallmark of the explanation of performance for the infants participating in Experiments 2 and 3 is that early exposure to the pacman shape makes infants perceive the ambiguous displays in Part 2 as containing pacmen rather than circles. In other words, the bias set by the Gestalt principle of good continuation is soft-wired and subject to interference. However, as observed in the introduction to Experiment 3, an alternative account is that infants in Part 1 encoded the pacman and the infants in Part 2 encoded the circle (without interference from the pacman from Part 1). This alternative account has it that infants consistently interpret the ambiguous displays in Part 2 as containing circles—the application of the Gestalt law of good continuation is not interfered with in any way. This is because during Part 1 of Experiments 2 and 3, infants get familiarized with pacman shapes. During Part 2, the infants are familiarized with circle shapes. If the pacman and circle exposure is approximately equal (Experiment 2), then infants show no preference for circles or pacmen. If the pacmen are shown more frequently (Experiment 3), then the infants look more to the circle because it is less familiar.

We believe that the results of Experiment 3 render this alternative account less likely. In particular, we would argue that if infants reach some criterion level of familiarity with *both* the pacman shape from Part 1 and the circle shape from Part 2, then the outcome of the Part 2 preference test should be a null result (i.e., no preference) as was observed in Experiment 2, rather than the preference for the circle shape that was observed in Experiment 3. We concede, nevertheless, that the results of Experiment 3 do not definitively rule out the alternative account and that further experimentation would be needed to do so. Future studies, could for example, replicate Experiment 3, but include two additional Part 2 familiarization trials, to return the pacman and circle shape to equal familiarity. The interference account would predict a continuing preference for the pacman shape, whereas the alternative account would predict a no preference result. One could also perform a replication of Experiment 3, and conduct additional preference tests after the Part 2 familiarization experience. These tests could examine infant preferences for the circle shape versus a completely novel shape and the pacman shape versus a completely novel shape. The interference account would predict a preference for the novel shape only when it is compared to the pacman shape, whereas the alternative account would predict a preference for the novel shape when it is paired with either the circle or pacman shapes.

However the results of the additional studies turn out, the present findings are consistent with the model of flexible feature creation put forth by Schyns et al. (1998) to explain the development of features in object concepts. In particular, the results suggest that perceptual units formed during category learning can be (1) entered into a perceptual system's working "featural" vocabulary, and (2) available to subsequent object recognition processes. The interference data reported in the present manuscript are complemented by the facilitation data of Needham, Dueker, and Lockhead (submitted) as reported by Needham (2001). The critical finding was that 4.5-month-olds were able to use a familiarization experience with different boxes to form a category representation of "box" that was then used to help parse a novel box from a cylinder–box display of adjacent objects. Both sets of experiments underscore the importance of studying the often-neglected linkage between the processes of object categorization and object recognition (Goldstone & Barsalou, 1998; Schyns, 1998), and support the more general idea that an individual's history of categorization will affect their subsequent object parsing abilities.

Previous research has demonstrated that the human perceptual system appears constrained to follow principles that specify how edge segments should be organized to form functional units of coherent object representations (Quinn et al., 1993, 1997, 2002). The present experiments speak to the power of a flexible feature-creation system that can override the organizational principles with which a perceptual system may be pre-equipped. It will be important in future work to inquire into the durability of the interference effects reported here, and whether they might be overcome with additional Part 2 familiarization experience. Further research will also be needed to determine more precisely how a constrained system of perceptual organization and a flexible feature-creation system come to interface with each other during the course of perceptual-cognitive development. A task for subsequent studies will be to determine if this system of feature creation replaces, reorganizes, exists in parallel, or works interactively with any system of perceptual organization that might be in place before the onset of environmental experience.

Acknowledgments

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