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Transfer and Scaffolding of Perceptual Grouping Occurs Across Organizing Principles in 3- to 7-Month-Old Infants

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Abstract

Previous research has demonstrated that organizational principles become functional over different time courses of development: Lightness similarity is available at 3 months of age, but form similarity is not readily in evidence until 6 months of age. We investigated whether organization would transfer across principles and whether perceptual scaffolding can occur from an already functional principle to a not-yet-operational principle. Six-to 7-month-old infants (Experiment 1) and 3- to 4-month-old infants (Experiment 2) who were familiarized with arrays of elements organized by lightness similarity displayed a subsequent visual preference for a novel organization defined by form similarity. Results with the older infants demonstrate transfer in perceptual grouping: The organization defined by one grouping principle can direct a visual preference for a novel organization defined by a different grouping principle. Findings with the younger infants suggest that learning based on an already functional organizational process enables an organizational process that is not yet functional through perceptual scaffolding.

The question of how human observers come to know which parts of an image belong together has been at issue in perceptual psychology since the early 1900s. Gestalt psychologists have argued that organization is an original sensory fact because infants come into the world with perceptual systems that are constrained to follow classic grouping principles, such as common movement, proximity, and similarity (Kohler, 1929). In contrast, Hebb (1949) argued that the development of perceptual organization would take considerable time because it depends on maturation of eye movements that yield holistic perceptions as visual scanning becomes more systematic. A more modern position is that, although some core principles are functional in the earliest months of life, other principles are learned by being bootstrapped onto the core principles (Spelke, 1982).

Developmental research conducted over the last 15 years has been examining whether infants utilize both classic and modern grouping principles to organize a variety of visual displays (Quinn, Bhatt, & Hayden, 2008a). The studies have revealed that common region, connectedness, good continuation, lightness similarity, and proximity are functional at 3 to 4 months of age; in contrast, form similarity is not readily in evidence until 6 to 7 months of age. Taken together, the findings indicate that different grouping principles become functional over different time courses of development and that not all principles are readily deployed in the manner proposed by Gestalt psychologists. The findings on form similarity are also consistent with Spelke's (1982) view that learning may play a role in acquiring certain aspects of perceptual organization.

Some of the findings on the grouping abilities of infants have suggested that perceptual organization can produce abstract processing units. For example, in Bhatt, Hayden, and Quinn's (2007) report on grouping by common region (Palmer, 1992), infants were familiarized with two pairs of shapes; one pair (e.g., A and B) was located together in one region, and the other pair (e.g., C and D) was located together in another region. Infants were then tested with a familiar within-region grouping (e.g., A with B) and a novel between-region grouping (e.g., B with C). The infants discriminated between the grouping of elements that had shared a common region during habituation and the grouping of elements from different regions. Importantly, the infants were habituated to vertical regions and tested with horizontal regions. Thus, when elements that were previously grouped in one region were subsequently encountered in a novel region, the infant's perceptual system expected the grouping to remain intact. The findings suggest a unitization process by which previously disparate elements become grouped and begin to function as coherent units in new contexts (Goldstone, 1998). In addition, in Quinn, Bhatt, and Hayden's (2008b) study of proximity grouping, infants were familiarized with bars and tested with elements. In that study, infants generalized from one to the other even though the physical dimensions of the bar stimuli were different from those of the element stimuli (i.e., the vertical and horizontal bars were longer and more closely spaced than the corresponding columns and rows of elements). There was actually more physical overlap between the bars and the elements depicting the novel organization. The results of both studies indicate that the units that arise as a consequence of grouping have an abstract quality in terms of their transfer.

Although the prior research suggests that there is flexibility in early grouping in that perceptual units formed by applying a particular grouping principle can be generalized to novel patterns organized by the same principle, it is not yet known whether the perceptual units formed from application of one grouping principle can be transferred to process a visual pattern organized by a different principle. It has also never been demonstrated how the process of bootstrapping, described by Spelke (1982), might be manifested. The latter notion goes beyond the idea of transfer across principles: It implies a scaffold from a functioning principle to one that is not quite functional.¹ We investigated the possibilities for transfer across principles in 6- to 7-month-old infants and scaffolding from one principle to another in 3- to 4-month-old infants.

EXPERIMENT 1

Experiment 1, we asked whether an organization learned by adherence to one principle could transfer and direct a subsequent visual preference for a novel organization based on another principle. To this end, 6- to 7-month-old infants were familiarized with arrays that could be organized into columns or rows based on lightness similarity. The infants were then given a novelty-preference test that paired arrays that could be organized into columns or rows based on form similarity (see Fig. 1). The question is whether infants will transfer an organization of alternating rows (or columns) of filled and unfilled squares (lightness similarity) to an organization of alternating rows (or columns) of Xs and Os (form similarity). The expectation is that, if the infants can organize the familiarized patterns by lightness similarity and use the represented organization as a basis for processing test patterns organized by form similarity, then they should display a preference for the novel organization. Six- to 7-month-old infants were selected because prior research had suggested that both lightness and form similarity are functional in this age group (Quinn & Bhatt, 2006; Quinn, Bhatt, Brush, Grimes, & Sharpnack, 2002). However, to our knowledge, no

¹The term "scaffold" as used here in the context of perceptual learning should be distinguished from use of the term scaffold in the context of Vygotsky's (1978) zone of proximal development. In Vygotsky's usage, "scaffold" refers to something that adults or more competent children provide to help a developing child succeed at a novel task.

prior studies have investigated whether an organization formed by adherence to the one principle could transfer to direct a visual preference based on the other principle.

Method

Participants—Participants were 16 healthy 6- to 7-month-old infants (9 females, 7 males; mean age = 195.00 days, $SD = 12.92$ days). One additional infant was tested but excluded from the data analysis because of failure to compare the test stimuli. Participants in both experiments were predominantly Caucasian and from middle-class backgrounds.

Stimuli—Familiar stimuli were arrays of filled and unfilled squares previously used by Quinn, Burke, and Rush (1993) and Quinn and Bhatt (2006). Test stimuli were arrays of *Xs* and *Os* used previously by Quinn et al. (2002) and Quinn and Bhatt (2005, 2006).

Apparatus—Infants were tested in a visual preference apparatus that was modeled after the apparatus used by Fagan (1970).

Procedure—Half the infants were familiarized with alternating columns of filled and unfilled squares for six 15-s trials; the other half were familiarized with alternating rows of filled and unfilled squares. Two identical copies of the familiar stimulus were presented on each familiarization trial. Immediately after familiarization, infants from both familiarization groups were presented with two stimuli, one of alternating columns versus one of alternating rows, both organized by shape (*Xs* vs. *Os*), on each of two 10-s preference test trials. Left-right positioning of the stimuli was counterbalanced across infants on the first test trial and reversed on the second test trial. Half the infants in each group were tested with stimuli in which the form elements (i.e., the *X* and *O* shapes) were equated for the visual angle they subtended, and the other half were tested with stimuli in which the form elements were equated for amount of contour (i.e., dark area).

Looking times to familiarization and test stimuli were recorded by trained observers who were naive to the hypotheses under investigation. Interobserver agreement, as determined by comparing the looking times measured by an observer using a peephole in the apparatus with those measured by an additional naive observer measuring looking times offline from videotape records, was calculated for the preference test trials of 12 infants participating across the two experiments. Average level of agreement was 97.78% ($SD = 2.10\%$).

Preliminary analyses were performed on novelty-preference percentages during test trials as a function of whether infants were tested with form elements equated for visual angle or with those equated for contour in each experiment. In neither case was performance affected by type of form element.

Results and Discussion

Familiarization Trials—Mean looking times are shown in Table 1. An analysis of variance performed on the individual scores, with factors of organization (columns vs. rows) and trial block (trials 1–3 vs. 4–6), did not yield any significant effects. The nominal decrement in responsiveness from the first to the second half of familiarization was not reliable. However, preference data indicated that the lack of habituation did not preclude processing.

Preference-Test Trials—Mean preference scores are shown in Table 1. Infants in the column, row, and combined groups looked reliably longer to the novel organization. Also, 15 of the 16 infants displayed a preference for the novel organization above 50%, $p = .0005$. Moreover, means for the column and row groups were not reliably different from each other,

$t(14) = 1.60, p > .10$. The results suggest that 6- to 7-month-old infants can organize visual pattern information by lightness similarity and then transfer the represented organization (i.e., columns or rows) to direct a preference for a novel pattern organized by form similarity (i.e., rows or columns).

EXPERIMENT 2

Given positive evidence of transfer in Experiment 1, we next inquired whether evidence might also be found for perceptual scaffolding, a process by which learning based on an already functional organizational process enables an organizational process that is not yet functional. That is, infants who might otherwise not be able to group based on an organizational principle might be induced to do so if they are previously allowed to group elements based on an already functional organizational process. Whereas 3- to 4-month-old infants readily organize based on lightness similarity (Quinn et al., 1993), organization by form similarity is not readily exhibited until 6 to 7 months of age (Quinn et al., 2002). In Experiment 2, we exploited this difference to ask whether 3- to 4-month-old infants who were familiarized with columns or rows of luminance elements and tested with columns versus rows of shape elements will show evidence of perceptual scaffolding. Experiment 2 was thus a repeat of Experiment 1, but conducted with the younger infants. An additional control group of younger infants was familiarized and tested with the form elements shown in Figure 2. This latter group constitutes a replication of Quinn et al. (2002) and provides a form-to-form baseline against which performance in the light-to-form task can be judged.

Method

Participants—Participants were 32 healthy 3- to 4-month-old infants (16 females, 16 males; mean age = 107.50 days, $SD = 11.63$ days). Three additional infants were tested, but one did not complete the procedure due to fussiness and two were excluded from the data analysis because of position preference (i.e., > 95% looking to one side of the display).

Stimuli and Procedure—Stimuli and procedure were identical to those of Experiment 1 for the light-to-form group. Additionally, a form-to-form control group was familiarized and tested with elements organized by form similarity as shown in Figure 2.

Results and Discussion

Familiarization Trials—Mean looking times are shown in Table 2. A Condition (form-to-form vs. light-to-form) $\times$ Organization $\times$ Trial Block analysis of variance performed on the individual scores yielded only a significant effect of trial block, $F(1, 28) = 57.83, p < .001$. The decline in responsiveness from the first to last half of familiarization was reliable, suggesting that the younger infants had habituated to the familiar stimulus information.

Preference Test Trials—Mean preference scores are shown in Table 2. A Condition $\times$ Organization analysis of variance performed on the individual scores yielded only a significant effect of condition, $F(1, 28) = 8.84, p < .007$, indicating that the light-to-form group had higher preference scores than the form-to-form group. In addition, when the mean preferences were compared to chance, only infants in the light-to-form group looked reliably longer at the novel organization. Moreover, 15 of 16 infants in the light-to-form group displayed a preference for the novel organization above 50%, whereas this was true for only 6 of 16 infants in the form-to-form group, Fisher's exact test, $p = .0008$. The results from the form-to-form group replicate those reported in Quinn et al. (2002) and indicate that 3- to 4-month-old infants do not readily organize by form similarity. However, the findings from the light-to-form group provide evidence of a scaffolding effect whereby 3- to 4-month-old infants group visual patterns into column or row organizations by lightness similarity and

then transfer the represented organization to direct a preference for a novel organization based on form similarity.

GENERAL DISCUSSION

Although prior research had suggested flexibility in early perceptual grouping in that perceptual units formed by applying a particular grouping principle could be generalized to novel patterns organized by the same principle (Bhatt et al., 2007; Quinn et al., 2008b), the findings from Experiment 1 with 6- to 7-month-old infants are the first to suggest that perceptual units formed from application of one grouping principle (lightness similarity) can be transferred to apprehend an organization defined by a different grouping principle (form similarity). Moreover, the results of Experiment 2 indicate that 3- to 4-month-old infants familiarized with elements organized into columns or rows by luminance displayed a subsequent preference for a novel organization of elements grouped by form. This outcome contrasted with the null results obtained when infants were familiarized and tested with form elements.²³ The data indicate that the already-developed luminance-based organizational system was able to facilitate grouping based on form similarity. The results suggest that the use of new organizational principles can, in some instances, be derived from previously functioning principles through a process of perceptual scaffolding. The findings are in accord with Spelke's (2000) arguments that certain types of knowledge about the world are built upon or bootstrapped onto other "core" knowledge and contradict the traditional Gestalt view that perceptual knowledge is automatic and engendered by brain structure (Koffka, 1935).

The present results also call into question the sufficiency of an approach that has been taken by developmental scientists over the past several decades; this approach has been based on an implicit assumption that there exist consistent perceptual capacities of infants at particular ages. Our findings show that 3- to 4-month-old infants' sensitivity to form-similarity cues, thought to be essentially null, changes after a relatively brief exposure to consistent lightness cues. Other work (Vishton, Ware, & Badger, 2005) has shown similar changes in sensitivity to certain Gestalt cues when the action task changes (e.g., from looking to object-directed reaching). In this regard, our findings can be linked with a range of empirical results demonstrating infant learning and transfer (Johnson & Shuwairi, 2009; Lany & Gomez, 2008; Needham, Dueker, & Lockhead, 2005; Wilcox & Chapa, 2004), as well as with dynamic systems and connectionist theory, which can readily accommodate situations in which changes in a single variable in a particular study can cause large changes in infants' performance (e.g., Spencer, Thomas, & McClelland, in press).

²One might argue that the performance difference between the two conditions of Experiment 2 can be attributed to differential difficulty in processing the lightness-element contrast (i.e., filled vs. unfilled squares) compared to the form-element contrast (i.e., *X* vs. *O* shapes). However, discrimination-control conditions in prior studies provided independent evidence that 3- to 4-month-old infants can discriminate between the light-dark and *X-O* elements in the displays at equivalent levels of performance (e.g., Quinn et al., 1993, 2002). The results of these control conditions thus indicate that it is unlikely that the performance difference in Experiment 2 is due to differential task difficulty.

³One might also question whether the two organizing principles (lightness and form) are functionally different on the grounds that a low-pass filter simulating infant visual capabilities would render the *X-O* form contrast and filled-unfilled lightness contrast as being equivalent to one another (i.e., elements with or without stuff in the middle). However, if this were the case, then one would not predict the developmental differences in the two principles that are described in the introduction. In addition, when row and column patterns defined by lightness similarity were subjected to low-pass filtering simulating the vision of 3-month-old infants, the results were that the form of the individual elements (i.e., squares vs. diamonds) making up the patterns was clearly discernable (see Figure 2 of Quinn et al., 1993). This observation was subsequently confirmed in behavioral experimentation reported in Quinn et al. (1993) and described in Footnote 2. Our view is that if the rectilinear form contrast of squares and diamonds (be they filled or unfilled) was clearly discernable, then the more salient form contrast between rectilinear *Xs* and curvilinear *Os* would also be clearly discernable (as empirically demonstrated in Quinn et al., 2002) and perceived distinctly from the lightness contrast between filled and unfilled elements.

The data from both experiments are also noteworthy because they indicate that perceptual organizing processes can produce abstract processing units. Units that arise as a consequence of such grouping mechanisms have a flexible quality in terms of their transfer. Our results thus imply that emergent features formed by infants from the deployment of perceptual organizational principles are conceptual-like in their generalizability. These findings are more broadly supportive of approaches to cognition that bring together perceptual and conceptual explanations of human performance under a common set of operating principles (Goldstone & Barsalou, 1998).

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Fig. 1.

Illustration of the lightness-to-form task presented to infants in Experiments 1 and 2. Participants were familiarized with columns or rows of filled and unfilled squares. After familiarization, during the preference test, infants were presented with columns and rows of *X* and *O* shapes. Looking time to the stimuli was measured during both familiarization and the preference test.

Fig. 2.

Illustration of the form-to-form task presented to infants in the control group of Experiment 2. Participants in this group were familiarized with columns or rows of *X* and *O* shapes. After familiarization, during the preference test, infants were presented with columns and rows of *X* and *O* shapes. Looking time to the stimuli was measured during both familiarization and the preference test.

TABLE 1

Results from Experiment 1: Mean Fixation Times During the Familiarization Trials and Mean Preference Scores for the Novel Organization During the Test Trials

Familiar stimulus organization	Fixation time (s)		Novelty preference	
	Trials 1–3	Trials 4–6	Mean preference score (%)	Mean vs. chance
Columns	5.39 (2.15)	4.48 (2.01)	71.50 (12.99)	$t(7) = 4.68^{***}$
Rows	6.11 (3.27)	5.67 (3.12)	62.91 (7.80)	$t(7) = 4.68^{***}$
Combined	5.75 (2.70)	5.08 (2.61)	67.20 (11.26)	$t(15) = 6.11^{****}$

Note. Standard deviations are given in parentheses.

 $p < .005$, one-tailed.

 $p < .0005$, one-tailed.

TABLE 2

Results from Experiment 2: Mean Fixation Times During the Familiarization Trials and Mean Preference Scores for the Novel Organization During the Test Trials

Task and familiar stimulus organization	Fixation time (s)		Novelty preference	
	Trials 1–3	Trials 4–6	Mean preference score (%)	Mean vs. chance
Form-to-form task				
Columns	7.13 (1.22)	5.61 (2.19)	47.81 (17.61)	$t(7) = -0.35$
Rows	9.44 (3.49)	6.01 (3.58)	47.13 (10.54)	$t(7) = -0.77$
Combined	8.29 (2.29)	6.81 (2.87)	47.47 (14.02)	$t(15) = -0.72$
Light-to-form task				
Columns	7.71 (3.86)	4.74 (3.84)	67.03 (17.71)	$t(7) = 2.72^{**}$
Rows	9.64 (3.49)	6.56 (3.10)	59.14 (12.15)	$t(7) = 2.13^*$
Combined	8.67 (3.69)	5.65 (3.50)	63.08 (15.23)	$t(15) = 3.44^{***}$

Note. Standard deviations are given in parentheses.

* $p < .05$, one-tailed.

** $p < .025$, one-tailed.

*** $p < .005$, one-tailed.