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How does Learning Impact Development in Infancy? The Case of Perceptual Organization

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Abstract

Pattern perception and organization are critical functions of the visual cognition system. Many organizational processes are available early in life, such that infants as young 3 months of age are able to readily utilize a variety of cues to organize visual patterns. However, other processes are not readily evident in young infants, and their development involves perceptual learning. We describe a theoretical framework that addresses perceptual learning in infancy and the manner in which it affects visual organization and development. It identifies five kinds of experiences that induce learning, and suggests that they work via attentional and unitization mechanisms to modify visual organization. In addition, the framework proposes that this kind of learning is abstract, domain general, functional at different ages in a qualitatively similar manner, and has a long-term impact on development through a memory reactivation process. Although most models of development assume that experience is fundamental to development, very little is actually known about the process by which experience affects development. The proposed framework is an attempt to account for this process in the domain of perception.

Research in developmental psychology has primarily been driven by questions about the mechanisms of development, as reflected in the debates over whether such mechanisms (1) originate in response to biological maturation or environmental experience, and (2) change in a quantitative or qualitative manner (e.g., Elman et al., 1996; Haith, 1998; Kagan, 2008; Spelke, 1998). Findings of early competence in the last few decades (e.g., Baillargeon, Spelke, & Wasserman, 1985; Meltzoff & Moore, 1977; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Wynn, 1992) have been interpreted as swinging the evidence in favor of the "nativist" camp, such that a current popular view is that infants' intelligent interactions with the environment are primarily driven by innately specified competencies. However, more recently, there has been a resurgence of interest in how learning may bring about the development of knowledge structures in infants (Aslin, 2009; Goldstone, Gerganov, Landy, & Roberts, 2008; Johnson, 2010; Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Newcombe, 2010; Woodward & Needham, 2009). The current paper takes up this debate with a specific focus on the issue of how infants come to establish perceptual organization in the domain of vision.

A problem that all infants must solve if they are to develop cognitively is how to establish the coherence of objects in a visual scene. How do infants know where one object stops and another object starts in a cluttered environment of continuous and partially overlapping surfaces? An analogous problem is faced by the infant word learner who must determine

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where one word ends and another begins in a continuous stream of speech (e.g., Jusczyk & Aslin, 1995; Thiessen & Saffran, 2003). What adds to the complexity of the problem is that, even in the simplest of displays, there are an indefinite number of ways those displays can be organized. The visual display depicted in Figure 1, for example, consists of uniformly dark elements of a common shape presented against a light background. Most adults would identify the pattern as a "square," in spite of the fact that there is nothing "squarelike" about the individual elements. One could argue that this identification is not surprising given the years of experience labeling a well-known object with a specific name. But this argument invites the developmental question of how a young infant would perceive such a display. Is the display perceived in the initial months of life as a summation of darkness against a light background, a set of dots, a set of spaces between dots, a subset of the dots (enough to represent an angle or corner of the whole form), a single dot, part of a single dot, or the whole form?

The developmental problem of receiving underspecified input and organizing it into coherent patterns cannot be overstated. Without organizational processes, individuals would take away different views of the world, and communication among conspecifics would be impossible because there would be no shared reality. The problem is compounded in real scenes, where the inputs are large in number and have complex spatial arrangements. Given the difficulty of the problem and the fact that children by about a year of age begin to identify objects with common names agreed upon within their culture, the development of visual cognition is believed to take place within a very short period of time and be driven by constraints (Newcombe, 2010; Simion & Leo, 2010; Slater, 1998; Spelke, 2000). Our work over the last decade and a half has been designed to determine what those constraints are in the domain of perceptual organization. In the present paper, using our empirical work and that of others in support, we lay out our understanding of which constraints are functional early, and which other constraints are less readily available early and may in fact be learned. We go on to outline a theoretical framework that emerges from this work. While in past writings we have emphasized the biological constraints that bring about perceptual organization (Quinn & Bhatt, 2001, 2009a; Quinn, Bhatt, & Hayden, 2008a), in the current effort, we attempt to provide a more complete accounting of the learning experiences that engender perceptual organization. Although some portions of the account are more hypothesis- than evidence-based at this juncture, this seemed an appropriate time to propose it, given the recent discussions of the relative roles of biology and experience in bringing about development in general or in specific domains. Moreover, by providing an in-depth proposal regarding the mechanisms that bring about organization in a particular domain, researchers working in related fields may be able to determine whether the principles of the account are generalizable to their domain.

Historical Perspective on Theoretical Approaches to Perceptual Organization

The question of whether organization is a starting point for perceptual-cognitive development or whether it is the end product of a slow learning process has been a central concern in perceptual psychology ever since the Gestalt psychologists of the 1920s raised the issue of how we come to know which parts of an image belong together as one object and which belong to different objects (Koffka, 1935; Kohler, 1929; Wertheimer, 1923). Gestalt theorists adopted a nativistic framework, contending that perceptual organization is automatic and present even in an initial encounter with a visual pattern. This is so because our perceptual systems are constrained to follow universal grouping principles that lead to the perception of one organization over other organizations that are equally physically possible. As Palmer (1999) notes, "Gestalt theorists…suggested that, most, if not all, of the basic organizational processes operate from birth and therefore do not need to be learned" (p. 305-306).

A counter to the Gestalt perspective was offered by Hebb (1949), who argued that perceptual organization is a learned process in which eye movements that are used to scan images generate the internal representation of objects. According to Hebb, eye movements are limited early in life, and sufficient to scan only small (not necessarily connected) portions of shape outlines. Scanning experience results in sequences of visual fixations that eventually allow infants to integrate contours and form holistic representations of shapes. By this view, the emergence of perceptual organization would take considerable developmental time, and is an outcome of experience.

Other theorists include both biologically- and experientially-based determinants of the development of perceptual organization. For instance, Gibson (1969) argued that, “The trends in perceptual development emerge as the product of both experience with an environment and the maturing powers of an individual” (p. 446). In addition, Spelke’s (1982) account of the development of object perception starts with the idea that perceptual organization of infants is driven by two core organizational principles (common movement and connected surface) that are derived from a primitive object concept. Adherence to these principles would essentially parse from a visual scene those surfaces that move together and maintain their coherence as they move, and grant them the status of objects. The object “blobs’ that are the output of the core principles can then be tracked over real time. This type of experience, according to Spelke, allows infants to discover that objects also exhibit other properties including similarity of surface, and good continuation of contour (see also Brunswik & Kamiya, 1953). In this way, what the Gestalt theorists had taken to be innate organizing principles are by the Spelke account learned through their natural correlation with the innately-specified common motion and connected surface core principles.

Contemporary Theorizing

A number of contemporary theorists agree with Spelke (1982) in acknowledging the influence of both native and experiential factors in the development of perceptual organization (for reviews, see Amso & Johnson, 2009; Baillargeon, Li, Ng, & Yuan, 2009; Johnson, 2009, 2010; Needham & Baillargeon, 1998; Quinn, Bhatt, & Hayden, 2008a). For example, Needham and Baillargeon suggest that cues that infants use to form perceptual units may come from a multiplicity of sources. Some of these cues fall under the heading of configural information (e.g., color, shape, and texture similarity) and may be characterized as bottom-up or unlearned. Other cues, such as knowledge of particular objects and object kinds, reflect experiential information. Johnson (2009) suggests that, whereas some basic visual mechanisms (such as attending to areas of high visual contrast) are innate, others (such as perceptual completion) are learned. Similarly, Baillargeon, Li, Ng, and Yuan (2009) conclude that infants’ perceptual organization of physical events is achieved by a combination of innate “core concepts and principles” (p. 67) and knowledge about the roles of different variables in particular situations that is acquired through experience.

Our Approach

Our approach is consistent with that of Spelke (1982) and the contemporary theories mentioned above in assuming that a variety of inherent and learned processes work in conjunction to engender perceptual organization. Like Johnson (2009), our position is that a full accounting of the development of object perception will require knowing both the innate and learning contributions, and their integration, towards the achievement of coherent object representations. In the current paper, we concentrate on learning processes that underlie perceptual grouping and development in infancy.

We believe that a comprehensive approach to the study of learning in perceptual organization and its development in infancy has to address the following: (a) Basic kinds of experiences that engender learning. That is, it is important to understand the kinds of interaction with the environment that promote perceptual learning in infants. (b) The mechanisms that underlie learning. We need to know what changes in perceptual processes are induced by experience that then allows the infant to behave differently after the learning episode. (c) Characteristics of the learning process. For instance, we need to know the general/specific nature of learning, and how it functions in different domains and at different ages. Most significantly, it is important to understand how learning affects development. We incorporate all of these issues in our framework. Before describing our theoretical framework in greater detail, however, we briefly review some empirical findings that form the basis of the framework.

Empirical findings that motivated the theoretical framework—The grouping of elements into perceptual units (e.g., rows or columns) is a standard approach for studying how perceptual organization is achieved in different populations, including adults (Kimchi & Razpurker-Apfeld, 2004), neuropsychological patients with brain damage (Behrmann & Kimchi, 2003), and individuals with Williams syndrome (Farran, 2005). The initial study to test perceptual organization in infants via the row versus column methodology examined sensitivity to luminance similarity as a grouping cue (Quinn, Burke, & Rush, 1993). Three- to 4-month-olds were presented with rows or columns of squares that could be organized only on the basis of the lightness versus darkness of the elements, and then tested with horizontal versus vertical bars (see Fig. 2). The rationale is that if the organization in the row and column arrays is apprehended, then infants familiarized with columns should prefer the novel horizontal bars and infants familiarized with rows should prefer the novel vertical bars. The findings provided positive evidence for the use of lightness similarity: infants preferred the orientation of bars that was oppositely organized relative to the array of elements presented during familiarization. Control conditions demonstrated that performance was due to luminance similarity rather than to other factors such as inability to discern separate image elements. These results indicated that infants as young as 3 months of age are sensitive to the classic grouping principle of luminance similarity (Wertheimer, 1923). Farroni, Valenza, Simion, and Umilta (2000) reported that infants as young as newborns utilize luminance similarity to organize visual patterns. The combined outcomes suggest an early onset of the ability to perceptually organize visual images using luminance similarity, and imply an initial ability to use this cue to draw boundaries between objects.

Subsequent research suggests that young infants are sensitive to a variety of organizational principles, including common region (Bhatt, Hayden, & Quinn, 2007), connectedness (Hayden, Bhatt, & Quinn, 2006), good continuation (Quinn & Bhatt, 2005a; Quinn, Brown, & Streppa, 1997; Quinn & Schyns, 2003; Quinn, Schyns, & Goldstone, 2006), and proximity (Quinn, Bhatt, & Hayden, 2008b). These findings are consistent with other outcomes in the literature that suggest early competence in many basic perceptual organizational tasks such as figure-ground segregation, shape and size constancy, and discrimination of face-like structural qualities such as symmetry in images (for reviews, see Slater, 1998; Simion & Leo, 2009). The onset of a variety of organizational functions soon after birth is consistent with the Gestalt view of an innately specified ability to organize information based on certain cues.

A role for learning—While 3- to 4-month-olds readily organize based on luminance similarity (Quinn et al., 1993; see Fig. 2) and other cues, they fail to organize using shape similarity when tested in an identical manner. Quinn, Bhatt, Brush, Grimes, and Sharpnack (2002) familiarized 3- to 4-month-olds with rows or columns of Xs versus Os, and then tested them with horizontal versus vertical bars (Fig. 3). Infants failed to display a preference. A control experiment showed that infants were capable of discriminating between the familiar arrays shown in Fig. 3 and arrays that consisted entirely of Xs or Os.

Thus, the failure of the infants to use form similarity was not due to an inability to discriminate between the constituent X and O shapes. These results indicated that young infants failed to group on the basis of shape similarity. In contrast, identically tested 6- to 7-month-olds were able to organize using shape similarity (Quinn et al., 2002), indicating a developmental change in the ability to organize using shape cues. Thus, inconsistent with the Gestalt theorists' view, not all cues for perceptual organization are readily available to young infants.

Subsequent studies indicated, however, that even young infants can be induced to utilize shape cues to organize if provided with variation in the patterns used to the depict rows or columns. For example, Quinn and Bhatt (2005b) found that even 3- to 4-month-olds infants could be "trained" to group using shape similarity if they are exposed to multiple shape contrasts depicting a common organization during familiarization (rather than only one set as in Quinn et al., 2002).

These and other findings on the role of learning in perceptual organization in our studies (described below in greater detail) are consistent with other researchers' conclusions that specific experiences in the laboratory affect perceptual organization (e.g., Baillargeon, Li, Ng, & Yuan, 2009; Johnson, 2009; Johnson & Shuwari, 2009; Needham & Ormsbee, 2003). For example, Needham, Dueker, and Lockhead (2005) reported that 4.5-month-old infants are able to use a familiarization experience with different boxes to form a concept of "box" that is then used to parse a novel box from a cylinder-box display of adjacent objects, a finding that supports the more general idea that an individual's history of categorization (i.e., the concepts possessed by that individual at a specific point in time) will affect their subsequent object parsing abilities (Peterson, 2003). Likewise, Vishton, Ware, and Badger (2005) have reported that gestalt processing is affected by remembered information. Collectively, these investigations indicate that specific experiences can affect perceptual organization and development in infancy.

Theoretical Framework

The findings described above have motivated the current theoretical framework, the objective of which is to formulate an account of the role of learning on perceptual organization and development in infancy and to generate testable predictions. As we indicated earlier, this framework includes identification of the kinds of experiences that mediate perceptual learning in infancy, the nature of the mechanisms that underlie learning, the characteristics of learning, and a proposal for the manner in which learning induces developmental change.

According to Palmer (2003), image processing involves the identification of entry-level units (typically, uniformly connected figural regions or elements) and the subsequent grouping of these units into higher-level structures (gestalts) and/or the parsing of the units into subordinate-level units. Both parsing and grouping involve many computational steps, including the application of gestalt organizational principles, such as similarity, to the elements. He further suggest that, "In natural settings, grouping processes are probably more important" (p. 12) than parsing. In keeping with this logic, the majority of our work is concerned with the grouping of elements into higher-order gestalts. However, we also recognize the importance of subordinate-level organization, such as parsing of images (Bhatt, Hayden, Kangas, Zieber, & Joseph, 2010), and incorporate that into our framework.

In principle, perceptual learning may be induced by a wide variety of learning experiences that affect one or more of the many aspects of organization identified by Palmer (2003; see also Roelfsma, 2006), including the local features (elements), global gestalts, and the computational processes that are involved in grouping and parsing. However, the variety and complexity of grouping and parsing processes are such that many aspects of these perceptual functions are unknown (Palmer, 2003), and this prevents an a priori identification of all of the kinds of learning experiences that could affect organization in infancy. Consequently, our framework relies upon empirical demonstrations in the literature, including our own, to generate the kinds of learning experiences that affect perceptual organization in infancy.

Specifically, we have identified five kinds of experiences that induce perceptual learning in infancy: (1) Exposure to variability. For example, experiencing a variety of images that share the same global shape but have different elements that compose that shape may enhance attention to the global shape. (2) Experience of new organizational tasks in conjunction with already functional systems. For instance, as discussed below, infants learn to organize using shape similarity if this task is presented in conjunction with a luminance-based organization task that they readily complete. (3) Exposure to holistic images that need to be generated by the organizational process (which primes the infant to the end point of the organizational process). An example of such learning might be experience with vertical contours that induces infants to organize local elements into vertical columns. (4) Exposure to features that signal to the infant the local elements or parts in images. As discussed below, sometimes an image is organized differently (e.g., its part structure is changed) because of pre-exposure to features. (5) Experience with feature correlations. Correlated features can become higher-order “emergent features” that facilitate subsequent perceptual organization.[1]

In addition, we propose that two mechanisms, attentional enhancement and unitization, underlie the positive effects of learning on perceptual organization. By attentional enhancement, we mean an increased weighting of the critical information (e.g., the global structure of the stimulus) that underlies organization in a particular situation. Unitization refers to the process by which combinations of elements function as higher-order building blocks that facilitate perceptual organization. We also identify four characteristics of learning as they apply to the process of perceptual organization. In particular, we will argue that the learning that produces perceptual organization has an abstract nature, is domain general, qualitatively similar across ages, and produces long-term developmental effects. Altogether, this framework provides a road map for understanding how perceptual learning and development may occur early in life.

Kinds of Learning Experiences

Based on our prior research (Bhatt et al., 2007; Hayden et al., 2008; Quinn & Bhatt, 2005b, 2009b, 2010) and that of others (e.g., Baillargeon et al., 2009; Goldstone, 2003; Johnson, 2009; Needham et al., 2005; Saffran, 2009; Vishton et al., 2005; Wilcox & Woods, 2009), we propose that the following five categories of learning experiences “teach” infants to use different kinds of perceptual organization. Our view is that these modes of learning are not necessarily mutually exclusive. In other words, specific learning episodes in infancy may concurrently incorporate more than one of these kinds of experiences.

[1]The fact that perceptual learning in our framework can be affected by multiple levels of perceptual information (i.e., elemental features, featural units, organized wholes) is in keeping with arguments that the placement of elemental features with other elemental features can result in additional levels of perceptual information, e.g., corners, angles, forms (Enns & Prinzmetal, 1984; Stupina & Pomerantz, 2009). The reader may question how featural units or organized wholes may provide input to learning processes that produce perceptual organization when it is the formation of the featural units or organized wholes that we seek to explain. In the following section on “Kinds of Learning Experiences”, we describe cases where, for example, a featural unit that becomes diagnostic of a category through a history of category learning can function as a unit in organizations of novel stimuli (i.e., novel instances of the category). In addition, organized wholes formed via the application of a functional grouping principle (i.e., lightness similarity) can provide input into the learning of an organized whole via a not yet functional grouping principle (i.e., form similarity). In this way, then, higher levels of perceptual information can both provide input to and be the output of learning processes that produce perceptual organization.

1. Variability exposure—Recall that Quinn et al. (2002) found that 3- to 4-month-olds are unable to organize using shape similarity whereas 6- to 7-month-olds are able to (Fig. 3). Quinn and Bhatt (2005b) found that even 3- to 4-month-olds organize using shape similarity if provided with experience with variable arrays (Fig. 4). That is, if infants were exposed to only one pair (X-O, square-diamond, or H-I) during familiarization, they failed to organize using shape similarity, but if they were exposed to all three pairs, then 3- to 4-month-olds did organize based on shape similarity. This result suggests that 3- to 4-month-olds can be "instructed" to use shape similarity to organize elements by providing varied examples with which to abstract the invariant arrangement of the pattern. Thus, variability facilitates perceptual organization based on shape similarity in young infants and enables them to exhibit more developmentally advanced organizational functions.

The facilitating effects of variability have been documented for different kinds of stimuli and in other domains also. Needham et al. (2005) found that 4.5-month-old infants are able to use a familiarization experience with different boxes to parse a novel box from a cylinder-box display. In addition, in the language domain, variability in sequences of speech sounds enhances toddlers' performance to learn nonadjacent dependencies (Gomez 2002). Similarly, Slater, Mattock, and Brown (1991) found that newborns can represent the angular relations between line segments if exposed to varying exemplars of the same angular relation. In addition to these empirical findings about the effects of variability, theorists have long argued that variability allows the developing organism to hone in on functionally critical invariants in the environment. For instance, Gibson (1969) suggested that exposure to variation engendered by exploratory activities allows infants to perceive new and relevant environmental information. Thus, we incorporate in our framework exposure to variability as a key mode of perceptual learning.

2. Experience of new organizational tasks in conjunction with already functional systems—Spelke (2000) stated that "core systems serve as building blocks for the development of new cognitive skills" (p. 1233). Thus, according to Spelke, new knowledge can be derived by building upon prior knowledge. For instance, a young infant who has noticed the unity of an object because of common movement of its parts (an innate competency, according to Spelke; but see Johnson , 2009; Slater, Johnson, Brown, & Badenoch, 1996; Slater et al., 1990) might then notice that the different parts of the object also share other commonalities, like color and texture. This will then enable the infant to subsequently utilize these cues to organize novel objects (see also Zuckerman & Rock, 1957). We propose that a similar scaffolding process engenders learning by enabling infants to group based on a new cue using an already functioning organizational process.

An example of the facilitating effects of experience in conjunction with previously functional systems was documented by Quinn and Bhatt (2009b). Recall that 3- to 4-month-olds readily utilize luminance cues but not shape cues for perceptual grouping. Quinn and Bhatt (2009b) examined whether the already functioning luminance cue system can be used to scaffold young infants' use of shape cues. One group of infants was tested on a shape-shape task in which they were familiarized to columns/rows of Xs and Os and then tested with rows/columns of X and O shapes. Another group, the luminance-shape group, was familiarized to columns/rows of dark and light squares and then tested with X and O shapes organized as columns/groups (Fig. 5). As expected, the shape-shape group failed to exhibit evidence of organization, indicating that 3- to 4-month-olds ordinarily do not organize using shape cues. However, the luminance-shape group did exhibit systematic novelty preference during the test. These results indicate that infants were able to organize using shape similarity during the test, provided they were initially able to generate the global gestalts during familiarization using a more readily available system, namely the luminance similarity system. This work demonstrates that new organizational principles can be learned via bootstrapping onto already functioning organizational principles. It may also be worth pointing out that the notion of a bootstrapping process is consistent with contemporary Bayesian models of learning (e.g., Fiser, 2009; Orban, Fiser, Aslin, & Lengyel, 2008), which suggest that organisms learn based on previously experienced probabilities. Exposure to a new organizational task in conjunction with an already functional system may "teach" infants to use hitherto unutilized cues to organize by focusing their attention on the probability of prevalence of organizational structures (such as vertical entities) in an environment as indicated by the already functioning system.

3. Exposure to holistic images—There are several examples of the facilitating effects of priming on perceptual organization in the infant and adult literatures (e.g., Baillargeon et al., 2009; Behrmann & Kimchi, 2003; Johnson & Shuwari, 2009; Wilcox & Woods, 2009). For instance, Johnson and Shuwari found that, while 4-month-olds do not normally anticipate the correct position of an object moving along a trajectory if its movement is partially occluded, they can be "trained" to anticipate correctly if prior to being tested they are exposed to a fully visible object moving along the trajectory.

We propose that such exposure can facilitate gestalt grouping also. Priming the final state of an organizational process by pre-exposing infants to the holistic image that is end-point of the organizational process might facilitate the subsequent generation of global gestalts from local elements. For instance, we predict that pre-exposing infants to global vertical/horizontal bars (i.e., holistic images that do not need to be generated by grouping local elements) will enable 3- to 4-month-old infants to organize rows/columns of shapes Xs and Os, although infants this age do not ordinarily use shape similarity to group elements (Quinn et al., 2002).

4. Exposure to features—While priming of the end-state of an organizational task can facilitate organization, we also believe that the features that are used to organize an image (i.e., the local elements that are the subject of the organizational process) can be affected by learning. For example, Wilcox and Chapa (2004) found that exposing infants to events in which differently colored objects are engaged in different functions allowed them to subsequently use color to individuate objects. Thus, the manner in which an image is organized in a particular situation might be affected by prior exposure to component features (also see Baillargeon et al., 2009; Schyns & Rodet, 1997).

The effect of pre-exposure to parts of an image on subsequent perceptual organization is illustrated in a series of studies by Quinn, Schyns, and Goldstone. Quinn and Schyns (2003) first familiarized 3- and 4-month-olds to a number of complex figures, examples of which are shown in the top portion of Fig. 6. 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. 6. The infants were found to recognize the circle as familiar as evidenced by their novelty preference for the pacman shape. This finding suggests that the infants had parsed the circle from the complex figures in accord with good continuation.

In follow-up experiments, Quinn and Schyns (2003; see also Quinn, Schyns, & Goldstone, 2006) asked whether an invariant feature abstracted during category learning would modify the subsequent organization of an image. The experiments consisted of two parts. In Part 1, the infants were familiarized with multiple exemplars, each marked by an invariant pacman shape, and were subsequently administered a novelty preference test that paired the pacman shape with the circle shape (Fig. 7).The pacman shape was recognized as familiar, as evidenced by a preference for the circle shape. Part 2 of the procedure was then administered and it simply followed the design of Experiment 1 (Fig. 6). The expectation was that if the category learning from Part 1 of the procedure, in particular, the representation of the invariant pacman shape, can modify the perceptual organization that was observed in Experiment 1, then the preference for the pacman shape that was observed in Experiment 1 should no longer be observed. In fact, if the representation of the pacman shape carries over from Part 1 to Part 2 of the procedure, one would expect the opposite result, that is, the infants should continue to prefer the circle. The latter result is what was observed, suggesting that pre-exposure to parts of an image (1) entered into a perceptual system's working "featural" vocabulary and, (2) became available to subsequent object recognition processes. Thus, an individual's history of exposure to particular features or parts of images can affect their subsequent perceptual organization (see Yoshida et al., in press, for a possible analog in the domain of audition/language).

5. Exposure to feature correlations—In addition to individual features, exposure to correlated features or other groupings of features may affect subsequent perceptual organization. Such exposure can lead to the formation of emergent features or units that then function as perceptual primitives. For instance, Shiffrin and Lightfoot (1997) found that correlated presentations of line segment features allow adults to form higher-level characters that are speedily detected in subsequent visual search tasks. Statistical learning studies show that infants are sensitive to spatiotemporal correlations in visual and auditory domains (Fiser, 2009; Fiser & Aslin, 2002; Kirkham, Slemmer, & Johnson, 2002; Saffran, 2009). Similarly, 3-month-olds are sensitive to "what-goes-with-what" relations between features (Bhatt & Rovee-Collier, 1994, 1996, 1997; also see Younger & Cohen, 1983).

Examples of this kind of learning in gestalt grouping tasks were found by Bhatt et al. (2007) and by Hayden et al. (2008). In Bhatt et al.'s (2007) study of 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 (Fig. 8). 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 of Bhatt et al. (2007) and Hayden et al. (2008) suggest a feature binding process by which previously disparate elements become grouped and begin to function as coherent units in new contexts (see also Feigenson & Halberda, 2008; Goldstone, 1998, 2003; Vickery & Jiang, 2009). Thus, learning can determine the higher order units that get organized in subsequent episodes. It is additionally worth noting that the learning of the correlated features may in at least some of these instances be facilitated by the deployment of Gestalt organizational principles. For example, in Bhatt et al. (2007) and Hayden et al. (2008), the correlation of the features was determined by the application of the common region principle (Palmer, 1992). Similarly, in the adult literature in both the vision and language domains, statistical learning is facilitated by the proximity, similarity, and connectedness of the elements to be learned (Baker, Olson, & Behrmann, 2004; Gebhart, Newport, & Aslin, 2009).

Learning Mechanisms

While the five kinds of learning proposed above indicate the kinds of experiences that allow infants to learn perceptual grouping, they do not indicate the mechanisms that mediate learning. By mechanisms, we mean learning-induced changes in the basic perceptual functions that underlie grouping. We believe that it is important to specify these changes in order to fully comprehend the role of learning in perceptual development in infancy. We propose that the following two mechanisms underlie the facilitating effects of learning on perceptual organization.

1. Attention to relevant information—Gibson (1966) argued that "the ultimate goal of perception is differentiation, the reducing of uncertainty" (p.361). She further suggested that "the effective stimulus which active and educated perception picks out is a reduced stimulus. It is extracted, filtered out" (p.361). A similar notion that perceptual learning involves increasing attention to relevant aspects of stimuli and decreasing attention to irrelevant aspects was put forth by Goldstone (2003) when he stated that one way perceptual learning occurs is "…by increasing attention to perceptual features that are important, or by decreasing attention to irrelevant dimensions or features, or both" (p. 241).

Several current models of the development of perceptual functions such as spatiotemporal completion and event perception posit a key role for attention. For instance, Johnson and his colleagues (Amso & Johnson, 2006) have shown that performance on visual completion tasks is related to attention as measured by performance on visual search tasks. Similarly, visual scanning is systematically related to spatial completion (Johnson, Slemmer, & Amso, 2004). These and other such findings led Johnson (2009) to conclude that the development of spatial completion is an experience-based process in which "… infants learn … via visual selective attention" (p. 59). Similarly, based upon findings that infants can be primed to include variables that they normally do not use when assessing physical events, Baillargeon et al. (2009) conclude that "… the development of infants' physical reasoning involves primarily learning what information to attend to…" (p. 99).

We hypothesize a similar role for attention as a mechanism of learning in our framework, and posit that learning of gestalt grouping in infancy involves the enhancement of attention to organized global structures and the diminishment of attention to the local elements of displays. Recall that variability exposure (one of the types of learning experiences that we identified above) in Quinn and Bhatt (2005b) enabled young infants to group using shape similarity. Variability may have led to grouping because it enabled infants to attend more to the relevant global information and less to the irrelevant local elemental information. There is precedence in the categorization literature for such a possibility: With increasing variability in exemplars, categorization is enhanced, but memory for the exemplars is compromised (Quinn, 1987). That is, variability facilitates the acquisition of categorical knowledge by emphasizing what is common to categories and deemphasizing characteristics that are peculiar to individual exemplars.

We believe attentional enhancement can also be the mechanism underlying learning with the other kinds of experiences that we described earlier. For instance, exposure to a novel organizational task in the presence of an already functional system or to global images might enhance the infants' attention to the global information and make it more likely that the infant will organize the image in accord with this information. Likewise, exposure to features and feature correlations might enhance attention to them and facilitate subsequent organization of images that contain them.

Needless to say, the role of attention as a mechanism of learning needs to be independently verified. Such evidence may come from eye tracking studies that document the scanning of images by infants (e.g., do infants scan in a more holistic manner after being exposed to variability or to global images?). Evidence can also come from traditional behavioral studies: Are infants less likely to discriminate local elements after being exposed to variability, as would be predicted if variability experience induces them to attend more to global than to local elements?

2. Unitization—We propose unitization as another mechanism of perceptual learning (Goldstone, 2003). By unitization, we refer to the combination of low-level features to form higher-level emergent units that then function as independent features or “psychological primitives” (Pomerantz, 2003, 2006). Unitization allows faster and more efficient processing of information, such that a task that originally required the separate processing of a number of individual units is now accomplished by processing fewer higher-order units. For instance, literate adults respond to words as a whole rather that at the level of individual letters presumably because extensive practice with these words has combined the constituent letters into units that allow more efficient processing of information (Goldstone, 1998). Similarly, Goldstone (2003) suggests that combining components of objects into diagnostic higher-order units can facilitate recognition.

The notion of unitization is also part of some developmental theories. For instance, Cohen and his colleagues (Cohen, 2010; Cohen & Cashon, 2006) argue that a crucial aspect of infant perceptual behavior is the combination of lower-level elements to form higher-level units. This can happen within increasing experience within a particular age, but is also a characteristic of development. That is, older infants tend to function with higher-level units more than younger infants. Thus, according to Cohen (2010), unitization is a constructive process that drives both learning and development.

We posit that unitization also plays a role in gestalt grouping in infancy. Recall that, exposure to feature correlations, one of the kinds of learning experiences that our framework includes, enabled infants to acquire knowledge of correspondences between arbitrary shapes in Bhatt et al. (2007) and Hayden et al. (2008). In those studies, relations between elements were signaled by presentations in common or disparate regions during both habituation and test. Infants were able to discriminate whether the pairing of elements in common regions during the test did or did not match the pairings during habituation, thereby indicating sensitivity to correlations between elements.

Is this sufficient evidence of unitization? We do not think so. Infants may be aware of correlations between elements but they may not treat these element groups as units in subsequent organizational episodes. In our judgment, at the very least, there should be evidence that infants will generalize the grouping to novel organizational tasks. For instance, if elements A and B become grouped according to the principle of common region and thus unitized, then they should behave as a group according to another principle also, say proximity.

We tested this possibility with 6- to 7-month-old infants (Kangas, Bhatt, Hayden, & Quinn, 2009). They were familiarized to two pairs of shapes in different regions as in Bhatt et al. (2007) (see Fig. 9). Then, they were tested for their preference between a pattern in which the pairs maintain their association in terms of proximity versus a pattern in which the pairs exhibit the opposite association based on proximity. Infants exhibited a novelty preference, indicating that they generalized grouping induced by common region to grouping based on proximity. These results illustrate experience-based unitization in grouping tasks in infancy.

Other kinds of evidence of unit formation via learning in infancy remain to be explored. For instance, configural superiority effects have been used as an index of unitization (Pomerantz, 2003, 2006) in the adult literature. Configural superiority effects refer to faster and more accurate detection of units than the individual features that comprise the unit. The idea is that in order to claim that feature clusters function as psychological primitives they should behave as “glued” holistic units. Configural superiority effects have been demonstrated in infancy also. For example, Quinn and Eimas (1986) found that infants were superior at discriminating between triangles and arrows than between the differently oriented line elements that composed these global shapes, thereby indicating a global superiority effect. However, it is not clear whether infants' representation of the global triangles and arrow shapes in these studies were learned in the first place. That is, the representation could have been formed via deployment of already functional principles such as lightness similarity, good continuation, proximity, and closure (the latter in the case of the triangle). Thus, we are not aware of any study that has used configural superiority effects to demonstrate unit formation via learning in infancy.

Relations between selective attention and unitization—We have proposed two mechanisms that underlie the facilitating effects of learning on perceptual organization in infancy. One question that arises is how these mechanisms relate to each other. In our view, these mechanisms might work independently or in unison. Under some circumstances, selective attention to correlated occurrences of features might enhance the unitization process. For instance, being exposed to correlations between two features (say, shape and color: shape A being red always and shape B being blue always) in the context of other varying features (say, size: shapes A and B both appearing small and large in different trials) might focus infants' attention on the critical invariant feature correlations (between color and shape, in the example). Similarly, unit formation might enhance attention to a particular dimension and/or to other correlated groups of elements in an image. For example, noting the correlated occurrence of the shapes X and O in an image might induce infants to attend more to those shapes in the image and possibly even look for other shape combinations (Dewar & Xu, in press).

On the other hand, in principle, unitization could occur without an enhanced role of selective attention: infants might group features into higher-order units without necessarily attending any more to the features or their correlations than to other features and other correlations. We note that eye tracking studies might be useful in this regard. For example, will correlated features elicit more visual fixation than other features presented as frequently but not in a correlated manner? Similarly, attention might function independently of unit formation: infants might organize elements because of enhanced attention in a particular situation but the global organization may not function as a unit in novel situations. For instance, infants might note the correlation between a color and a shape because of enhanced attention to these features induced by variability in a particular context, but this correlation may not be subsequently processed as a unit in a different context.

We thus view attention and unitization as separate mechanisms that together or individually mediate the learning of perceptual grouping in infancy. This notion of independent mechanisms is consistent with findings in adults that attention and grouping affect each other under certain conditions but function independently under other conditions (for a review, see Kimchi, 2009).

Characteristics of Perceptual Learning in Infancy

Thus far we have proposed modes of learning and learning mechanisms in our theoretical framework. However, many issues concerning learning and perceptual development remain unaddressed. For example, is learning domain specific (e.g., is the learning that we have already demonstrated with shape cues also possible with color cues)? Do infants at different ages exhibit similar kinds of learning? How does learning translate into different kinds of behavior at different ages? These and other such key questions have to be answered before it is possible to comprehensively understand the role of learning in perceptual organization and its development.To this end, we augment our theoretical framework by hypothesizing that the perceptual learning process in infancy has the following characteristics.

1. Perceptual learning is abstract—Wilcox and Woods (2009) suggest that infant learning can be highly specific. In one study, they found that priming with colors subsequently enables infants to individuate objects only if the colors used during priming are the same as those subsequently used during the individuation event. In other words, infants in their studies could not be primed to generally attend to colors.

However, many studies report more general learning by infants. For instance, infants learn abstract same/different concepts (Tyrrell, Zingaro, & Minard, 1993) and other kinds of abstract rules (Marcus, et al., 1999). In our own studies (Bhatt et al., 2007; Hayden et al., 2008), we found that infants generalize pairings from one kind of region (e.g., vertical) to another kind of region (e.g., horizontal), thereby indicating a certain level of abstract functioning in perceptual organization. Additionally, shape similarity seems to be learned most readily when different element contrasts (i.e., X-O, H-I, square-diamond) are used to depict a given organization, i.e., rows vs. columns (Quinn & Bhatt, 2005b), thereby suggesting that the organization formed is not limited to a particular element contrast. Moreover, Kangas et al. (2009) found that infants generalize grouping based on common region to grouping based on proximity. Based on these latter studies, we propose that learning in the service of perceptual organization is flexible enough to go beyond highly specific aspects of experiences.

2. Perceptual learning is domain-general—In the area of event knowledge, Baillargeon et al. (2009) suggest that learning about variables that affect events is highly specific to different categories. They argue that "a variable identified in one event category is not generalized to another category, even when equally relevant; rather it is learned independently in another category" (p. 80) (see also Quinn, Adams, Kennedy, Shettler, & Wasnik, 2003).

Hitherto, the majority of our studies on perceptual learning in infancy have involved shape-based processing. Given the specificity of learning that other researchers such as Baillargeon and Wilcox have discovered (discussed above), one question that arises is whether similar kinds of perceptual learning will be evident in other domains also, such as color-based grouping. Our view is that it is unlikely that our species would have evolved to have learning mechanisms that are so specific as to be confined to just one domain such as shape. This view is buttressed by the fact that other kinds of perceptual learning appear to be general. For instance, Saffran, Pollak, Seibel, and Shkolnik (2007) found that infant rule learning is not specific to language. Similarly, statistical learning has been observed in a variety of domains, including visual, auditory, and touch (Fiser,2009). Thus, we hypothesize that perceptual learning of the sort that we have already documented in the case of shape-based organization will be available in other domains also.

3. Perceptual learning is qualitatively similar across ages in infancy—Older infants generally learn faster than younger infants in many situations[2], although there is little evidence of qualitative differences in learning mechanisms (e.g., Gibson, 1969; Hill, Borovsky, & Rovee-Collier, 1988; Quinn, 2008). We are not aware of any studies that have examined developmental differences in perceptual learning in the context of grouping. However, we hypothesize that there are unlikely to be qualitative differences in perceptual learning, and hence propose that similar perceptual learning modes and mechanisms will be available at different ages. Specifically, we predict that the kinds of learning and the learning mechanisms that we have proposed in this framework will be evident across ages in infancy. This prediction does not deny that older infants have a greater level of knowledge

[2]Examples of perceptual narrowing, i.e., cases in which older infants learn more slowly than younger infants, would be an important exception (e.g., Kelly et al., 2007; Pascalis, de Haan, & Nelson, 2002; Werker & Tees, 1983).

and may in some instances be able to acquire knowledge more quickly than younger infants, but we do not expect any qualitative differences in the sense of a complete absence of learning at one age versus another.

Recent evidence obtained by Quinn and Bhatt (2010) is consistent with this expectation. As background, 6- to 7-month-olds exhibit a novelty preference when familiarized to columns/ rows of Xs and Os and tested with horizontal and vertical bars (Quinn et al., 2002). However, they fail to organize if familiarized to vertical/horizontal bars and tested with columns/rows of Xs and Os (Quinn & Bhatt, 2006; see Fig. 10). This asymmetry in performance is likely due to the fact that infants in the elements→ bars version of the task have extended exposure to the elements during familiarization and are able to construct the holistic gestalts, whereas those in the bars→elements version of the task see the elements only during two 10-s test trials. Quinn and Bhatt (2010) examined whether variability in the stimuli used to depict the bars in the bars→elements version of the task will enable 6- to 7-month-olds to organize using shape similarity. They obtained an affirmative answer to this question: Infants exposed to three different kinds of bars during familiarization exhibited a novelty preference with columns/rows of elements, whereas those exposed to only one kind of bar during familiarization failed to exhibit a preference. Thus, variability enhanced 6- to 7-month-olds' grouping based on shape similarity. This is similar to the learning induced in 3- to 4-month-olds by variability experience in Quinn and Bhatt (2005b).These studies therefore suggest that similar kinds of learning may be evident at different ages in infancy.

4. Perceptual learning has long-term effects on organization and mediates development—For learning to be a viable vehicle for perceptual development, it has to have sustained and long-term effects on infants' behavior. Research suggests that infants 3 months of age and older can have surprisingly robust memories, with retention lasting several weeks and months (Courage & Howe, 2004; Fagan, 1973; Rovee-Collier, 1999; Rovee-Collier & Cuevas, 2008). We propose, therefore, that perceptual learning in infancy will have long-term effects on organization.

We further posit that *memory reactivation* is a mechanism by which perceptual learning mediates development by engendering long-term facilitative effects on visual organization. Memory reactivation refers to a process in which an apparently forgotten memory is reinstated by a brief exposure to aspects of the original learning experience (Campbell & Jaynes, 1966; DeFrancisco & Rovee-Collier, 2008; Rovee-Collier, Sullivan, Enright, Lucas, & Fagen, 1980; Spear, 1973). It has been proposed as a mechanism by which memories are sustained for long durations and thereby allow learning to affect development.

Johnson and Shuwairi (2009) recently found that a reactivation experience can reinstate the facilitating effects of priming on a predictive tracking task. They based their study on the finding that 4-month-olds fail to track an object if its trajectory is partially occluded. If infants are pre-exposed to an unobstructed view of the object's trajectory, they subsequently are able to track accurately even if the trajectory is partially occluded. This priming effect is lost if there is a 30-min delay between the pre-exposure and the test. If, however, infants are provided a brief reminder of the priming prior to being tested, they then recover and exhibit accurate tracking. Thus, reactivation prolonged the effects of training on a perceptual task.

In accord with the Johnson and Shuwari (2009) findings, we propose that memory reactivation is a mechanism by which the effects of perceptual learning persist for long durations in infancy and mediate development. Thus, we suggest that repeated learning experiences with a variety of objects and events in the everyday environment combined with reactivation of learning experiences result in a cumulative transformation that results in different organizational behaviors in older infants.

Limitations and Challenges

Like some prior models of perceptual organization (e.g., Baillargeon et al., 2009; Johnson, 2009; Spelke, 1982), our framework incorporates the idea that development in infancy originates from core competencies. For example, we assume that the infant comes into the world with the ability to use certain cues to generate global gestalts. This assumption is validated by the finding by Farroni et al. (2000) that newborns use luminance similarity to discern column/row arrangements. However, the use of most gestalt cues has been documented only with infants as young as 3 months (Quinn et al., 2008), and has not been tested with newborns. Consequently, there is a lack of a clear picture of what is available at birth and what is not. Documentation of the competencies available at birth, changes in these competencies, and the onset of “new” competencies would better constrain models of learning. For instance, some competencies may have a late onset because they require more attentional resources, apply to fewer objects in the typical environment of the infant, and/or apply to ecologically less relevant objects. Models of learning could take such factors into account in specifying the kinds of experiences that would facilitate the onset of these competencies. But for this theoretical progress to occur, we need to first know more about which principles are functional at birth and which are not, and their developmental trajectories.

Another limitation of the framework is the lack of specification of the boundary conditions for learning processes. Consider variability exposure. Quinn and Bhatt (2010) found that 6- to 7-month-olds benefit from variability if it is experienced sequentially across trials but not if it is experienced simultaneously within trials. Thus, not all kinds of variability experiences are equally effective in inducing learning: the manner in which variability is experienced, its packaging (sequential versus simultaneous), determines learning. Quinn and Bhatt (2010) suggest that sequential variability experience (i.e., trial-to-trial changes in local elemental information presented against an invariant global organization) focuses infants’ attention on the global information that is necessary for them to derive the holistic gestalts, but simultaneous variability experience does not. This example of the limitations of variability points to the need for a systematic specification of the boundary conditions for the functioning of various aspects of learning included in our framework.

It should also be noted that the kinds of learning experiences that we incorporated into our framework were derived from empirical studies. A better understanding of the computational processes involved in organization may allow for a more systematic formulation of the kinds of experiences that induce learning (e.g., Gerganov, Grinberg, Quinn, & Goldstone, 2007). For instance, if it is established that a class of organizational tasks involves a particular kind of information and a particular algorithm for the use of this information, then one could postulate the kinds of experiences that could affect the encoding of the information and the operation of the algorithm.

The social environment should be another consideration for models of perceptual learning. Meltzoff et al. (2009) have argued that, “Learning is social… Social cues highlight what and when to learn” (p. 285, see also Wu & Kirkham, 2010). Many perceptual and cognitive functions such as imitation, face processing, and language learning are inherently social. Cultural differences exhibited by adults, such as Westerners’ tendency to attend to figures in images and East Asians’ tendency to attend to context (Ambady & Bharucha, 2009), suggest that some basic perceptual functions are also affected by the social environment. In addition, there is some evidence that holistic object recognition is facilitated by object name learning (Smith, 2009).These observations and data suggest that perceptual grouping might also be subject to such influences. Consequently, the effects of the social environment need to be incorporated into models of perceptual development in infancy.

A final issue that concerns not only our framework but also other models of perceptual learning is the lack of specification of how learning functions in the natural environment of the infant. Many demonstrations of learning in infant perception studies involve very minimal experience. For example, 3- to 4-months-olds in Quinn and Bhatt (2005b) learned to use shape similarity to organize information with less than 2 min of exposure to variability. If infants in laboratory tasks are so easily trained, why is it that this kind of training did not occur in the infant's typical environment? (If it had occurred, presumably, infants would not have exhibited an inability to function without this training.). Ultimately, we will have to tackle such issues in order to understand how learning and development actually occur in the real world.

Conclusion

We believe that the detailed manner in which our framework specifies the role of learning in perceptual organization provides both a model of how learning may affect development and a structure for further empirical analyses. However, we do not mean to ignore the contributions of biological constraints to the developmental process, which we have in fact emphasized in past writings (Quinn & Bhatt, 2009a; Quinn et al., 2008). We believe that ultimately it will be found that mechanisms of learning work interactively with maturational factors to drive development. For instance, selective attention to relevant cues in a grouping task, which we have proposed as a key mechanism of perceptual learning, may benefit from maturation of the parietal cortex circuits that have been associated with basic attentional processes (Amso & Johnson, 2009; Schlesinger, Amso, & Johnson, 2007).

Indeed, the starting point for our framework is innate capacities. We believe that the human infant comes into the world prepared to organize environmental information using some core processes. These provide an initial platform upon which the infant can build more sophisticated organizations later in life, learning to organize using cues that they originally do not readily use (Quinn & Bhatt, 2009b). In this respect, our framework is consistent with other theories of perceptual development (e.g., Amso & Johnson, 2009; Baillargeon et al., 2009; Johnson, 2009; Johnson & Morton, 1991; Spelke, 1982, 2000). In the domain of face-processing, for example, Johnson and Morton (1991) proposed that the initial biologically-specified *Conspec* face processing system is built upon by the experience-driven *Conlern* system, leading to the development of the mature face-processing network. Also, as stated earlier, Spelke (1982) proposed that perceptual completion using cues such as similarity develops via a bootstrapping mechanism from the core principles of common movement and connected surface.

To illustrate how our framework envisions the functioning of the perceptual learning system in infants, we provide the following examples based upon the findings that, whereas luminance cues are used to organize global gestalts even by newborns (Farroni et al., 2000), the use of shape cues to generate global gestalts is not readily evident even at 3 to 4 months of age (Quinn et al., 2002). An infant lying in her crib soon after birth might notice the columnar organization of the bars of the crib because of luminance differences between the bars and the gaps between them. She may then notice that alternate bars of the crib are composed of beads of different shapes. The constant juxtaposition of the local shape cues and global vertical organization discerned using luminance differences may allow her to begin to notice that the columnar organization parallels differences in local shape elements also. This relationship between the global and local shapes may then induce her to start organization based on the local shape cues themselves. Similarly, the infant might initially organize the different bushes or trees outside her window based on the luminance differences among their leaves (e.g., Holly bushes vs. Spirea bushes, or Dogwoods vs. Japanese Maples). In time, the infant might begin to notice that the luminance-based organization of the bushes is correlated with differences in the shapes of the leaves. Sufficient experience with these kinds of correlation may then enable her to start using shape cues themselves to organize other examples of these bushes, trees, and other kinds of objects. An experimental illustration of this idea comes from the demonstration that shape-based perceptual structure in young infants can be facilitated by presenting shape-based grouping tasks in the presence of luminance-based organization (Quinn & Bhatt, 2009b). Moreover, the infant's experience of a variety of objects that differ in terms of shape elements but whose global organization are roughly the same (e.g., vertical stacks of books, dishes, diapers, etc.) may tune the infant's attention toward the global organization, and act like the variability experiences provided to infants in Quinn and Bhatt (2005b) that enabled shape-based organization to be derived from multiple element contrasts.

As we described earlier, we hypothesize that such learning experiences are driven by changes in underlying mechanisms such as selective attention to the global organization of stimuli. Ultimately, these mechanisms may incur permanent changes, in the sense that, with increasing age, the infant may start to "automatically" attend to cues that they previously were not processing in the context of an organizational task. We believe that this kind of development is achieved by infants' repeated experience with a variety of cues and is aided by a potent mechanism that sustains memories for long durations, namely memory reactivation, which is achieved by re-experience of components of the original learning episode.

Our view is that these kinds of learning-based changes are not confined to the first few months of age but continue into at least the second half of the first year of life (and possibly well into childhood and even adolescence; e.g., Hadad & Kimchi, 2006; Hadad, Maurer, & Lewis,2010; Kimchi, Hadad, Behrmann, & Palmer, 2005; Kovacs, 2000; Scherf, Behrmann, Kimchi, &Luna, 2009; Smith, 2009). In this way, the infant begins to build upon learning experiences in a cumulative manner across stimulus domains and organizational tasks. With greater experience and age, this learning allows the human infant to solve in an increasingly mature manner the fundamental organizational problem identified earlier: How does one convert the sensory information from the complex environment of continuous surfaces around us into coherent objects with which we can functionally interact?

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References

Ambady N, Bharucha J. Culture and the brain. Current Directions in Psychological Science. 2009; 18:342–345.

Amso D, Johnson SP. Learning by selection: Visual search and object perception in young infants. Developmental Psychology. 2006; 42:1236–1245. [PubMed: 17087555]

Amso, D.; Johnson, SP. Building object knowledge from perceptual input. In: Hood, BM.; Santos, L., editors. The origins of object knowledge. New York: Oxford University Press; 2009. p. 211-226.

Aslin, RN. The role of learning in cognitive development: Challenges and prospects. In: Needham, A.; Woodward, A., editors. Learning and the Infant Mind. New York: Oxford University Press; 2009. p. 286-295.

Baillargeon, R.; Li, J.; Weiting, N.; Yuan, S. An account of infants' physical reasoning. In: Needham, A.; Woodward, A., editors. Learning and the infant mind. New York: Oxford University Press; 2009. p. 66-116.

Baillargeon R, Spelke ES, Wasserman S. Object permanence in five-month-old infants. Cognition. 1985; 20:191–208. [PubMed: 4064606]

Baker C, Olson C, Behrmann M. Role of attention and perceptual grouping in visual statistical learning. Psychological Science. 2004; 15:460–466. [PubMed: 15200630]

Behrmann M, Kimchi R. What does visual agnosia tell us about perceptual organization and its relationship to object perception? Journal of Experimental Psychology: Human Perception and Performance. 2003; 29:19–42. [PubMed: 12669745]

Bhatt RS, Hayden A, Kangas A, Zieber N, Joseph JE. Part perception in infancy: Sensitivity to the short-cut rule. Attention, Perception, & Psychophysics. 2010; 72:1070–1078.

Bhatt RS, Hayden A, Quinn PC. Perceptual organization based on common region in infancy. Infancy. 2007; 12:147–168.

Bhatt RS, Rovee-Collier C. Perception and 24-hour retention of feature relations in infancy. Developmental Psychology. 1994; 30:142–150.

Bhatt RS, Rovee-Collier C. Infant's forgetting of correlated attributes and object recognition. Child Development. 1996; 67:172–187. [PubMed: 8605826]

Bhatt RS, Rovee-Collier C. Dissociation between features and feature relations in infant memory: Effects of memory load. Journal of Experimental Child Psychology. 1997; 67:69–89. [PubMed: 9344488]

Brunswik E, Kamiya J. Ecological cue validity of 'proximity' and other gestalt factors. American Journal of Psychology. 1953; 66:20–32. [PubMed: 13030843]

Campbell BA, Jaynes J. Reinstatement. Psychological Review. 1966; 73:478–480. [PubMed: 5976739]

Cohen, LB. A bottom-up approach to infant perception and cognition: A summary of evidence and discussion of issues. In: Johnson, SP., editor. Neoconstructivism: The new science of cognitive development. New York: Oxford University Press; 2010. p. 335-346.

Cohen, LB.; Cashon, CH. Infant Cognition. In: Damon, W.; Lerner, RM.; Kuhn, D.; Siegler, RS., editors. Handbook of child psychology: Vol 2 Cognition, Perception, and Language. 6. New York: Wiley; 2006. p. 214-251.

Courage ML, Howe ML. Advances in early memory development: Insights about the dark side of the moon. Developmental Review. 2004; 24:6–32.

DeFrancisco BS, Rovee-Collier C. The specificity of priming effects over the first year of life. Developmental Psychobiology. 2008; 50:486–501. [PubMed: 18551465]

Dewar K, Xu F. Induction, overhypothesis, and the origin of abstract knowledge: Evidence from 9-month-old infants. Psychological Science. in press.

Elman, JL.; Bates, EA.; Johnson, MH.; Karmiloff-Smith, A.; Parisi, D.; Plunkett, K. Rethinking innateness: A connectionist perspective on development. Cambridge, MA: MIT Press; 1996.

Enns JT, Prinzmetal W. The role of redundancy in the object-line effect. Perception & Psychophysics. 1984; 35:22–32. [PubMed: 6709471]

Fagan JF. Infants' delayed recognition memory and forgetting. Journal of Experimental Child Psychology. 1973; 16:424–450. [PubMed: 4771431]

Farran EK. Perceptual grouping ability in Williams syndrome: evidence for deviant patterns of performance. Neuropsychologia. 2005; 43:815–822. [PubMed: 15721194]

Farroni T, Valenza E, Simion F, Umilta C. Configural processing at birth: Evidence of perceptual organization. Perception. 2000; 29:355–372. [PubMed: 10889944]

Feigenson L, Halberda J. Conceptual knowledge increases infants' memory capacity. Proceedings of the National Academy of Sciences. 2008; 105:9926–9930.

Fiser J. Perceptual learning and representational learning in humans and animals. Learning and Behavior. 2009; 37:141–53. [PubMed: 19380891]

Fiser J, Aslin RN. Statistical learning of new visual feature combinations by infants. Proceedings of the National Academy of Sciences. 2002; 99:15822–15826.

Gebhart AL, Newport EL, Aslin RN. Statistical learning of adjacent and nonadjacent dependencies among non-linguistic sounds. Psychonomic Bulletin & Review. 2009; 16:486–490. [PubMed: 19451373]

Gerganov, A.; Grinberg, M.; Quinn, PC.; Goldstone, RL. Simulating conceptually-guided perceptual learning. In: McNamara, DS.; Trafton, JG., editors. Proceedings of the Twenty-ninth Annual

Conference of the Cognitive Science Society. Austin, TX: Cognitive Science Society; 2007. p. 287-292.

Gibson EJ. Perceptual development and the reduction of uncertainty. Proceedings of the 18th International Congress of Psychology. 1966:355–363.

Gibson, EJ. Principles of perceptual learning and development. New York, NY: Meredith Corporation; 1969.

Goldstone RL. Perceptual learning. Annual Review of Psychology. 1998; 49:585–612.

Goldstone, RL. Learning to perceive while perceiving to learn. In: Kimchi, R.; Behrmann, M.; Olson, CR., editors. Perceptual organization in vision: Behavioral and neural perspectives. Mahwah, NJ: Erlbaum; 2003. p. 223-278.

Goldstone, RL.; Gerganov, A.; Landy, D.; Roberts, ME. Learning to see and conceive. In: Tommasi, L.; Peterson, M.; Nadel, L., editors. The new cognitive sciences. Cambridge, MA: MIT Press; 2008. p. 163-188.

Gomez RL. Variability and detection of invariant structure. Psychological Science. 2002; 13:431–436. [PubMed: 12219809]

Hadad BS, Kimchi R. Developmental trends in utilizing perceptual closure for grouping of shape: Effects of spatial proximity and collinearity. Perception & Psychophysics. 2006; 68:1264–1273. [PubMed: 17378413]

Hadad BS, Maurer D, Lewis TL. The development of contour interpolation. Journal of Experimental Child Psychology. 2010; 106:163–176. [PubMed: 20227089]

Haith MM. Who put the cog in infant cognition? Is rich interpretation too costly? Infant Behavior & Development. 1998; 21:167–179.

Hayden A, Bhatt RS, Quinn PC. Perceptual organization based on illusory regions in infancy. Psychonomic Bulletin & Review. 2008; 15:443–447. [PubMed: 18488666]

Hebb, DO. The organization of behavior. New York: Wiley; 1949.

Hill WH, Borovsky D, Rovee-Collier C. Continuities in infant memory development over the first half-year. Developmental Psychobiology. 1988; 21:43–62. [PubMed: 3338627]

Johnson, MH.; Morton, J. Biology and cognitive development: The case of face recognition. Oxford, UK: Blackwell; 1991.

Johnson, SP. The role of learning in cognitive development: Challenges and prospects. In: Needham, A.; Woodward, A., editors. Learning and the infant mind. New York: Oxford University Press; 2009. p. 286-295.

Johnson, SP. Perceptual completion in infancy. In: Johnson, SP., editor. Neoconstructivism: The new science of cognitive development. New York: Oxford University Press; 2010. p. 47-65.

Johnson SP, Shuwairi SM. Learning and memory facilitate predictive tracking in 4-month-olds. Journal of Experimental Child Psychology. 2009; 102:122–130. [PubMed: 18448114]

Johnson SP, Slemmer JA, Amso D. Where infants look determines how they see: Eye movements and object perception performance in 3-month-olds. Infancy. 2004; 6:185–201.

Jusczyk PW, Aslin RN. Infants' detection of the sound patterns of words in fluent speech. Cognitive Psychology. 1995; 29:1–23. [PubMed: 7641524]

Kagan JL. In defense of qualitative changes in development. Child Development. 2008; 79:1606–1624. [PubMed: 19037935]

Kangas, AR.; Bhatt, RS.; Hayden, AN.; Quinn, PC. Grouping of elements generalizes across Gestalt organizing principles: Evidence for a perceptual unitization process in infancy; 2009, April; Poster presented at the meeting of the Society for Research in Child Development; Denver, CO.

Kelly DJ, Quinn PC, Slater AM, Lee K, Ge L, Pascalis O. The other-race effect develops during infancy: Evidence of perceptual narrowing. Psychological Science. 2007; 18:1084–1089. [PubMed: 18031416]

Kimchi R. Perceptual organization and visual attention. Progress in Brain Research. 2009; 176:15–33. [PubMed: 19733747]

Kimchi R, Hadad B, Behrmann M, Palmer SE. Microgenesis and ontogenesis of perceptual organization: Evidence from global and local processing of hierarchical patterns. Psychological Science. 2005; 16:282–290. [PubMed: 15828975]

Kimchi R, Razpurker-Apfeld I. Perceptual grouping and attention: Not all groupings are equal. Psychonomic Bulletin & Review. 2004; 11:687–696. [PubMed: 15581119]

Kirkham NZ, Slemmer JA, Johnson SP. Visual statistical learning in infancy: evidence for a domain general learning mechanism. Cognition. 2002; 83:B35–B42. [PubMed: 11869728]

Koffka, K. Principles of Gestalt psychology. New York: Harcourt, Brace & World; 1935.

Kohler, W. Gestalt psychology. New York: Horace Liveright; 1929.

Kovacs I. Human development of perceptual organization. Vision Research. 2000; 40:1301–1310. [PubMed: 10788641]

Marcus GF, Vijayan S, Rao SB, Vishton P. Rule learning by seven-month-old infants. Science. 1999; 283:77–80. [PubMed: 9872745]

Meltzoff AN, Kuhl PK, Movellan J, Sejnowski TJ. Foundations for a new science of learning. Science. 2009; 325:284–288. [PubMed: 19608908]

Meltzoff AN, Moore MK. Imitation of facial and manual gestures by human neonates. Science. 1977; 198:75–78. [PubMed: 17741897]

Needham A, Baillargeon R. Effects of prior experience on 4.5-month-old infants' object segregation. Infant Behavior and Development. 1998; 21:1–24.

Needham A, Dueker GL, Lockhead G. Infants' formation and use of categories to segregate objects. Cognition. 2005; 94:215–240. [PubMed: 15617672]

Needham, A.; Ormsbee, SM. The development of object segregation during the first year of life. In: Kimchi, R.; Behrmann, M.; Olson, CR., editors. Perceptual organization in vision: Behavioral and neural perspectives. Mahwah, NJ: Erlbaum; 2003. p. 205-232.

Newcombe, NS. What is neoconstructivism?. In: Johnson, SP., editor. Neoconstructivism: The new science of cognitive development. New York: Oxford University Press; 2010. p. v-viii.

Orban G, Fiser J, Aslin RN, Lengyel M. Bayesian learning of visual chunks by human observers. Proceedings of the National Academy of Sciences. 2008; 105:2745–2750.

Palmer SE. Common region: A new principle of perceptual grouping. Cognitive Psychology. 1992; 24:436–447. [PubMed: 1516361]

Palmer, SE. Vision science: Photons to phenomenology. Cambridge, MA: MIT Press; 1999.

Palmer, SE. Perceptual organization and grouping. In: Kimchi, R.; Behrman, M.; Olson, C., editors. Perceptual organization in vision: Behavioral and neural perspectives. Hillsdale NJ: Erlbaum; 2003. p. 3-43.

Pascalis O, de Haan M, Nelson CA. Is face processing species-specific during the first year of life? Science. 2002; 14:199–209.

Peterson, MA. On figures, grounds, and varieties of surface completion. In: Kimchi, R.; Behrmann, M.; Olson, CR., editors. Perceptual organization in vision: Behavioral and neural perspectives. Mahwah, NJ: Erlbaum; 2003. p. 87-116.

Pomerantz JR. Wholes, holes, and basic features in vision. Trends in Cognitive Sciences. 2003; 7:471–473. [PubMed: 14585437]

Pomerantz JR. Color as a Gestalt: Pop out with basic features and with conjunctions. Visual Cognition. 2006; 14:619–628.

Pomerantz, JR.; Stupina, AI. Simple gestalts: Emergent features in two-line stimulus space; 2009, November; Paper presented at the 50th Annual Meeting of the Psychonomic Society; Boston, MA.

Quinn PC. The categorical representation of visual pattern information by young infants. Cognition. 1987; 27:145–179. [PubMed: 3691024]

Quinn PC. In defense of core competencies, quantitative change, and continuity. Child Development. 2008; 79:1633–1638. [PubMed: 19037937]

Quinn PC, Adams A, Kennedy E, Shettler L, Wasnik A. Development of an abstract category representation for the spatial relation BETWEEN in 6- to 10-month-old infants. Developmental Psychology. 2003; 39:151–163. [PubMed: 12518816]

Quinn PC, Bhatt RS. Object recognition and object segregation in infancy: Historical perspective, theoretical significance, "kinds" of knowledge, and relation to object categorization. Journal of Experimental Child Psychology. 2001; 78:25–34. [PubMed: 11161420]

Quinn PC, Bhatt RS. Good continuation affects discrimination of visual pattern information in young infants. Perception & Psychophysics. 2005a; 67:1171–1176. [PubMed: 16502839]

Quinn PC, Bhatt RS. Learning perceptual organization in infancy. Psychological Science. 2005b; 16:515–519.

Quinn PC, Bhatt RS. Perceptual organization in infancy: Bottom-up and top-down influences. Optometry and Vision Science. (Special Issue on Infant and Child Vision Research: Present Status and Future Directions). 2009a; 86:589–594.

Quinn PC, Bhatt RS. Transfer and scaffolding of perceptual grouping occurs across organizing principles in 3- to 7-month-old infants. Psychological Science. 2009b; 20:933–938. [PubMed: 19538436]

Quinn PC, Bhatt RS. Learning perceptual organization in infancy: The effect of simultaneous versus sequential variability experience. Perception. 2010; 39:795–806. [PubMed: 20698474]

Quinn PC, Bhatt RS, Brush D, Grimes A, Sharpnack H. Development of form similarity as a Gestalt grouping principle in infancy. Psychological Science. 2002; 13:320–328. [PubMed: 12137134]

Quinn, PC.; Bhatt, RS.; Hayden, A. What goes with what? Development of perceptual grouping in infancy. In: Ross, BH., editor. Psychology of Learning and Motivation. Vol. 49. San Diego: Elsevier; 2008a. p. 105-146.

Quinn PC, Bhatt RS, Hayden A. Young infants readily use proximity to organize visual pattern information. Acta Psychologica. 2008b; 127:289–298. [PubMed: 17643382]

Quinn PC, Brown CR, Streppa ML. Perceptual organization of complex visual configurations by young infants. Infant Behavior & Development. 1997; 20:35–46.

Quinn PC, Burke S, Rush A. Part-whole perception in early infancy: Evidence for perceptual grouping produced by lightness similarity. Infant Behavior & Development. 1993; 16:19–42.

Quinn PC, Eimas PD. Pattern-line effects and units of visual processing in infants. Infant Behavior & Development. 1986; 9:57–70.

Quinn PC, Schyns PG. What goes up may come down: Perceptual process and knowledge access in the organization of complex visual patterns by young infants. Cognitive Science. 2003; 27:923–935.

Quinn PC, Schyns PG, Goldstone RL. The interplay between perceptual organization and categorization in the representation of complex visual patterns by young infants. Journal of Experimental Child Psychology. 2006; 95:117–127. [PubMed: 16797025]

Roelfsema PR. Cortical algorithms for perceptual grouping. Annual Review of Neuroscience. 2006; 29:203–227.

Rovee-Collier C. The development of infant memory. Current Directions in Psychological Science. 1999; 8:80–85.

Rovee-Collier, C.; Cuevas, K. Infant memory. In: Byrne, JH.; Roediger, H., editors. Learning and memory: A comprehensive reference Vol 2: Cognitive psychology. Oxford, UK: Elsevier; 2008. p. 687-714.

Rovee-Collier C, Sullivan MW, Enright MK, Lucas D, Fagen JW. Reactivation of infant memory. Science. 1980; 208:1159–1161. [PubMed: 7375924]

Saffran, JS. What can statistical learning tell us about infant learning?. In: Needham, A.; Woodward, A., editors. Learning and the infant mind. New York: Oxford University Press; 2009. p. 29-46.

Saffran JR, Pollak SD, Seibel RL, Shkolnik AÂ. Dog is a dog is a dog: Infant rule learning is not specific to language. Cognition. 2007; 105:669–680. [PubMed: 17188676]

Scherf KS, Behrmann M, Kimchi R, Luna B. Emergence of global shape processing continues through adolescence. Child Development. 2009; 80:162–177. [PubMed: 19236399]

Schlesinger M, Amso D, Johnson SP. The neural basis for visual selective attention in young infants: A computational account. Adaptive Behavior. 2007; 15:135–148.

Schyns PG, Rodet L. Categorization creates functional features. Journal of Experimental Psychology: Learning, Memory & Cognition. 1997; 23:681–696.

Shiffrin, RM.; Lightfoot, N. Perceptual learning of alphanumeric-like characters. In: Goldstone, RL.; Schyns, PG.; Medin, DL., editors. The Psychology of Learning and Motivation. Vol. 36. San Diego: Academic Press; 1997. p. 45-82.

Simion, F.; Leo, I. A neoconstructivist approach to the emergence of a face processing system. In: Johnson, SP., editor. Neoconstructivism: The new science of cognitive development. New York: Oxford University Press; 2010. p. 314-332.

Slater, AM. The competent infant: Innate organization and early learning in infant visual perception. In: Slater, AM., editor. Perceptual development: Visual, auditory, and speech perception in infancy. East Sussex, UK: Psychology Press (Taylor & Francis); 1998. p. 105-130.

Slater A, Johnson SP, Brown E, Badenoch M. Newborn infants' perception of partly occluded objects. Infant Behavior and Development. 1996; 19:145–148.

Slater A, Mattock A, Brown E. Form perception at birth: Cohen and Younger (1984) revisited. Journal of Experimental Child Psychology. 1991; 51:395–406. [PubMed: 2072083]

Slater A, Morison V, Somers M, Mattock A, Brown E, Taylor D. Newborn and older infants' perception of partly occluded objects. Infant Behavior and Development. 1990; 13:33–49.

Smith LB. From fragments to geometric shape: Changes in visual object recognition between 18 and 24 months. Current Directions in Psychological Science. 2009; 18:290–294.

Spear NE. Retrieval of memory in animals. Psychological Review. 1973; 80:163–194.

Spelke, ES. Perceptual knowledge of objects in infancy. In: Mehler, J.; Garrett, M.; Walker, E., editors. Perspectives on mental representation. Hillsdale, NJ: Erlbaum; 1982. p. 409-430.

Spelke ES. Nativism, empiricism, and the origins of knowledge. Infant Behavior and Development. 1998; 21:181–200.

Spelke ES. Core knowledge. American Psychologist. 2000; 55:1233–1243. [PubMed: 11280937]

Spelke ES, Breinlinger K, Macomber J, Jacobson K. Origins of knowledge. Psychological Review. 1992; 99:605–632. [PubMed: 1454901]

Thiessen ED, Saffran JR. When cues collide: Use of statistical and stress cues to word boundaries by 7- and 9-month-old infants. Developmental Psychology. 2003; 39:706–716. [PubMed: 12859124]

Tyrrell D, Zingaro MC, Minard KL. Learning and transfer of identity-difference relationships by infants. Infant Behavior and Development. 1993; 16:43–52.

Vickery TJ, Jiang YV. Associative grouping: perceptual grouping of shapes by association. Attention, Perception, & Psychophysics. 2009; 71:896–909.

Vishton PM, Ware EA, Badger AN. Different Gestalt processing for different actions? Comparing object-directed reaching and looking time measures. Journal of Experimental Child Psychology. 2005; 90:89–113. [PubMed: 15683858]

Werker JF, Tees RC. Developmental change across childhood in the perception of non-native speech sounds. Canadian Journal of Psychology. 1983; 37:278–286. [PubMed: 6616342]

Wertheimer, M. Principles of perceptual organization. In: Beardslee, DC.; Wertheimer, M., editors. Readings in perception. Princeton, NJ: Van Nostrand; 1923/1958. p. 115-135.

Wilcox T, Chapa C. Priming infants to attend to color and pattern information in an individuation task. Cognition. 2004; 90:265–302. [PubMed: 14667698]

Wilcox, T.; Woods, R. Experience primes infants to individuate objects: Illuminating learning mechanisms. In: Needham, A.; Woodward, A., editors. Learning and the infant mind. New York: Oxford University Press; 2009. p. 117-143.

Woodward, AL.; Needham, A., editors. Learning and the infant mind. New York: Oxford University Press; 2009.

Wu R, Kirkham NZ. No two cues are alike: Depth of learning during infancy is dependent on what orients attention. Journal of Experimental Child Psychology. 2010; 107:118–136. [PubMed: 20627258]

Wynn K. Addition and subtraction by human infants. Nature. 1992; 358:749–750. [PubMed: 1508269]

Yoshida KA, Iverson JR, Patel AD, Mazuka R, Nito H, Gervain J, Werker JF. The development of perceptual grouping biases in infancy: A Japanese-English cross-linguistic study. Cognition. in press.

Younger BA, Cohen LB. Infant perception of correlations among attributes. Child Development. 1983; 54:858–867. [PubMed: 6617307]

Zuckerman CB, Rock I. A reappraisal of the roles of past experience and innate organizing processes in visual perception. Psychological Bulletin. 1957; 54:269–296. [PubMed: 13465923]

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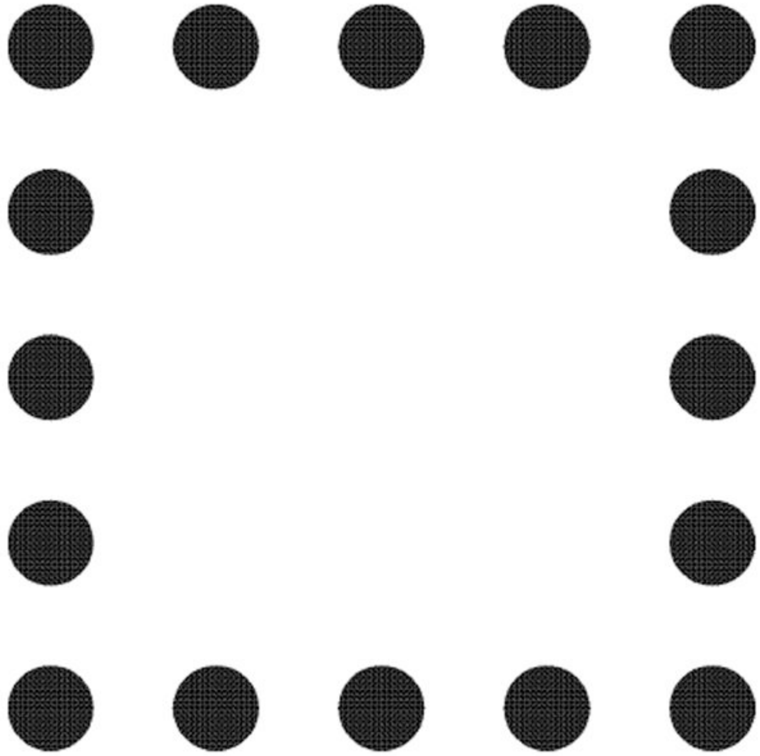

Figure 1.
A pattern of elements that adults organize into a “square” form.

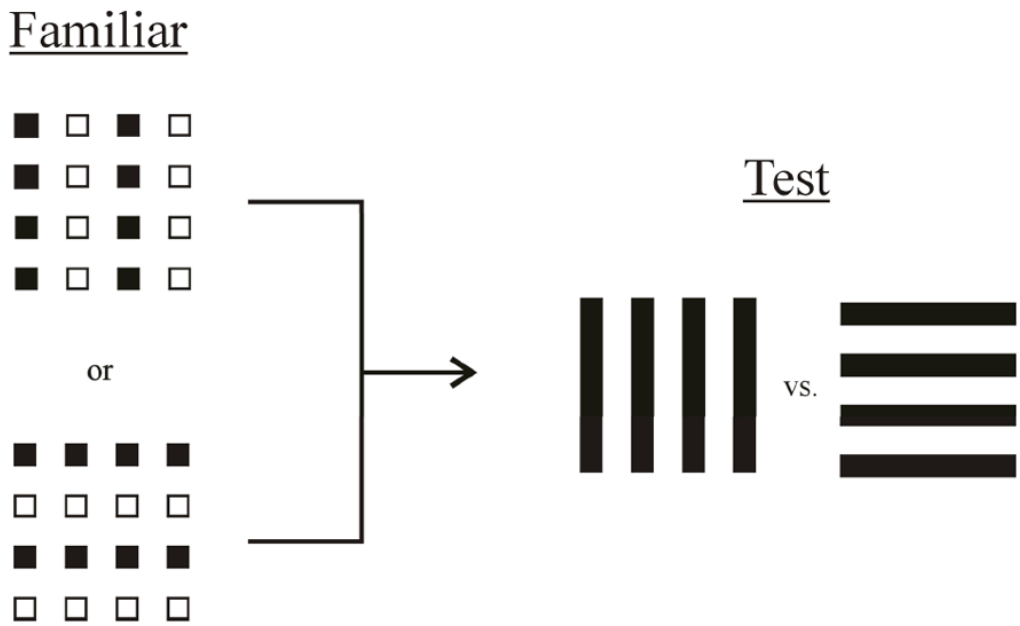

Figure 2.
Familiarization and test stimuli used in the Quinn et al. (1993) study investigating whether 3- to 4-month-olds can organize visual pattern information in accord with luminance similarity.

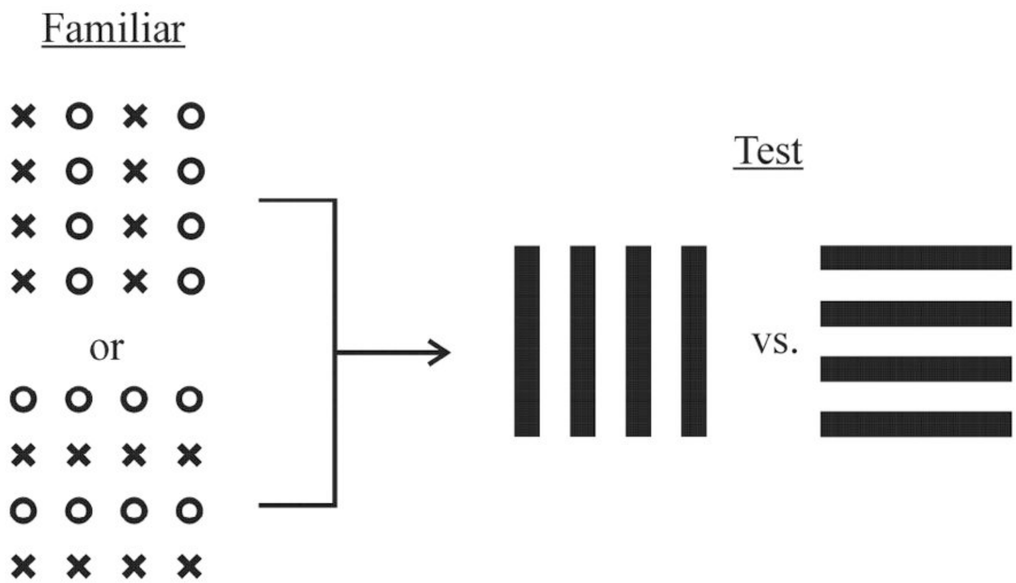

Figure 3.
Familiarization and test stimuli used in the Quinn et al. (2002) study that examined whether infants can organize visual pattern information in accord with shape similarity.

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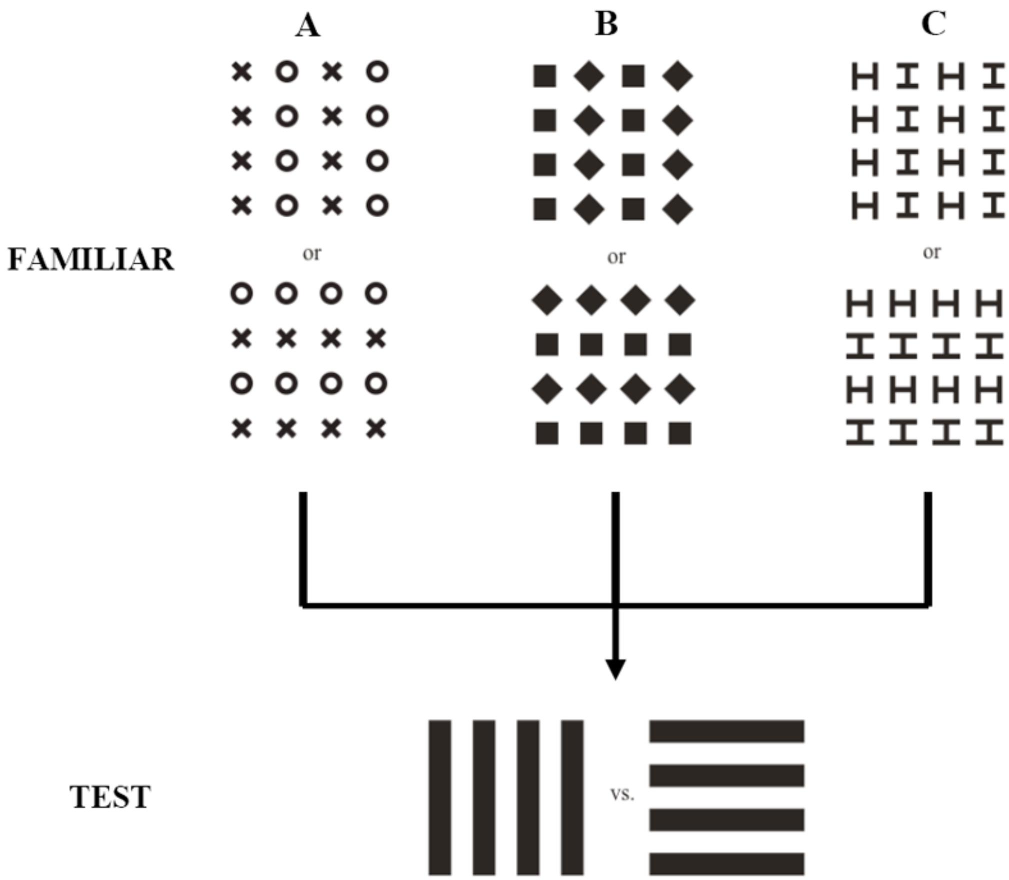

Figure 4.
Familiarization and test stimuli used in the Quinn and Bhatt (2005b) study investigating whether 3- to 4-month-olds can use shape similarity to organize visual patterns if exposed to variable shapes during familiarization. Infants in the single pair condition were familiarized to one of the pairs shown in panels A, B, and C, whereas those in the variable condition were familiarized to all three pairs.

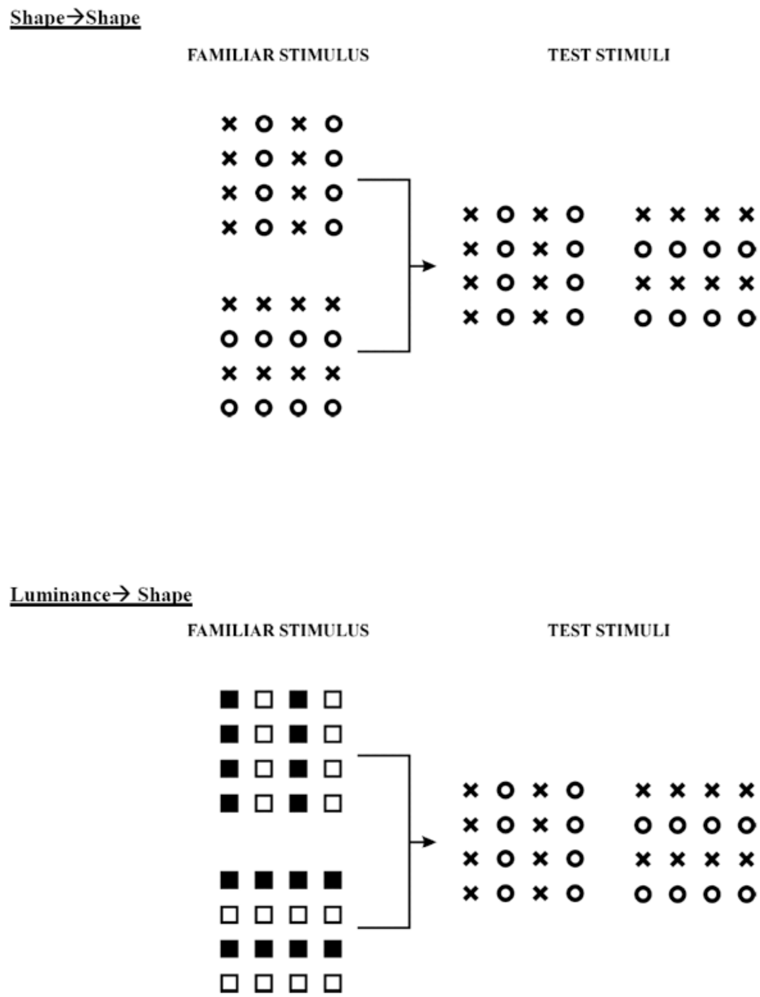

Figure 5.
Illustrations of the shape→shape and luminance→shape tasks presented to infants in Quinn and Bhatt (2009b) to examine whether infants will learn to use shape cues to organize if presented in the context of organization based on luminance cues.

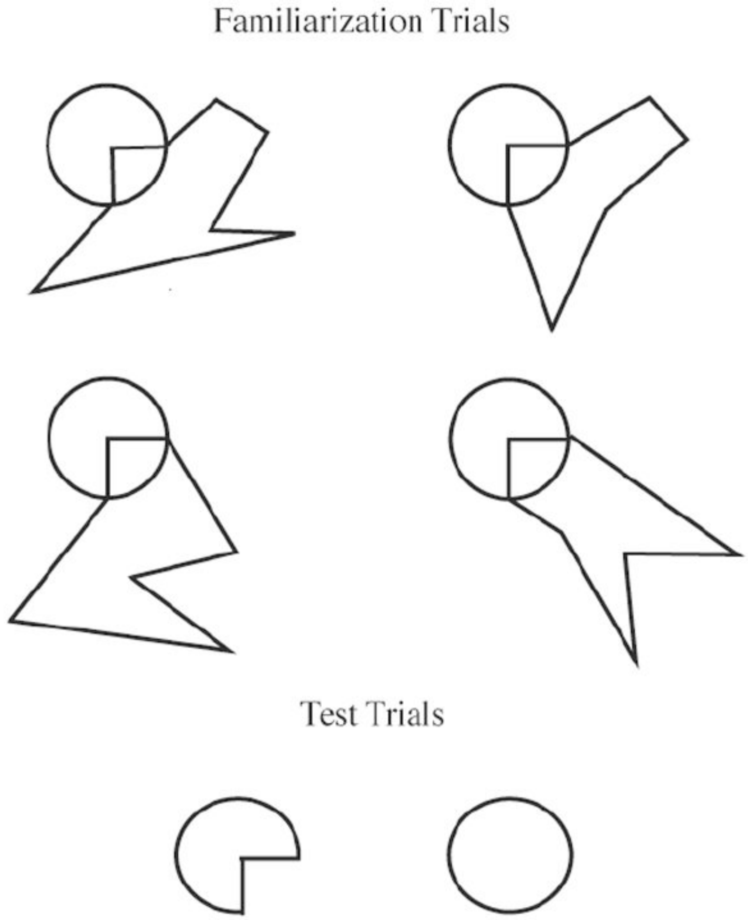

Figure 6.
Illustrations of the stimuli used by Quinn and Schyns (2003) to examine whether infants parse the circle shape in accord with the principle of good continuation.

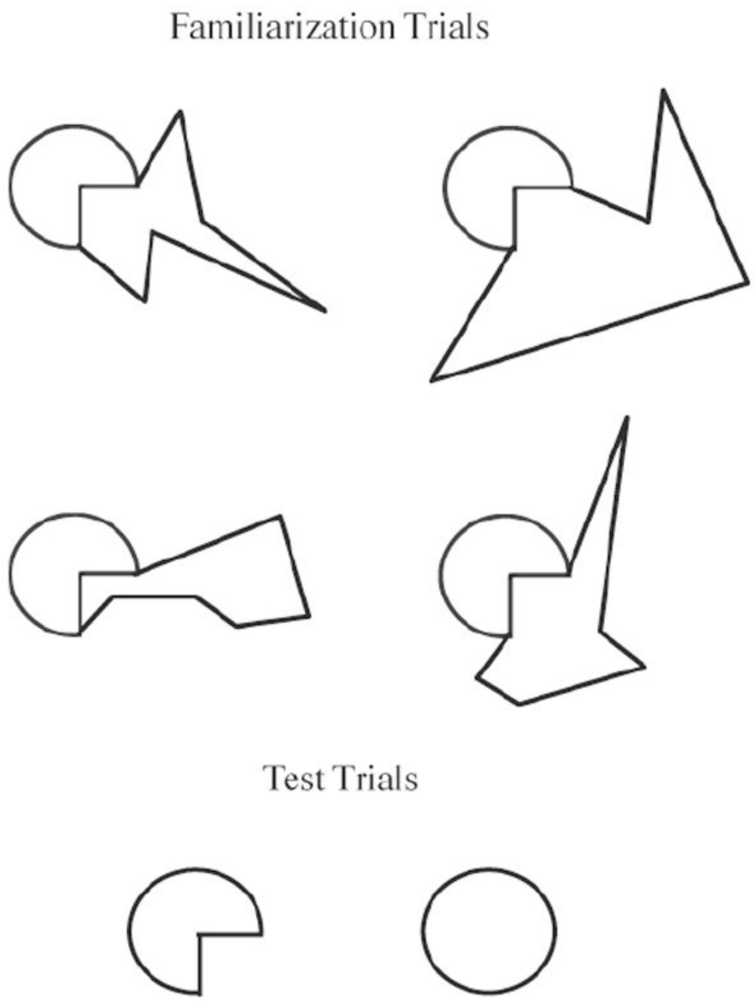

Figure 7.
Illustrations of the stimuli used by Quinn et al. (2006) to investigate whether exposing infants to novel features (pacman shape) causes them to parse images (shown in Fig. 6) in novel ways.

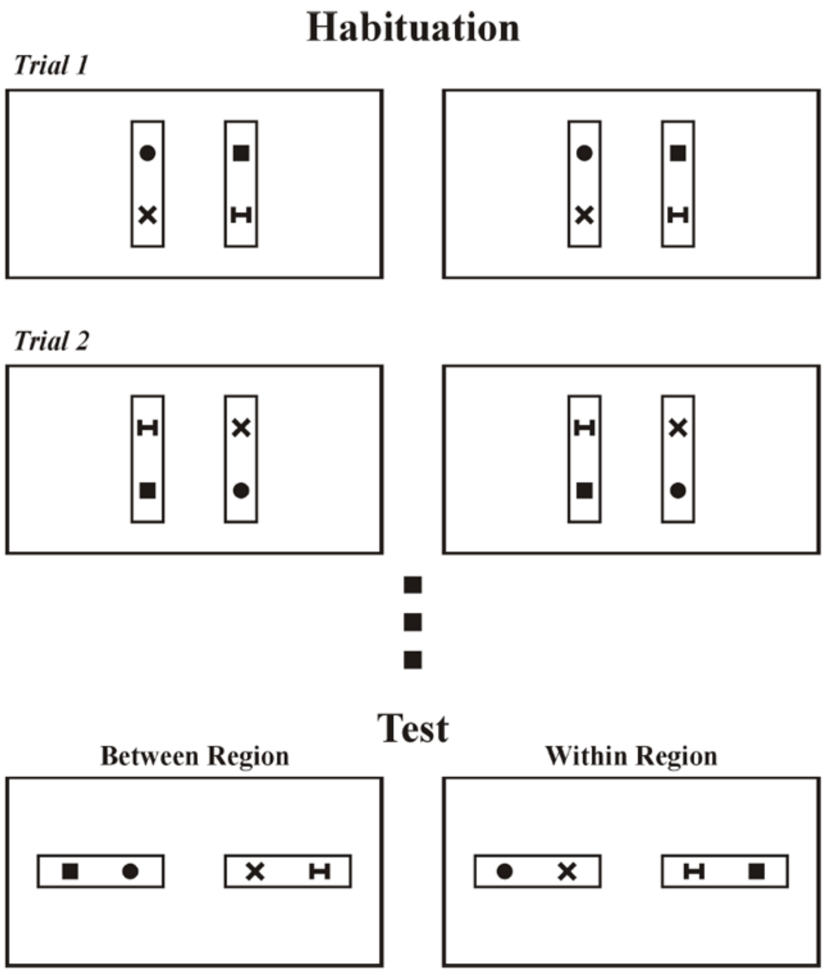

Figure 8.
Illustrations of the stimuli used by Bhatt et al. (2007) to examine organization based on common region.

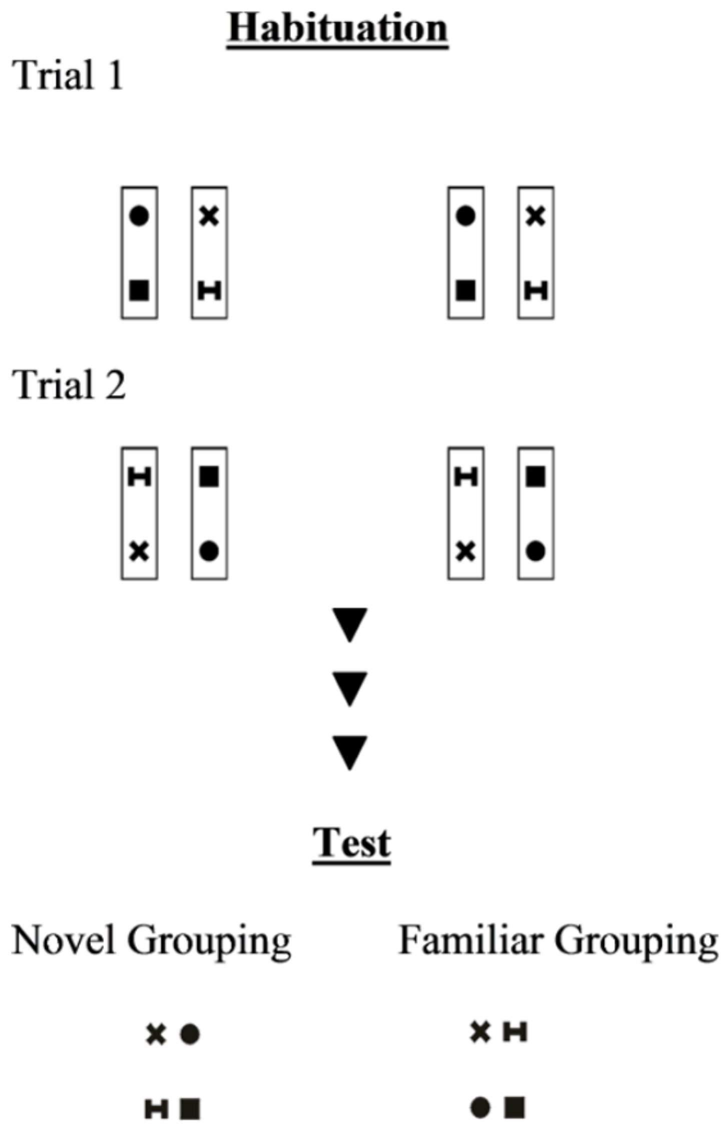

Figure 9.
Illustrations of the stimuli used by Kangas et al. (2009) to examine unitization as evidenced by transfer of grouping from common region to proximity.

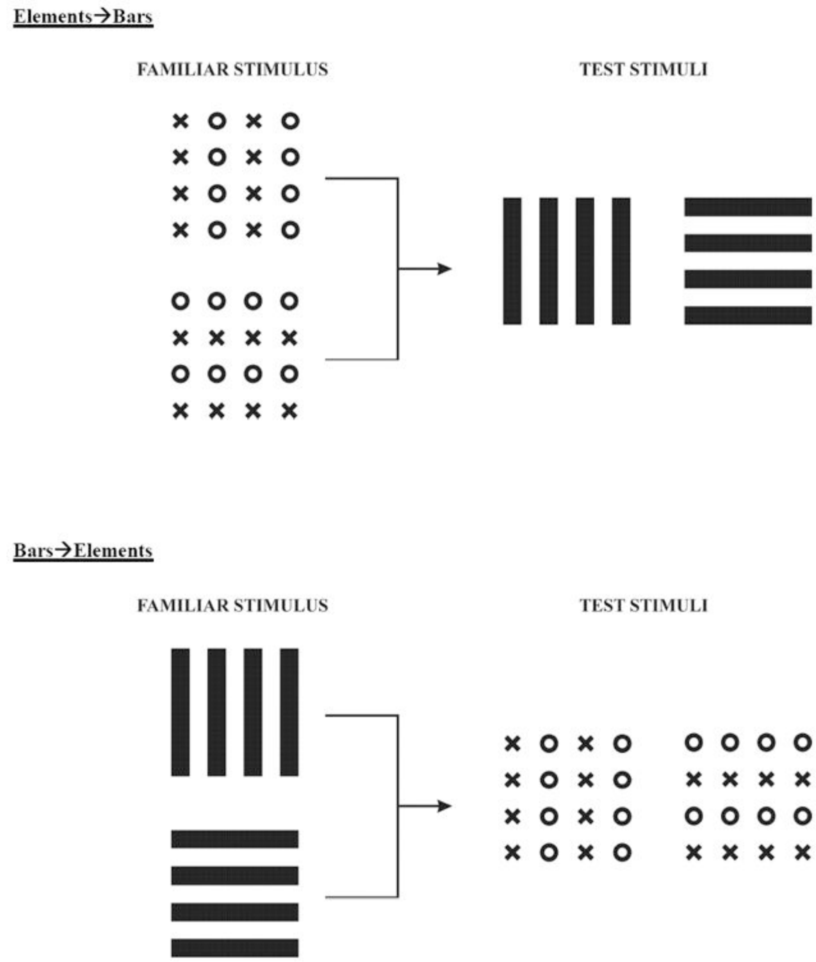

Figure 10.

Examples of the familiarization and test stimuli used by Quinn and Bhatt (2006) in elements → bars and bars → elements tasks to examine the nature of organization by shape similarity.