Published in final edited form as:
Infancy. 2011 ; 16(1): 61–68. doi:10.1111/j.1532-7078.2010.00056.x.

Different Approaches to the Study of Early Perceptual Learning

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Bhatt and Quinn (2011) review evidence indicating that learning plays a powerful role in the development of perceptual organization, and provide a theoretical framework for studying this process. The fact that prominent researchers in diverse areas of cognitive development and adult cognition have commented on this paper (Aslin, 2011; Goldstone, Son, & Byrge, 2011; Peterson, 2011) points to the centrality of learning as a contributor to the emergence of cognitive skills. These thoughtful commentaries identify areas of agreement with the Bhatt and Quinn (2011) framework, while also proposing different conceptualizations of the findings and alternative theoretical approaches to the study of learning in perceptual development. We respond to these commentaries in the following paragraphs.

ASLIN

Our framework of perceptual learning is based on the idea that many organizational processes may be acquired via experience (see Quinn & Bhatt, 2005, 2009; Quinn, Bhatt, & Hayden, 2008), which is contrary to the view of some Gestalt theorists that all principles of perceptual organization are innately specified. Aslin (2011) concurs with this notion, and suggests that demonstrations of rapid learning early in life illustrate this point. As we noted in our paper, one of the key gaps in our knowledge base is the lack of information about newborns' use of different Gestalt principles. Such information is necessary to indicate which perceptual processes are innately specified and which might be learned.

Another point of agreement between our framework and the model proposed by Aslin (2011) is the notion that learning provides flexibility in perceptual organization. For instance, the studies by Quinn, Schyns, and Goldstone (2006) discussed in Bhatt and Quinn (2011) show that what is treated as a perceptual feature (i.e., as a distinctive part of an image) in a particular situation may be influenced by prior experience.

Aslin (2011) suggests that a Bayesian approach might be a simpler alternative to our framework. The Bayesian approach has been quite successful in accounting for a variety of learning phenomena in both humans and animals (Fiser, 2009), and has become a powerful tool in psychology. It promises to be quite useful in the analysis of learning and development. We believe, however, that several issues need to be considered before one can decide whether the Bayesian approach or our framework better capture the data and whether they are actually competing models at the same level of analysis.

In generating our framework, we distinguished between learning experiences and mechanisms. We view *experiences*, such as variability exposure, as externally induced

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processes that enable infants to learn to organize. In contrast, *mechanisms* are hypothetical cognitive constructs that we believe mediate this learning. The Bayesian model proposed by Aslin (2011) does not distinguish between these possibilities. For instance, Aslin suggests that variability exposure and selective attention can both be captured by one construct in the Bayesian approach, namely, the weighting of information source in proportion to reliability. However, we believe that it is helpful to view *experiences* (external events interacting with the infant) that induce learning and *mechanisms* that underlie learning as separate entities. Such a distinction will enable us to manipulate experiences and test the functioning of the hypothetical mediating mechanisms.

It is also not clear whether the Bayesian approach as proposed by Aslin (2011) is truly simpler than our approach. There are many constructs in the Bayesian approach—identification of different kinds of information and information sources, reliability calculation, weighting of sources, hierarchical models, updating of priors, etc.—and it remains to be seen whether the totality of these mechanisms are more efficient in modeling perceptual learning in infancy than our framework.

Another issue is the assumption by the Bayesian approach that learning involves updating of priors based on new information acquired from experience. It is not clear, however, how this new information is acquired in the first place for it to become part of the probability equation. If the notion is that all theoretically possible kinds of organizations of a visual pattern are computed and then evaluated by the infant, then it quickly becomes too computationally intense to be plausible. Thus, some constraints are necessary. Gestalt principles of organization may be viewed as providing these constraints. They indicate ways in which the Bayesian problem might be reduced to manageable levels.

Gestalt psychologists suggested that these constraints are not acquired: They are inherent in the nature of the world and the makeup of the human brain. However, as we describe in Bhatt and Quinn (2011), empirical findings suggest that the Gestalt position is incorrect. Experience seems to be necessary for some of these constraints (principles of organization) to be functional.

Our framework tries to bridge the gap between the Gestalt and Bayesian perspectives by suggesting that infants acquire information by being exposed to several kinds of experiences, and by postulating mechanisms that drive learning and development. In this sense, we believe that it is better to view our framework as functioning at a different level of analysis than the Bayesian framework. Our framework is trying to model how infants at different ages begin to acquire information; the Bayesian approach as proposed by Aslin (2011) suggests how different kinds of information that are already available to the infants are used by them to organize and view the world.

It should be noted, however, that both our framework and the Bayesian approach have limitations. A key limitation is that neither predicts what is learned and what is innate. Our framework is based on empirical findings of perceptual learning early in life, for example, the fact that while 3- to 4-month-olds do not readily utilize shape similarity to organize, they can be “trained” to do so (Quinn & Bhatt, 2005). In contrast, even newborns appear to readily utilize luminance similarity to organize, suggesting an innate capacity (Farroni, Valenza, Simion, & Umilta, 2000). A more comprehensive model would include predictions about what is learned and what is innate early in life.

GOLDSTONE, SON, AND BYRGE

Goldstone et al. (2011) make the important point that the role of learning as envisioned in our framework and the work of other researchers (e.g., Johnson, 2010; Spelke, 1982)

suggests a strong interdependence between learning and innate mechanisms of development. Theorists have argued for a long time now that at least some innate organizational processes [what Goldstone et al. (2011, p. 45) call "evolutionary-scale learning"] must be functional early in life and provide a foundation upon which learning can build the apparatus for mature perceptual organization. For instance, Zuckerman and Rock (1957) write that, "At some point, the assumption of innate organizing principles must be made in order to explain how learning itself is possible" (p. 278). In Bhatt and Quinn (2011), we present evidence suggesting that some organizational processes (such as those based on luminance similarity) are functional soon after birth (Farroni et al., 2000). We then suggest that new organizational processes (such as those based on shape similarity) can be acquired by building upon these already functional processes via a bootstrapping process of the sort envisioned by Spelke (1982). Empirical support for this notion was obtained by Quinn and Bhatt (2009). Thus, our framework assumes a synergy between innate and learned processes, and is in accord with recent attempts to bring together evolutionary and developmental approaches into a common explanatory framework (Mareschal, Quinn, & Lea, 2010).

While agreeing with our proposal that attention and unitization processes function as mechanisms underlying perceptual learning in infancy, Goldstone et al. (2011) propose a third mechanism: attribute differentiation. They suggest that, in some instances, attribute differentiation might be a necessary precursor to attentional enhancement. In other words, an attribute has to be differentiated away from other attributes in order for it to be enhanced via an attentional process. We agree with this conception, although we did not emphasize attribute differentiation in our framework because (a) it was mostly focused on grouping processes, (b) empirical findings suggest that infants' lack of use of grouping cues is not due to an inability to discriminate relevant dimensions (for instance, although younger infants fail to group using shape similarity, they are sensitive to the relevant attribute, namely shape differences among the local elements [see Quinn, Bhatt, Brush, Grimes, & Sharpnack, 2002]), and (c) other theories of perceptual organization (e.g., Cohen, 2010) view perceptual development in infancy as involving greater holistic processing rather than differentiation.

A third major point made by Goldstone et al. (2011) is that given the significance of learning early in development as a powerful tool that affects cognitive function throughout life, adults might tend to rely on established knowledge, whereas infants might still be trying to discover that knowledge, and may thus be more likely to discern structure in patterns under certain circumstances. We agree. Empirical evidence suggests that in some domains, young infants have access to certain information that adults do not have ready access to. For instance, Pascalis, de Haan, and Nelson (2002) found that while 6-month-olds discriminate between monkey faces, older infants and adults do not, indicating a perceptual narrowing process. This kind of perceptual specialization and narrowing implies a broader receptivity in younger infants than older infants and adults to new information, suggesting a more flexible and learning-based perceptual world early in life.

PETERSON

Based upon the results of Quinn and Bhatt (2005), we had concluded that exposure to variability "instructs" younger infants to organize using shape similarity by triggering attentional mechanisms. Peterson (2011) identifies a conundrum here and asks how this instruction can happen if the infants do not have shape similarity in their repertoire of grouping cues. She suggests that it would be better to conceptualize the effects of variability as a facilitation of a "latent shape similarity based organization."

We agree that some basic level of capacity to organize based on shape similarity should be present even in younger infants. For instance, to use shape similarity to organize, infants

need to be able to discriminate between the local shapes. Quinn et al. (2002) found this to be the case: Younger infants discriminated between local elements even in displays in which they failed to generate global shapes using shape similarity.

However, it is not clear whether conceptualizing the role of variability as enhancing latent organization is truly an alternative to our formulation. This is because the notion of latent organization begs many of the same kinds of questions as the "learning" idea: Why is shape-based organization latent but not other kinds of organization (such as luminance-based)? How does experience allow a previously latent organization to be expressed? What are the mechanisms that underlie this latency unblocking process? Thus, although our learning notion conceptualizes infants' failure to respond to organization based on shape similarity as a failure to organize rather than as a "latent" organization that is overshadowed by competing organizations, both frameworks address similar issues. It remains to be seen therefore whether it will be possible to experimentally distinguish between our notion of learning and the idea of latent organization.

Peterson (2011) additionally suggests that it is not necessary to invoke attention as a mechanism that underlies learning of perceptual organization. Instead, it is proposed that differential weighting of different kinds of information might be a better conceptualization of the mechanisms underlying learning processes. The distinction between the concepts of "attention" and "differential weighting" boils down to the question of whether the enhanced weighting of one kind of information occurs at a cost to others (attention) or whether weighting can occur without differential levels of processing (differential weighting). That is, does enhanced weighting of some information alter sensitivity to other information (e.g., Eckstein, Drescher, & Shimozaki, 2006)? We agree that either attention or differential weighting (or some combination of the two) might underlie the facilitating effects of learning on perceptual organization in infancy. Future research will have to discriminate between the different possibilities.

Peterson (2011) wonders whether infants can simultaneously entertain more than one organization of a visual display. Quinn, Burke, and Rush (1993) found that infants discriminate between local square versus diamond shapes under conditions in which they are sensitive to luminance-based global structures provided by these elements. Hayden, Bhatt, and Quinn (2009) showed that infants can simultaneously entertain global organizations based on two different cues: When exposed to organization based on luminance and uniform connectedness cues, infants exhibited sensitivity to both kinds of organization (although organization based on luminance dominated the one based on connectedness). Thus, there is evidence indicating that infants are simultaneously sensitive to different kinds of organizations of visual displays.

Peterson (2011) further provides an alternative to our conclusion that the Quinn and Bhatt (2009) findings suggest a bootstrapping mechanism. She proposes that it may be better to view the facilitating effects of luminance-based organization on subsequent shape-based organization as a kind of priming induced by the context. However, empirical evidence argues against a priming interpretation. Quinn and Bhatt (2006) found that infants fail to organize using shape similarity during test trials after being exposed to vertical/horizontal bars during familiarization. In other words, infants who were directly exposed to global shapes during familiarization failed to group based on shape similarity during the test. Thus, it appears that a constructive process of grouping local elements during familiarization is necessary for infants to also group elements based on shape similarity during the test trials. This finding suggests that an explanation based on simple contextual priming does not account for the Quinn and Bhatt (2009) results.

FINAL REMARKS

We thank the commentators for their thoughtful and constructive critiques of our paper. The different approaches to perceptual learning (e.g., Bayesian), alternative theoretical constructs (e.g., attention versus differential weighting), and additions to our proposal (e.g., attribute differentiation) suggested by the commentators have enriched and challenged our thinking about perceptual learning in infancy. The collection of papers as a whole emphasizes the importance of the analysis of learning as a critical driver of development. We look forward to similar exchanges in the future.

Acknowledgments

Preparation of this manuscript was supported by NIH Grants HD-52724, MH-086958, and HD-46526.

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