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Infant Object Segregation Implies Information Integration

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Abstract

Researchers, including Needham (this issue), have found that infants as young as 4.5 months of age have the ability to use featural information to segregate objects. However, considerable research on infants' perception of color, shape, size, orientation, etc. has shown that infants younger than 4.5 months are capable of using these featural cues to discriminate between objects, or other test items. Infants as young as 2 months of age also can perceive a moving object as unified. In this paper, we argue for an information processing explanation of these results, which centers on the development of infants' ability to integrate both featural and object information. The proposed explanation is based upon Cohen's (1991, 1998) information processing propositions and is consistent with the evidence on object segregation, as well as evidence from our laboratory and others' on infant perception and cognition.

Object Segregation Implies Information Integration

An important question in infant cognition is how infants come to segregate objects, that is how they come to learn that one object is a unique entity, independent of the background or other objects. This question often is investigated by asking what physical properties the infant uses to distinguish one object from another. Of course, an equally important, related question asks about the developmental acquisition of object segregation. Just when are infants first able to segregate one object from another? In this paper we shall attempt to answer both of these questions.

One might assume a simple, straightforward approach to answering these questions would be to use the most common tool for investigating infant perception and cognition: habituation. Just habituate infants through repeated presentations of one object and then test the infants with that object versus a novel object. Assuming that at some age, but not at an earlier age, infants do in fact respond differentially to the two objects, we would appear to have answered the questions. Unfortunately, a simple approach is not always the best approach. Such a study certainly would show that at some age infants are able to discriminate between the two "entities" we presented, but not necessarily that they were treating the "entities" as objects. As Xu and Carey (1996) noted, to show that infants can individuate objects, or realize the number of objects present in an event, is a difficult task. To demonstrate this knowledge in infants, investigators must do more than provide evidence that infants can discriminate between two objects on the basis of physical properties. They also need to show that infants perceive the entities in question as objects so that they can test whether or not the objects are actually being segregated. Thus, the answer to the object segregation question requires evidence both that infants can tell the objects apart based upon differences in their properties and that infants are actually treating these "entities" as independent objects.

But how can one assess that these “entities” we present to infants are perceived as objects? Considerable evidence indicates that, for infants, the perception of “objectness” centers around the coordinated movement of the object’s parts. As Kellman and Spelke (1983) reported, the key to the young infant’s perception of objectness is the coordinated movement of an object's surface in relation to the background. This movement allows the infant to integrate what could appear to be independent parts into a single unified object and to determine if a complex combination of shapes is, in fact, one object, or more than one object (Hofsten & Spelke, 1985). We shall return to these seminal experiments later. For now, it is sufficient to note that as a consequence of trying to demonstrate both objectness and discrimination in their attempts to assess object segregation, researchers have had to resort to the use of complex displays that include multiply moving objects with different physical properties. In some cases, the objects disappear and then reappear from behind screens. In other cases, a hand picks up, shakes, and then moves one or more objects. In all cases the cognitive requirements of the task go well beyond the infant's ability to perceive an object as an object or to discriminate one object from another. For example, it is often assumed that the infants will be surprised by an impossible event or will expect something to happen when, in fact, something else happens. Given the complexity and variety of these tasks, it is little wonder that estimates of the earliest age of object segregation range widely from about 5 months to 11 or 12 months of age.

At one extreme, Xu and Carey (1996) reported that 12-, but not 10-month-olds, behaved in a way that showed they individuated objects. The procedure reported by Xu and Carey (1996) involved showing infants events in which one object moved behind an occluder, and then a different object emerged from the other side, after which the whole sequence continued in reverse. Then infants were shown test events in which either one or two objects were revealed. The basic assumption was that when infants were shown a test event that was considered to be “consistent” with the occlusion event, they should look less

than when they were shown an event that was considered “inconsistent” with the occlusion event. Thus, if the infants had reasoned correctly that there were two objects present in the first event, they should have been surprised in the test to see only one object, and thus look longer at that test event. Xu and Carey found that 12-, but not 10-month-olds, behaved in that way, and concluded that infants have to be 12 months of age before they can individuate objects.

Using different types of events, Wilcox and Baillargeon (1998) concluded that infants could use featural information to individuate objects earlier than Xu and Carey (1996) had claimed. They referred to Xu and Carey's procedure as "event-mapping" because infants were required to compare a representation from a previously seen occlusion event to a subsequent non-occlusion event and make a judgment about the consistency of one event with the next event. They asserted that because of the difficulty of these tasks, researchers might be able to demonstrate that younger infants are capable of this type of object individuation if simpler events were used. In fact, using what they termed as “event-monitoring” events, Wilcox and Baillargeon reported that infants much younger, as young as 7.5 months of age, could use featural information to determine whether there were one or two objects present. In one of their experiments, infants watched a ball go behind an occluder that was either narrow or wide, followed by a box that emerged from the other side of the occluder. It was reasoned that if infants 1) understood that two distinct objects were present, and 2) that two objects could fit behind the wide screen but only one behind the narrow screen, then infants should be surprised to see the ball change to the box in the narrow screen condition, but not the wide condition. According to Wilcox and Baillargeon, the important distinction between their events and those used by Xu and Carey is that, in their events, infants only had to determine whether one event was reasonable, not whether two separate events were consistent with one another. Thus, the difference in complexity between Xu and Carey’s event-mapping events and Wilcox and Baillargeon’s event-

monitoring events seems to have led to very different results and a much earlier estimate of object individuation in the Wilcox and Baillargeon study. In fact, in a more recent set of experiments, Wilcox (1999) reported finding that 4.5-month-old infants can use both size and shape as cues to individuate objects, 7.5-month-olds can use pattern, and 11.5-month-old infants can use color.

Another early estimate has also been reported by Needham and colleagues (See her current article in this issue.). Needham has taken yet another approach to object individuation, or segregation, and the role of featural information in this process. Her unique approach involves showing infants two events that involve the same two adjacent objects. The difference in the events is that in one, the objects move together; in the other, one object moves while the other remains stationary. Needham and Baillargeon (1997) found in a previous experiment that, upon seeing these two events, 8-month-olds look longer at the "objects-move-together" event than the "one-object-moves" event. They concluded that infants realized that these were separate objects, and thus were surprised to see them move together.

The current article by Needham (this issue) is based further on the finding that 4.5-month-olds need prior experience with one of the objects before acting surprised by the move-together event (Needham & Baillargeon, 1998). Now she has posed the question of what featural similarities/differences 4.5-month-olds deem important between the object seen prior to the test and the objects seen in the test events. Or to restate the question, do infants tie structural features of objects to particular objects, and if so, which features?

The procedure Needham used in the current set of experiments, like her previous studies, were simpler than the procedures used by Xu and Carey or by Wilcox and Baillargeon in that no objects are ever occluded. In her studies, infants were given prior exposure to one of the test objects, as in Needham and Baillargeon (1998), but the object varied from it's equivalent test object on some dimension(s). In Experiments 1 and 2 she

investigated the role of texture, in Experiment 3 she focused on orientation, and in Experiments 4, 5, and 6 she looked at the importance of color. The basic assumption in this set of experiments was that if infants perceived the object to which they previously had been exposed as similar to the one they were seeing in the test, they would respond differently to the "objects-move-together" and "one-object-moves" test events. If they perceived the objects as different, or too different, they would not respond differently to the test events. This innovative approach appears to reveal the interesting result that infants use differences in color, but not differences in texture or orientation, between two objects as a cue that the objects are different. One potential drawback to this design, however, is that a negative result on any one experiment (i.e. no difference in response to the test events) is being used as an indication that the previously exposed and test objects are different to the infant. Yet, such a result may not indicate that the infants believe the objects are very different, just that they cannot make the distinction or, more likely, have not made the comparison in the first place. Nevertheless, the overall pattern to emerge from the paradigm used by Needham seems to indicate some degree of object segregation based upon certain object features, but not others, by 7, or perhaps even 5, months of age.

One might assume this lower age limit of 4.5 to 5 months on infants' ability to segregate objects results from younger infants' inability to perceive "objectness," that the "entity" out there is an individual object. However, the evidence does not support that assumption. In Kellman and Spelke's (1983) groundbreaking experiments, 4-month-old infants were shown to perceive the unity of the parts of a moving object. Infants were habituated to a vertical rod translating back and forth, its center hidden by an occluding object. Thus, all the infants could see were the top and bottom portions of the rod. During the test, the occluder was removed and infants saw either a single moving rod, or just the previously visible upper and lower pieces separated by a space. Infants looked longer at the

two pieces, suggesting that those pieces were novel and that they had perceived the occluded rod during habituation as a single continuous object. Based upon the results from a number of such studies, Kellman and Spelke concluded that the key to the young infant's perception of objectness was the coordinated movement of the object in relation to the background. Kellman and Spelke's results have been replicated with infants as young as 2 months of age (Johnson and Aslin, 1995) and with rotating instead of translating objects (Johnson, Cohen, Marks, Lawson, Saunders, & Sheese, 1999).

Perhaps even more relevant to the present topic were additional findings by Kellman and Spelke (1983) and by Spelke, Breinlinger, Jacobson, and Phillips (1993). They reported that for infants under 6 or 7 months of age, the coordinated movement of an object's parts was much more a determiner of the unity of an object than were other factors such as uniform color, texture, good continuation, or good form. Young infants, then, apparently attend to the "objectness" of the moving entity rather than to the static properties of that object.

But does that mean infants under 5 to 7 months of age are incapable of perceiving properties of objects such as color, shape, size, or orientation? Clearly not. Numerous studies over the past 30 years have demonstrated that infants 3 months of age or younger can discriminate between, and even remember, values of these properties in two, as well as, three dimensional displays. One study from our laboratory, using three-dimensional Styrofoam objects, even found that 5-month-olds could remember all of these properties; size, shape, color, and orientation, after a one-minute delay. Shape and color information was remembered after 5 minutes, and shape information after 24 hours (Strauss and Cohen, 1980).

If very young infants can perceive the objectness of a "thing" as well as that "thing's" characteristic properties, why do they have such difficulty with object

segregation or individuation? We believe the answer lies in their inability to integrate the object information with the property information. That inability may stem in part from the amount of information or distraction produced by a moving display. Almost 30 years ago Bower (Bower, Broughton, and Moore, 1971; Bower, 1974) claimed that infants younger than 20 weeks of age do not detect the properties of moving objects. The strong form of Bower's claim clearly has been refuted by Burnham and Day (1979), who habituated infants between 8 and 20 weeks of age to a revolving patterned cylinder and found that the infants were not only sensitive to the movement, but also to the color of the moving pattern. In another study, Day and Burnham (1981) reported that infants as young as 8 weeks of age were sensitive to the shape of a laterally moving pattern. So, young infants obviously can detect some properties of moving objects.

However, a weak form of Bower's claim may be more tenable. It could be that the presence of movement reduces the infant's ability to process relationships among the properties of objects. If one assumes that "objectness" is one such property, it could well follow that young infants can perceive the perceptual characteristics of an object as well as the fact that it is an object (i.e., its objectness), but they have difficulty integrating these properties into a single individuated object. That version of the claim receives some indirect support from a study by Burnham, Vignes, and Ihsen (1988). Using a version of the "switch design" originally described by Cohen (1973) to detect infants' perception of color-form compounds, they found that infants as young as 4 months of age could perceive the relationship between a pattern's color and form when the pattern remained stationary, but not when it moved.

The developmental progression from independently processing the properties or parts of an object or event, to being able to integrate those properties or parts into a unique whole, is a core assumption of our information processing view of infant perceptual and cognitive development (Cohen, 1988; 1989; 1991; 1998). To briefly review this view, we

assume that infants progress through a series of levels of information processing, with each level defined by the types of relational information processed as a unified whole or unit. The approach can be summarized by the following set of six propositions (Cohen, 1998). Some of them may appear to be self-evident, whereas others undoubtedly remain more controversial.

1. Perceptual/cognitive development follows a set of domain general information processing principles.

2. Information in the environment can be processed at a number of different levels of organization.

3. Higher (more holistic) levels can be defined in terms of the types of relations among lower (parts) levels.

4. Development involves progressing to higher and higher levels.

5. There is a bias to initiate processing at highest level available.

6. If an information overload occurs (such as when movement is added or when the task involves forming a category), the optimal strategy is to fall back to a lower level of processing.

To provide an idea of the breadth of the studies and the ages involved, support for these principles can be found from studies of infants' perception of line segments and angles at 1 to 3 months (Cohen and Younger, 1984); simple forms and abstract patterns at 3 to 5 months (Bower, 1966); line drawings of animals and their parts at 4 to 7 months (Younger and Cohen, 1986); causal events involving the interaction of two objects from 7 to 10 months (Oakes and Cohen, 1990); causal events embedded in even more complex events from 10 to 15 months (Cohen, Rundell, Spellman, and Cashon, 1999); and the rapid association of verbal labels with objects and events from 14 to 18 months (Werker, Cohen, Lloyd, Casasola, and Stager (1998); Casasola and Cohen, in press). To this list we can now add infants' ability to segregate or individuate objects from about 4 to 7 months of age.

Sufficient space is not available in this commentary to present all of the documentation supporting this position and, in fact, that has been done elsewhere (e.g., Cohen, 1988; 1998). However, we would like to provide one bit of evidence, since it illustrates many of the information processing principles mentioned above and it is particularly relevant to the present discussion. The experiments come from four different laboratories, and the topic is infants' perception of object unity. As we have already mentioned, in what is a classic set of studies, Kellman and Spelke (1983) habituated 4-month-old infants to a vertical rod moving horizontally (i.e., translating) behind an occluder so that the center portion of the rod was obscured. When tested with the previously visible upper and lower parts of the rod versus a solid rod, the infants looked longer at the parts. The authors assumed this pattern of results meant the parts were more novel to the infants, and therefore, during habituation the infants had perceived (or possibly inferred) a solid moving rod. One interpretation of this result could be that the perception of object unity is an innate predisposition present very early in life. Difficulty with this interpretation appeared when Johnson and Aslin (1995) found that 2-month-olds could perceive object unity only when the occluder was quite a bit thinner than in a previous study (Johnson & Náñez, 1995). And even greater difficulty appeared when Slater et al. (1990) found that newborns actually looked longer at the solid rod. Using the same logic as Kellman and Spelke, one would have to conclude, particularly from the Slater et al. result, that there was a developmental trend from processing the independent, visible parts of the rod at birth to processing the relationship between those parts (i.e. the solid rod) at 4 months. In other words, the results were quite consistent with propositions 2, 3, 4, and 5 of our information processing approach. But there is more. Very recently, Eizenman & Bertenthal (1998) attempted to replicate Kellman and Spelke but with the occluded rod slowly rotating about its center point, like a propeller, rather than translating across the screen. Four-month-olds showed no signs of perceiving the rod as unified. In fact, there was a trend for them to look

longer at the solid rod. It was not until six months of age that infants showed a significant preference for the broken object during the test trials. From our point of view, a rotating rod would be much more complex and category-like than a translating rod. Infants would be seeing the rod's parts in many different angles and distances relative to the occluder. Under these conditions, one might well expect an information overload, with 4-month-old infants regressing back to an earlier level of processing. In other words, the result they obtained would be quite consistent with our proposition 6. In fact, this one set of experiments could possibly be considered a prototypic example of our set of information processing principles.

At this point, a few clarifications or disclaimers regarding the approach may be in order. First, we are not claiming the approach being advocated here subsumes all of the contradictory evidence or resolves all of the ambiguities in the infant perception and cognition literatures. It does, however, provide a framework for organizing a substantial portion of that literature, and more importantly, for organizing it in a developmentally relevant way.

Second, we are not claiming this approach is new or unique. Just the contrary is true: It is an amalgamation taken from other well-known theories. In fact, that may be one of its strengths. One can clearly see elements of a constructionist, neo-Piagetian or neo-Hebbian approach, particularly in propositions 2, 3, and 4, since the perception of relations among lower order parts is based to a large degree on picking up on the correlations (or as some say today, the statistical regularities) among those parts. On the other hand, the approach also incorporates certain Gibsonian principles. Propositions 5 and 6 certainly are in the spirit of differentiation. Finally, the idea presented in propositions 5 and 6, that the infant's actual performance on a task is part of a complex system that depends to a large extent on the demands of the particular task, would be consistent with the dynamical systems approach presented by Thelen and Smith (1994).

We are certain many will not endorse the entire information processing formulation we have outlined here. So, let us concentrate on an infant's ability to segregate objects. We know that object segregation requires that the infant both perceive (or understand) that the items in question are objects, and distinguish between these objects based upon their perceptual differences. We know that a complicating factor, movement of at least one object, is required to demonstrate object segregation. We know that additional complications in object segregation tasks have probably led to widely different estimates, ranging from 12 months to 4.5 months, as to the earliest age infants understand object segregation. However, we also know that infants considerably younger than 4.5 months of age, 2 months in fact, have some notion of "objectness," at least as expressed by object unity experiments. And infants less than 4 months also can perceive and discriminate stimuli based upon the same perceptual characteristics (e.g., color, shape, size, pattern, orientation) used in the object segregation studies. Thus, what appears to be missing in these younger infants is the ability to integrate the perceptual information with the objectness information. That developmental progression from processing independent pieces of information first and later integrating those pieces into a unified whole, is the most basic assumption underlying our information processing approach. Another assumption, that an information overload will lead infants to fall back to a lower level of processing, also seems to apply to object segregation, supported by the evidence that as the task demands increase, the age required to show object segregation also increases. We appreciate that this information processing viewpoint is quite different from the viewpoints expressed by those conducting research on object segregation. If we can get past those differences, at the very least, hopefully, we can all agree that object segregation implies information integration.

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