An Information Processing Approach to Infant Perception and Cognition

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If one takes the sheer volume of published reports as the standard, over the past 25 years research on infant development has made extraordinary progress. In the late 1960's, I was fortunate to be among a mere handful of investigators who met informally for the first time to share research ideas about infant development. By the mid-1970's, a more formal group of approximately 200 researchers met for the first time at the 1st International Conference on Infant Studies in Providence, Rhode Island. The latest conference, the 10th biennial meeting, convened once again in Providence, with well over 1000 scientists attending. Back in the 1960's and early 1970's, it was a rare treat to find an article in a psychological journal on infant development. In 1978, a specialized journal devoted entirely to infant research, Infant Behavior and Development, published its first volume. Today, less than 20 years later, I would estimate that at least a fifth of all articles published concerning developmental psychology relate to some aspect of infancy.

Research on infant perception and cognition has been a major reason for this dramatic increase. Over the past decade alone, hundreds, if not thousands, of articles have appeared on topics ranging from infant audition to infant vision, from infant form perception to infant event perception, and from infants' categorical perception of phonemes to their categorization of animate objects.

Judged solely by the volume of published articles, progress in infant perception and cognition has been truly remarkable. But what about progress judged by a different standard, by the qualitative standard of whether researchers have made meaningful progress toward a coherent explanation of what does and does not develop perceptually and cognitively during the first year or two of life? Unfortunately, by this standard, the enterprise often appears to be approaching a state of chaos.

Attempting to synthesize the conclusions of these myriad studies can be a confusing, if not totally bewildering experience. In some reports one reads that very young infants can hardly see, and must be at least three months of age before they can respond in any special way to a picture of a face (Dannemiller & Stephens, 1988) yet, according to others, even newborns are sophisticated enough to tell a face from a non-face (Morton & Johnson, 1991). Initial evidence suggested that infants had to be at least two months of age before they showed true habituation (Wetherford & Cohen, 1973), yet now there is evidence of habituation in the womb (Madison et al., 1986a; Madison, Madison & Adubato, 1986b). According to some reports, infants can demonstrate object permanence by three to four months of age (Baillargeon, 1987). But according to others, infants can't actually distinguish one object from another until 12 months of age (Xu & Carey, In press). Considerable evidence suggests that infants cannot tell the difference between small numerosities (e.g., two items from three items) until they are approximately 5 or 6 months old (Strauss & Curtis, 1984); yet according to one recent study, they can add and subtract by 3 months (Wynn, 1992). The earliest age at which infants can categorize is 7 months (Cohen & Younger, 1983), or is it 3 months (Bomba & Siqueland, 1983), or perhaps even at birth (Granrud, 1987), or (Slater, Mattock, Brown & Bremner, 1991)? According to some, categorization begins with the ability to process basic level categories and then advances to more abstract, superordinate categories (Mervis, 1986). According to others, the pattern appears to be just the reverse (Mandler, 1988). Infants can't really think, or form true concepts until they are 12 months of age (Mandler, 1992); yet they seem to be able to make inferences about objects as early as 2 1/2 months of age (Spelke, Breinlinger, Macomber & Jacobson, 1992). According to some, infant perception and cognition are two sides of the same coin (Cohen, 1991). According to others, they are totally different currencies (Mandler, 1993).

What is happening in our field? Are we making real progress or aren't we? It may be enlightening to report on a totally unscientific and unreliable test I recently gave to a number of my colleagues. I showed them an oversimplified continuum, much like the one in Figure 1, which leads from sensation at one end, to perception, then to cognition, and finally, at the far end, to language.

Insert Figure 1 about here.

I simply asked my colleagues to mark off where they thought the major divisions were along this continuum; which areas tended to go together and which tended to be distinctly different. In a sense I was attempting to measure my colleagues' categorical perception of these overlapping areas. The results were illuminating, if not surprising. Those whose research emphasized either end of the continuum -- either sensation or language -- tended to draw a single major boundary between perception and cognition as shown in the upper portion of the figure. It was obvious to them that sensation and perception were one and the same domain, while cognition and language were, collectively, a distinctly different domain. On the other hand, those whose research emphasized perception or cognition had more difficulty finding a distinct difference between the two. Instead, they tended to draw two boundary lines, one between sensation and perception and the other between cognition and language as shown in the bottom portion of the figure. For them, perception and cognition represented different aspects of the same domain.

This poll of my colleagues provides just one of many indications that confusion about the fundamental relationship between perception and cognition may be at the heart of the apparent chaos that seems to characterize the field of infant perceptual and cognitive development. It suggests that the confusion in the experimental literature may be largely a result of the conflicting and divergent ways we, as researchers, frame our questions and organize the core concepts in our field. This conceptual disarray leads to disarray in the design and interpretation of seemingly straightforward experiments

But our field need not settle for the sort of continuing confusion suggested by the conflicting conclusions cited above. In fact, out of this apparent chaos, one can find at least some semblance of order by interpreting the relevant studies in a unified manner. What is required is some organizing principle or framework for the facts we already have accumulated; something that can tie together topics as diverse as infant pattern perception and infant event perception, infant habituation and infant categorization. In this chapter, I shall argue that a viable candidate for such an organizing framework is the infant's developing information processing ability. For some, what I shall propose may seem obvious; for others it may appear heretical, turning well-accepted beliefs upside down.

In some circles it apparently is in vogue to assume that processes such as attention, habituation, memory, and categorization -- the methods by which infants deal with information in their environment -- all improve with age; whereas the content of their information, the infant's perception, or knowledge, of patterns, objects, and events, the laws of physics, abstract concepts and categories, all are pre-wired, modular, and available very early in life. In this chapter I shall present the opposite thesis, that infant perception and cognition operate the other way around; that major developmental changes occur in the content of information, in what constitutes an integrated, meaningful, unit of information for the infant. If we, as researchers, can determine what that unit is and how it becomes elaborated over age, we may discover that the processes for utilizing the information, i.e., the mechanisms of attention, habituation, memory, and categorization, all remain relatively constant throughout infancy.

Let me begin by clarifying what I mean by an information unit. When infants process almost any picture, object or event, they have the opportunity to do it at multiple levels. They can process it in terms of its independent parts or they can integrate those parts into a single higher level unit or whole. My proposal is that the primary developmental change over age is in the highest level of information infants can process as a single unit.

Let me provide an example. Several years ago Barbara Younger and I (Cohen & Younger, 1984) conducted a study in which we habituated 6- and 14-week-old infants to a simple angle (either 45 or 135 degrees) and then tested them on various transformations of that angle. These angles are shown in Figure 2.

Insert Figure 2 about here.

One of the test angles, A_fO_f, was identical to the one shown during habituation. A second angle, A_fO_n, was rotated so that although the angle remained the same, i.e., 45 or 135 degrees, the orientation of the individual line segments producing the angle had changed. A third angle, A_nO_f was the reverse. The orientation of each line segment was unchanged, but the angle itself was novel; it changed from 45 degrees to 135 degrees or the reverse. The fourth test angle, A_nO_n, was novel in both degrees of angle and line orientation.

Our assumption was that if the infants were processing the actual angle; i.e., the relationship between line segments, their looking times should dishabituate to those test stimuli in which the angle had changed, namely, A_nO_f and A_nO_n. On the other hand, if the infants were not processing the angle, but instead were simply attending to the orientation of individual line segments, the angle should be irrelevant, and they should dishabituate to stimuli in which the orientations had changed, namely, A_fO_n and A_nO_n.

Our results were somewhat unexpected, and may have provided us with an important clue as to how infant information processing changes over age. Figures 3 shows the test data for both 6- and 14-week-old infants.

Insert Figures 3 about here.

As can be seen from the upper portion of Figure 3, the 6-week-olds dishabituated to A_fO_n and A_nO_n, but not to A_fO_f and A_nO_f. In other words, they noticed the change in orientation of the individual line segments but appeared oblivious to the change from a 45 degree angle to a 135 degree angle. In sharp contrast, as can be seen in the lower portion of Figure 3, the 14-week-olds did just the opposite. They dishabituated to A_nO_f and to A_nO_n. They noticed the change in angle, but not the change in line segment orientation.

This pattern of results is provocative. It suggests what may be a general principle about the development of infant information processing. At 6 weeks, the infants appear to process the stimuli as independent elements, as line segments in particular orientations, whereas at 14 weeks they appear to be able to integrate those elements into a larger whole, an angle, defined not by the orientation of individual line segments but by the relationship between those orientations.

As is often the case, one intriguing result can raise more questions than it answers. Is this part to whole progression unique to angle perception? Does the progression occur only from 1 1/2 to 3 months of age, or is it a more general phenomenon that reoccurs repeatedly, albeit with different stimuli, at older ages? If it does tend to reoccur, what are the relevant parts and relevant wholes produced by those parts? Also, to what extent does this progression depend upon the type of procedure used? That is, would one find one pattern of results from a standard habituation task and yet a different pattern of results from, say, a discrimination learning or categorization task? At least partial answers to these questions are already available and we continue to explore these questions in our laboratory.

Answers to all of these questions appear to be linked. Considerable evidence, both direct and circumstantial, indicates that the transition from perceiving parts to perceiving wholes occurs at several different ages, but the particular age at which the transition occurs depends upon the nature of the stimuli involved.

A few examples may clarify this point. Three decades ago, in a study rarely cited these days, Bower (1966) reported operantly conditioning infants' head-turns to a stimulus constructed from a circular disk upon which was placed a large X and two dots, similar to the object shown in Figure 4.

Insert Figure 4 about here.

Bower then tested for response generalization to the whole object and to the various parts of the object (i.e., the disk, the X and the dots). He reported that through 4 months of age, the number of conditioned responses to the whole was equal to the sum of the responses to the parts. At 5 months, however, responses to the whole became greater than the sum of the parts. The obvious implication was that the disk, the X, and the dots were perceived as independent parts by infants under 5 months of age, whereas they were integrated into a unique whole or pattern at 5 months of age. So Bower both produced additional evidence for the part to whole progression, and did so using a different procedure, conditioned head turning.

Another implication, this time a developmental one, can be drawn from a comparison of Bower's (1966) results with those of Cohen and Younger (1984). It will be recalled that Cohen and Younger, using simple angle stimuli, found the parts to whole transition occurring between 1 1/2 and 3 months of age. Bower, using a more intricate pattern, found it between 4 and 5 months of age. Apparently, this transition does reoccur at older ages if the stimuli are complex enough. In fact, considerable additional evidence suggests that the period from 3 to 5 months of age may be particularly important in the transition from processing simple shapes or forms. such as circles or squares. as independent elements, to integrating those shapes or forms into relatively complex patterns. For example, Strauss and Curtis (1981, April) have reported that a more symmetrical, regular patterns of dots can be processed as a single unit at a somewhat younger age (at 3 months) than can a less symmetrical, irregular pattern (at 5 or 7 months.) Columbo, Freeseman, Coldren & Frick, (1995) have also shown, with 4 month old infants, that short-lookers (a characteristic of maturity) tend to process these same types of patterns initially as wholes, whereas long-lookers (a characteristic of immaturity) tend to process the patterns in terms of their elements.

For several years, Bertenthal (1993) has been investigating infants' perception of motion using point light displays. With adults, he finds that if the display is right side up, they perceive a coherent set of dots representing a person walking. However, if the display is upside down, they lose that coherence and perceive local groups of dots moving together. Five-month-old infants show the same disparity between right-side up and up-side down-dots. Apparently, they perceive the dots in a coherent, integrated way, as do adults. Three- or four-month-olds, on the other hand, respond in the same way whether the dot pattern is right side up or upside down. A reasonable interpretation, one that would be consistent with the present thesis, is that even in the right -side-up display, the 3- to 4-month-old infants are perceiving local groups of dots, but not the overall integrated display of a person walking.

What about even more complex patterns, such as drawings of objects or animals? One might well expect the perceptual transition from parts to wholes to occur at or beyond 5 months of age. A few years ago, Barbara Younger and I (Younger & Cohen, 1986) examined how infants of different ages process line drawings of imaginary animals. The animals were constructed from identifiable parts -- bodies, legs, tails, ears, etc. -- combined in arbitrary ways. We also used a procedure designed specifically to test whether infants processed those parts independently or integrated them into an entire animal.

A general outline of this design, which we have subsequently used in many other experiments on a wide variety of topics, is shown in Figure 5. For reasons which will become apparent in a moment, we have labeled it the “Switch Design”, Cohen (1992).

Insert Figure 5 about here.

The two essential characteristics of the Switch Design are first, that infants be habituated to at least two different stimuli, and second, that the critical test stimulus, also known as the “Switched Stimulus”, be constructed from a novel combination of old parts or features previously presented in the habituation stimuli. As indicated in Figure 5, infants would be habituated to two different stimuli, described as , 1 1 X and 2 2 X. The numbers refer to values of features a, b, and c respectively. The X for feature c simply means that the value of c is the same for both stimuli, and irrelevant in the present context. Also, as shown in Figure 5, the subsequent test items include a familiar stimulus seen during habituation, a totally novel stimulus, and most importantly, a switched stimulus. In the switched stimulus the critical feature values will all be familiar. For example, in Figure 5 the critical feature values for the switched stimulus are 1 and 2. It is this combination or arrangement of those values that is novel. Infants have never before seen an A 1 paired with a B 2. If infants dishabituate to this switched stimulus, it can't be because the individual parts are novel. They have all been seen before during habituation. It must be because the infants are sensitive to the new arrangement of those parts. In other words, this switch design can assess whether or not the infants are perceiving the stimulus as a whole or only as a set of independent parts.

To provide a concrete example of an effective use of the Switch Design, consider one study in a series of experiments reported some time ago on infant categorization by Younger and Cohen (1986). In this study, we habituated 4-, 7-, and 10-month-old infants to pictures of two different imaginary animals such as those shown in Figure 6.

Insert Figures 6 and 7 about here.

The experimental procedure (as shown in Figure 7) precisely followed the switch design just described. The animals differed on three features, type of body, feet, and tail. Infants were habituated to two animals, each with different feature values; e.g., one had a bear-like body with webbed feet and a feathered tail, and the other had a giraffe-like body with club feet and a furry tail. (The type of ears and number of feet did not vary across animals.) The critical test item, the switched stimulus, was a composite of parts taken from both habituation animals; two of the features came from the first habituation animal, whereas the other feature came from the second habituation animal. (A third animal, the elephant-like creature was also presented in the test as a novel control stimulus.) If infants responded to the switched animal as novel, it would indicate their ability to organize the parts and to respond to the animal as a whole. On the other hand, if they responded to the switched animal as old, it would indicate that for them the "animal" was merely a collection of independent parts.

Our results were quite clear. Both 7- and 10-month-olds did respond to this switched test animal as novel. They looked substantially longer at it than at a familiar animal they had seen during habituation. In contrast, the 4-month-olds looked no longer at the switched animal than at the familiar animal. Apparently for them, the switched animal was simply a collection of familiar and independent parts.

Thus, once again, we found evidence of a developmental transition from processing parts to processing wholes; this time, however, with more complex patterns than either the single angles used by Cohen and Younger (1984) or the simple disk used by Bower (1966). Also, this time the transition appears to occur at a somewhat older age, probably around 6 to 7 months of age.

We have now arrived at a developmental level at which infants apparently can process complex pictures or perhaps entire objects as single integrated wholes. What should be the next higher level in this sequence? One way of describing this developmental progression so far is that single lines became integrated into a simple form such as an angle; then simple forms, such as circles and Xs, were integrated into Bower-type and other simple patterns; and then simple patterns, such as line drawings of a foot, an ear, a tail, etc. were integrated into an entire animal. At each level of information processing, the wholes that infants processed can be described, at least in part, as the relationship among lower-order wholes, and those wholes, in turn, can be described as the relationship among yet lower-order wholes. Thus, each higher level involves processing relationships among wholes at the level just below it. Returning, then, to the question of what level an infant should attain after mastering relatively complex objects, the most plausible answer would be a level at which the whole is based upon the relationship between different complex objects.

Therefore, the next step in our research program was to investigate infants' reactions to a simple, classic type of relationship between objects: a direct launching event. A direct launching can be described as one object moving across a screen or surface until it comes into contact with a second object. Once contact is made the first object stops, and the second object then continues the motion of the first. To both Michotte (1963) and to Leslie (1986) this direct launching of one object by another represents the prototypic causal event, and should be perceived directly and automatically as causal. Without getting into difficult theoretical issues relating to the possible meanings of direct or automatic perception, the most relevant questions for us would be how can one demonstrate that infants perceive the causal relationship between two objects, and at what age are they capable of doing so?

In answer to the first question consider the four types of events listed in the upper portion of Figure 8.

Insert Figure 8 about here.

The direct launching (lower left-hand corner of the square) has already been described. It is an event in which one moving object contacts a second object that then moves upon contact. This event is universally perceived as causal by adult observers. Now consider the same event but with a 1 sec delay inserted between the first object's contact and the second object's movement. This delayed launching (upper left-hand corner of the square) is not perceived as causal by most adults. Neither is a no-collision event (lower right-hand corner), in which no delay occurs, but the second object moves prior to any contact by the first object. Of course, an event that includes both delay and no-collision (upper right-hand corner) is also not perceived by adults as causal.

How then do infants treat these events? One possibility is that they are not responding to the causal (or non-causal) relationship between objects. Instead, they are treating each dimension -- the presence or absence of a delay, and the presence or absence of a collision -- as an independent perceptual feature. If this is the case, then assuming a simple additive model, the perceived difference between any two events would be indicated by the linear distance between those events in the square shown in Figure 8. For example, one prediction would be that the perceptual difference between a no-collision event and a delayed launching event should be just as great as the difference between a direct launching event and an event involving no-collision and a delay. Either set of events involves a change in both temporal (delay) and spatial (collision) characteristics Or, to take another example, the difference between a no-collision and a delayed launching, which differs temporally and spatially, should be greater than the difference between either a direct launching and no-collision, or a direct launching and a delayed launching, since each of these last two pairs differ along only one dimension.

On the other hand, if infants are responding in terms of the causal relationship between objects, then, as shown in the bottom portion of Figure 8, the direct launching, which is the only causal event, should be perceived as quite different from the other three events. In contrast, the three non-causal events -- the delayed launching, the no-collision, and the delay plus no collision -- should all be perceived as being relatively equivalent.

Over the past several years we have conducted numerous experiments concerning infants' developing perception or understanding of causal events. In one of our earliest studies (Oakes & Cohen, 1990), we attempted to determine at what age infants organize simple launching-type events on the basis of causality, as depicted in the lower portion of Figure 8. We showed 6- and 10-month-old infants videotaped recordings of moving, realistic toy objects. Infants were habituated either to a direct launching, a delayed launching, or a no-collision event, and then were tested on all three events. As a control, they were also tested on a very different event with totally different objects.

The results were quite interesting. The 6-month-olds showed no evidence of causal perception. They dishabituated when the objects or patterns of movement changed, but nothing about the relationship between the objects affected their looking time. In contrast, the 10-month-olds were sensitive to the causal relationship between the objects. They responded as one would predict from the lower portion of Figure 8. When habituated to a direct launching -- the only causal event -- they dishabituated to both of the non-causal events: the delayed launching and no-collision. However, as shown in the lower portion of Figure 9, when habituated to either non-causal event, they dishabituated only to the causal event, and not to the other non-causal event.

Insert Figure 9 about here.

This early study, and later related studies from our laboratory and elsewhere, have yielded consistent results. When realistic objects are presented in the events, infants have to be approximately 10- to 12-months of age before they respond to the causal relationship between objects. When simpler, uniform shapes such as circles or squares are presented, some infants as young as 6- to 7- months may be able to respond in terms of causality. But with these very simple stimuli, the infants are not confronted with the initial task of integrating complex pattern and other information within the objects themselves. Also, even with these simple stimuli, 3 -to 4-month-old infants seem to be unable to perceive the causal relationship (Cohen, 1994; Lecuyer, 1994).

Thus far, I have described a variety of studies conducted at different ages, which together support a recurring theme in infant perceptual development. The theme is constructivist. The infant at one age processes holistic units which become elements in the construction of higher-order units at a later age, and those units, in turn, become elements in the construction of yet higher orders at an even later age. I could have presented a great deal of additional evidence on infant pattern or object perception that would also be consistent with this theme. And although this repeating sequence does provide some overall organization for a rather diverse set of findings on infant perception during the first year of life, it certainly cannot be the whole story. The view also leads to a number of significant theoretical questions. For example, one could ask what might be the next perceptual unit or level of organization more complex than a simple event. Whatever the exact unit might be, it would likely involve the relationship between two or more simple events. Bauer (1996) has been examining just that sort of relationship in her investigation of infant memory during the second year of life. Her work indicates that, generally speaking, beginning in the second year, infants can remember and imitate sequences of events if they are in some meaningful temporal relationship to one another.

Another theoretical question would be what happens to lower-order units once infants are capable of using them as elements in higher-order units? This is essentially a levels of processing question. Do infants lose the ability to process information at that lower level, or is that level still available to them, and if it is available, under what circumstances is it available? We know one thing from the studies I have already presented. Infants must, at least under the conditions of these studies, be top-down processors; that is, they initially attempt to process information at the highest level available to them. If they did not behave this way, then we would not consistently observe older infants tending to process information at higher levels than younger infants. There would be no reason, for example, for 3-month-olds to process whole angles rather than individual lines, or for 7-month-olds to process whole animals rather than individual body parts.

But if they do generally process information at the highest level available, does that imply they have lost the ability to process information at lower levels? I would argue that they certainly have not, and that this tendency to process at the highest level is an adaptive bias that easily can be overcome. Perhaps we can draw an analogy between an infant attempting to understand her perceptual world and a young child attempting to read. Initially, when learning to read, the child generally begins by processing the sounds of letters. She then moves on to words, then to phrases, and finally to the gist of entire sentences or paragraphs. This is plainly a constructive process similar to the one being proposed for infant perception more generally.

Once the child has become a competent reader, however, she has not lost the ability to process single words or letters under appropriate circumstances. While processing on such a lower level would not normally be useful or necessary, what if the child were to come to a passage that she did not understand? What if the construction of the sentence or the meaning of a word were unclear? More than likely, the child would drop down to a simpler word or letter level, and attempt to process the passage bottom-up from that lower level.

Perhaps something similar happens more globally in the realm of infant perception. Perhaps under conditions in which the object of perception is unclear or unknown, or if the information load is too great, infants will drop down to a lower level of processing. Some evidence has already been presented to suggest that information load may influence level of processing. Recall that some 6- to 7-month-olds can process a causal relation, but only if very simple objects are involved. If the objects are more realistic or complex, however, the infants apparently must be closer to 10-months-of age to perceive the causal relationship.

Additional, more direct evidence on this issue has been reported by Cohen and Oakes (1994). As is apparent and as mentioned earlier, they replicated the Oakes and Cohen (1990) causality study with 10-month-old infants, but with one small modification: the objects varied from trial to trial. Recall that the critical conditions in these experiments were the ones in which infants were habituated to one non-causal event (either delayed launching or no-collision) and then tested on the familiar non-causal event, the causal event (direct launching) and the other non-causal event. The most important question was whether infants would respond to the other non-causal event as if it was familiar or novel. If they responded to it as familiar, it would indicate that perception was occurring at the level of causality, as depicted by the bottom portion of Figure 8. If they responded to it as novel, it would indicate perception not in terms of causality, but at the lower level of the separate spatial and temporal parameters of the events, as depicted in the upper portion of Figure 8.

The results, plotted in terms of response level to familiar non-causal, causal, and other non-causal test event, are shown in the upper portion of Figure 9. The bottom portion of the figure simply displays the data from the earlier presented Oakes and Cohen (1990) study; i.e., the results when the same two objects are used in the event. As you can see, and as I mentioned earlier, 10-month-old infants clearly responded to the other non-causal event as familiar. In other words, they responded in terms of causality. But the results from the Cohen and Oakes (1993) study show that when different objects were used on each trial, 10-month-old infants now responded on the basis of the spatial and temporal perceptual characteristics, and not in terms of causality.

According to some theoretical viewpoints (e.g., Leslie, 1986; Michotte, 1963), this variation from trial to trial in the objects used in the events should make no difference. The causal, non-causal distinction should be just as apparent. However, that clearly was not the case. Varying the objects from trial to trial --essentially presenting the infants with a category of events --made the task more difficult. It presumably forced the infants to process the events at a lower, perceptual level, rather than at the level of the causal relationship between objects.

Thus, the combined results from Oakes and Cohen (1990) and then from Cohen and Oakes (1993) indicate that, depending upon the circumstances, infants at the same age (i.e., 10-months) can process an event either in terms of the causal relationship or, if the perceptual demands are too great, at a lower, more immature level. A logical next question is whether this tendency, under certain circumstances, to drop to a lower level of processing, is merely an idiosyncratic feature of causal perception, or a more general feature of perceptual processing over a number of domains.

Earlier in this chapter, a study by Younger and Cohen (1986) was described in which infants were shown line drawings of imaginary animals. In that study (See Figure 7), infants were habituated to two separate animals, each defined as particular values of three features. A total of 10 habituation trials were given, five with each animal. So, for example, an infant might have received five presentations of one animal that had webbed feet, a feathered tail, and a bear body along with five presentations of a second animal that had club feet, a fluffy tail, and a giraffe body. It will be recalled from the earlier description that 4-month-olds processed the animals in terms of their independent features, whereas 7-month-olds integrated those same features into a single, whole animal.

Actually, this study was only one of a series on infants' perception of correlated features. Two additional studies were almost identical to the first, but with one critical exception. Instead of three features being correlated (and the other two features remaining constant) as was the case in the first study, now three were correlated, but the other two varied randomly as is shown in Figure 10. So now an infant would see four different animals rather than one with webbed feet, a feathered tail and a bear body and also four other animals with club feet, a fluffy tail, and a giraffe body. Of course the animals were presented in random order. In essence, the task was transformed from a simple object recognition problem in which the infant had to remember two different objects, to a categorization problem with two categories, each having four exemplars.

Insert Figure 10 about here.

In one such "category" study, 4- and 7-month-olds received a total of 12 habituation trials. The 4-month-olds performed precisely as they had done previously. They habituated rapidly and indicated by their test performance that they were processing the attributes independently . The 7-month-olds, in contrast, had great difficulty with the task. They didn't show any evidence of decreased looking during the 12 habituation trials**.** This difficulty in habituating is understandable if one assumes that the 7-month-olds were trying to process the animals as wholes. Unlike the previous study in which they only had to remember two different animals each with a different set of attribute values, the present study required the infant to remember either two distinct categories, or four distinct animals with considerable overlap among attribute values.

In an effort to maximize the possibility that 7-month-olds would process the stimuli at some level, an additional study was conducted in which infants were not given a fixed number of habituation trials. Instead, they were continued in the habituation phase of the experiment until they reached a criterion of habituation. Under this more stringent condition, the question was whether the infants would now be able to process in terms of either categories or whole animals. The answer was that they could do neither. The 7-month-olds regressed to the level of 4-month-olds. They now processed the independent features rather than the animals as a whole.

So once again, we found evidence that when the information load was too great, infants reverted to a lower level of processing. In this instance, as opposed to the one involving 10-month-olds' perception of causality, we were dealing with 7-month-olds who dropped from processing a whole picture of an animal to processing particular features or attributes of that animal, but the processing strategy remained the same. If the information load was increased by making the task a category problem, infants reverted to a simpler level of processing.

The next question in this logical sequence is whether the same drop-down strategy would be at work with even simpler stimuli, but at younger ages. The answer may be that it is. Recall that early in this chapter an experiment by Cohen and Younger (1984) was described in which 3-month-olds processed a simple angle as the relationship between two lines (i.e., an angle); whereas 6-week-olds processed the same angle as separate line segments in particular orientations. Recently, Slater (1991) has reported a series of studies on the angle perception of newborns. First, replicating the Cohen and Younger (1984) study with acute versus obtuse angles, he showed that newborns behaved like 6-week-olds: they processed the angles as separate line segments, and not as angles per se. Next, he converted the task into a category-like problem by presenting the same angle in different orientations on each habituation trial. Now it seemed, at least on first analysis, that newborns were responding in terms of angle rather than orientation. However, as even Slater has noted, a more conservative interpretation would be that, in this category context, the infants actually dropped down to some simpler level of processing, such as differences in low spatial frequency information at the apexes of acute versus obtuse angles, or differences in the degrees of visual angle subtended by the acute angles as a group versus the obtuse angles as a group. Without additional research, we cannot be certain what cues these newborns were using, but we can be certain that converting the task into a category problem changed the way the newborns responded to these angle stimuli, perhaps forcing a reduction in the level at which those stimuli were processed.

From the evidence presented so far, what conservative conclusions can be drawn regarding development of infant perception and cognition? At the very least, we are seeing a picture of development in which the level at which infants process information increases repeatedly with age. It appears to be the content or complexity of information units that is changing with development. An integration of information from multiple units at one level forms a single, more complex unit at the next higher level. Furthermore, once infants progress to that next level, they do not irretrievably lose the ability to process information at the lower level. On the contrary, infants merely have a tendency to be top-down processors. If they can process the information at their highest level, then they do so. But if the task is made too difficult for them, perhaps by introducing a category or presenting more complex, lifelike objects, the infants may well drop down to their next lower level, and attempt to process the information at that level.

If the content of information units changes with age, what about the processes that deal with these units? What about processes such as attention, habituation, memory, or categorization? As I have argued elsewhere (Cohen, 1991) it could be that these processes change very little developmentally. We know, for example, that when presented with a complex picture, older infants will tend to stop looking sooner than younger infants. Rather than interpreting this difference in terms of processing speed per se, it could simply be that as infants become older, while the duration of their attention to a single unit remains more or less constant, the units themselves have become larger, and more relational. Thus, for any given picture, the absolute number of units they need to process decreases.

We know that younger infants usually take longer to habituate than older infants. This difference in habituation speed is often taken as an indication that younger infants have poorer memories than older infants. But perhaps the ability to remember a relatively small number of units remains constant over age. The younger infants' lower processing level dictates that for any given stimulus, the younger infant will have more units to remember than an older one. So it may not be that the younger infant has a poorer memory, but rather that the memory demands are simply greater at a younger age because of the increased number of units to be processed.

Early categorization research in our laboratory (Cohen & Caputo, 1978; Cohen & Strauss, 1979), produced evidence suggesting that infants had to be at least 7 months of age before they could form categories of objects. But these categories tended to include rather complex pictures such as photographs of dogs or faces. More recent research has provided evidence that infants as young as 3 months of age can form categories, but interestingly, these categories tend to be of simple geometric patterns, such as triangles or squares. Still more recent research suggests that even newborns may form categories, but these categories tend to be even simpler. They seem to be based upon sizes of blobs, degrees of visual angle, or some gross indication of object size. So it may be that an infant’s ability to categorize also remains relatively invariant with age, and what really changes, once again, is the complexity of the units being categorized.

At this point, one might well ask how this information processing approach can be reconciled with the abundant evidence presented in recent years that infants are much more cognitively precocious than had previously been believed. The answer is that many of these claims have been exaggerated. When one gets beyond the nativist rhetoric and carefully examines the research that has been done, one finds a pattern of unsubstantiated assumptions about what infants are supposedly thinking or inferring. (See Haith and Benson (In press) for a recent evaluation of this literature.) In those few cases in which an attempt has been made to test these nativist claims rigorously, the results have actually been more supportive of the developmental, information processing approach advanced in this chapter.

One example is the growing body of research on infants' perception of causality. In the original studies on this topic, Leslie (1986) claimed that infants were built with a causal module that operated from a very early age, and automatically produced the perception of causality whenever the spatial and temporal conditions were appropriate. More recent evidence, some of which has been reported earlier in this chapter, indicates that the story is much more complex and constructivist than Leslie proposed.

In fact, a more accurate account of the development of infant causal perception, and of the primary cues infants seem to use at each stage of processing, would be the one proposed by Cohen (1994,) and shown in Figure 11. At an early phase, around 4 months of age, infants are sensitive to certain elements of a causal event. They can distinguish between continuous and discontinuous movement and can distinguish between objects based upon differences in those objects' features. It is not until somewhat later, around 6 or 7 months of age, that they begin to notice certain relationships between these objects and their movement, such as whether a particular movement goes with a particular object. At an even later age, usually around 10 months, these perceptual relationships are organized on the basis of the meaning of the event. In other words, at this age the infants are able to perceive the event in terms of its causality. However, there is yet more to learn, and it is not until around 14 months of age that infants can distinguish between different types of causal relationships, or begin to associate verbal labels with different causal events.

Insert Figure 11 about here.

Another example would be the research on infants' understanding of an object's solidity. Spelke (1992) has proposed that infants as young as 2 1/2 months of age understand that one solid object cannot pass through a second solid object. Once again, the suggestion is that infants come equipped with an innate, well organized cognitive system. An understanding of solidity implies, at the very least, an understanding of the relationship between two objects. If Spelke's proposal were correct, it would seriously undermine our contention that such an understanding does not develop until much later in the first year of life.

Our extensive research on this topic (Cohen, 1995; Cohen, Gilbert & Brown, 1996) which included some essential control groups not used previously, indicated that Spelke was incorrect. She reported that infants as young as 2 1/2 or 4 months of age responded with surprise (or at least looked longer) when one solid object appeared to pass through a second solid object. In our studies, infants as old as 7 months of age also looked longer when one object passed through a second object, but we also found that they looked longer even when the first object had an opening in it, so it was no longer impossible for the second object to pass through it. In fact, the infants were looking longer at the "passing through" events either because the first object moved for a longer period of time than when the first object stopped at the second object, or because, when compared with the habituation event, this "passing through" event was just more perceptually novel than the one in which the first object stopped at the second object. In neither case did the data require one to accept that the infants understood "solidity", or that they were responding to the nature of the physical relationship between the objects. In our studies, it was not until 10 months of age that the infants clearly responded on the basis of this solidity relationship. Recall that, perhaps not accidentally, this is the same age at which they also clearly begin to respond to a causal relationship between objects. With solidity, as with causality, our evidence has been much more consistent with a developmental, information processing approach than with a modular or nativist approach.

Finally what about the supposed continuum from sensation to perception to cognition to language? When a theoretical approach extends developmentally from informational units like low spatial frequency blobs, to simple forms, to complex objects, to simple perceptual relationships among objects, and then to meaningful relationships among such simpler perceptual relationships, attempting to draw distinct lines in this continuum seems rather arbitrary.[1] The arbitrariness is even more apparent when one considers that the information processing approach emphasizes the continuity of development more than the change. The units of information change with age, but there is constancy in both the constructive process of building new units from old units, and the top-down processing bias. The processes that select, store, and group these units remain relatively constant as well. Processes such as attention, habituation, learning, memory, or even categorization may change little, if at all, during the first year of life. Placing an artificial boundary either between sensation and perception or between perception and cognition does a disservice to our understanding of these underlying processes, and erroneously encourages fragmented research based on the premise that these topics are truly distinct. The information processing approach encourages just the opposite. It suggests that much of infant sensation, perception, and cognition during the first year of life can most accurately be characterized as a single domain, a domain that in some ways is gradually being constructed as the infant develops, but in other ways is under the control of the same processes whether the infant is a newborn or a toddler.

Where then do we stand in our effort to understand infant perception and cognition. Superficially, the flood of research in this area seems to have produced a spate of conflicting, chaotic results and contradictions. However, the picture is not that bleak. As promised early in this chapter, I have attempted to provide a theoretical framework for organizing a substantial portion of the relevant research in a developmentally useful way. That framework can best be characterized as an information processing approach to infant perception and cognition. The approach certainly doesn't answer all of the questions or resolve all of the ambiguities. Indeed, it raises many unanswered questions. But on balance, it is consistent with a large body of research in the area, and it provides a starting point for analysis when conflicting results or inconsistencies appear in the literature. My hope is that continuing to apply the approach and the experimental procedures generated by it, such as the switch design, to an ever wider list of topics within infant perception and cognition, will lead to further insights, and will continue to reduce the apparent chaos in the field.

Footnote

[1] The same arbitrariness could be claimed for the boundary between cognition and language. Certainly certain linguists, e.g., cognitive semanticists, would not want to draw a sharp distinction between the two. Our own research on infants' labeling of objects (Lloyd, V.L., Cohen, L.B., Werker, J.F., Foster, R., & Swanson, C.S., 1994; Lloyd, V.L., Werker, J.F., & Cohen, L.B.,1993) and of actions (Casasola & Cohen, 1996) has made use of the switch design to show the same part-to-whole progression in infants' early labeling. Such a progression suggests that at least certain aspects of linguistic development should not be treated as a distinct domain.

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Figure Captions

Figure 1. Possible categorical perception of traditional areas within experimental psychology.

Figure 2. Design of Cohen and Younger (1984) angle experiment. Half of the subjects were presented the stimuli shown on the top line. The other half were presented the stimuli shown on the bottom line.

Figure 3. Results of Cohen and Younger (1984) for both 6- and 14-week-old infants.

Figure 4. Type of stimuli used in Bower's (1966) conditioning experiment.

Figure 5. Basic switch design.

Figure 6. Examples of animal pictures used by Younger and Cohen(1986).

Figure 7. Application of simple version of switch design by Younger and Cohen(1986).

Figure 8. Schematic representation of two possible models for infants' processing of causal events.

Figure 9. Results from infant causal event studies. Upper figure is consistent with independent features model, whereas the bottom figure is consistent with the causal perception model.

Figure 10. Application of switch design by Younger and Cohen(1986) to a more complex category study.

Figure 11. Possible developmental progression in infants' processing of simple causal events.

Figure 1

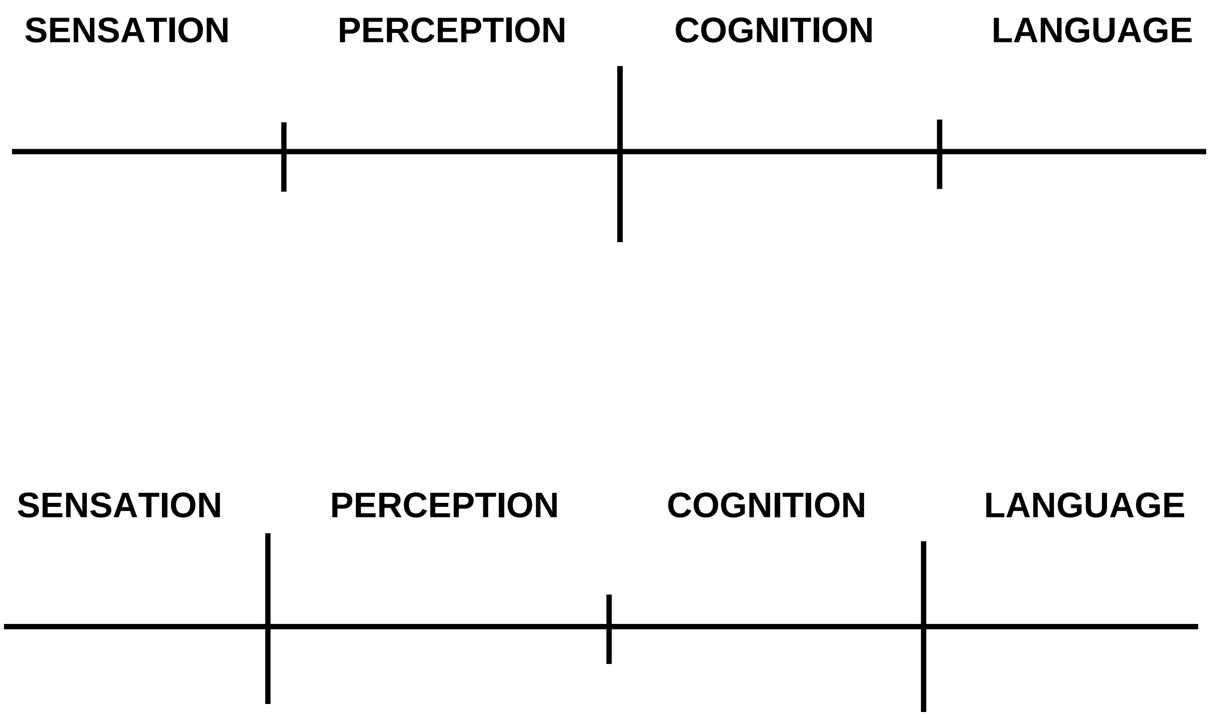

SENSATION
PERCEPTION
COGNITION
LANGUAGE
SENSATION
PERCEPTION
COGNITION
LANGUAGE

Figure 4

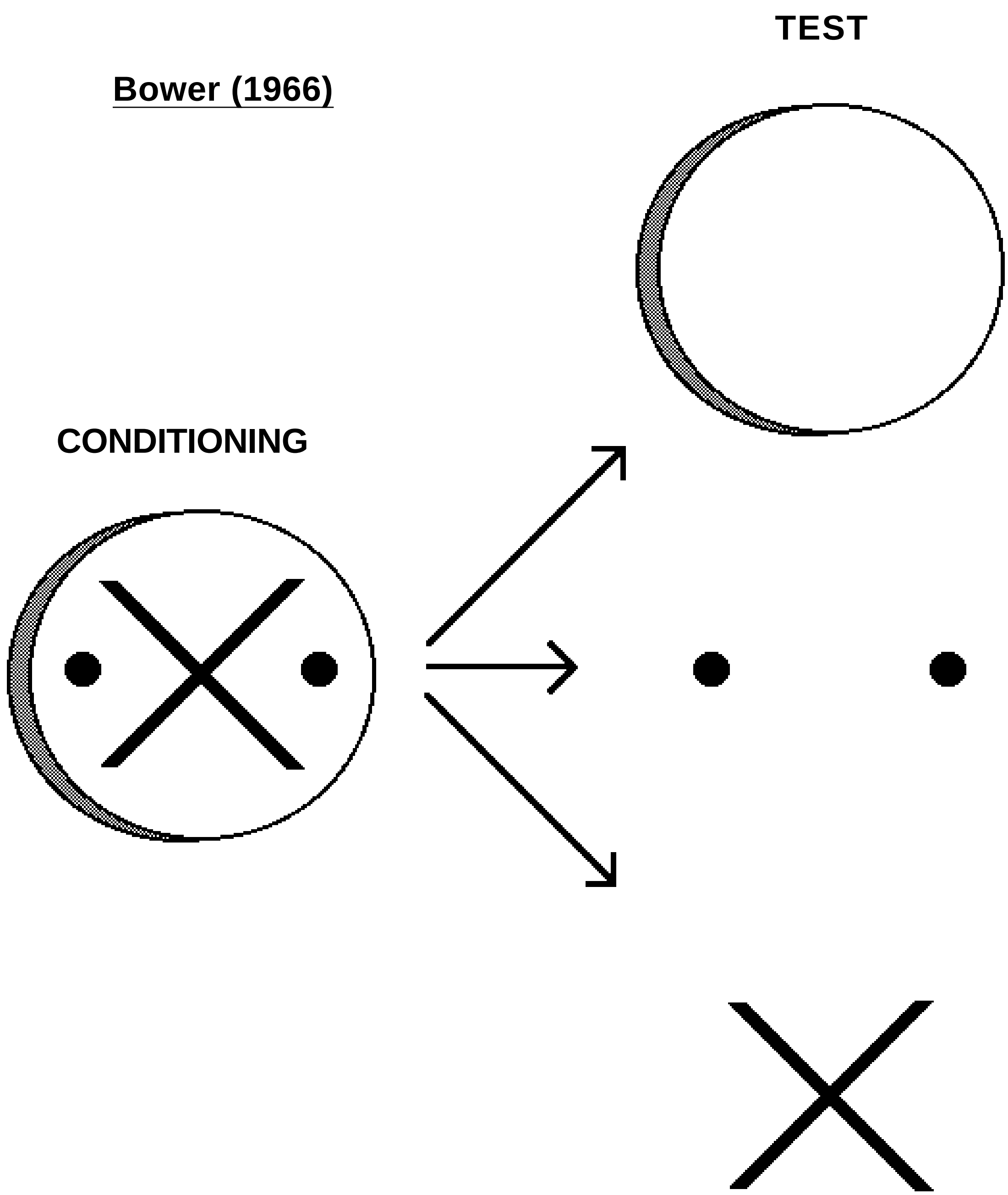


Figure 5

Part-Whole Experiments

(Switch Design)

HABITUATION STIMULI

Features

a	b	c
1	1	X
2	2	X
•	•	•
•	•	•
•	•	•
•	•	•

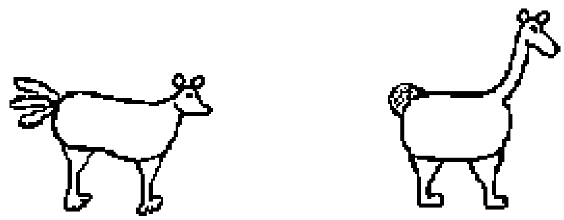
TEST STIMULI

	a	b	c
same:	1	1	X
switched:	2	1	X
novel:	3	3	X

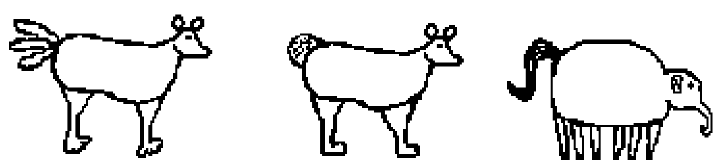
Figure 6

STIMULI FROM YOUNGER AND COHEN (1986)

HABITUATION STIMULI



TEST STIMULI



same **switched** **novel**

Figure 7

Younger and Cohen (1986)

(Simple Switch Design Experiment)

HABITUATION STIMULI

	feet	tail	body	ears	# of legs
Animal 1	web	feather	bear	round	two
Animal 2	club	fluffy	giraffe	round	two

TEST STIMULI

	feet	tail	body	ears	# of legs
Same	web	feather	bear	round	two
Switched	club	fluffy	bear	round	two
Novel	hoof	horse	elephant	human	six

Figure 8

CAUSAL EVENT STUDIES

INDEPENDENT FEATURES MODEL

CAUSALITY MODEL