The Development of Infant Causal Perception

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Some degree of causal understanding permeates almost everything we do and think. Whether it is in our social relationships, political actions, legal decisions, scientific understanding, or even our basic survival, we are almost incapable of not inferring cause and effect. How does this conception of causality begin and what would our world be like if we had no notion of causality?

Lightman (1993) considers this latter possibility in a humorous book of essays about physical reality called Einstein's Dreams:

> Consider a world in which cause and effect are erratic. Sometimes the first precedes the second, sometimes the second the first. Or perhaps cause lies forever in the past while effect in the future, but future and past are entwined.
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> * * *
>
> In this acausal world, scientists are helpless. Their predictions become post-dictions. Their equations become justifications, their logic, illogic. Scientists turn reckless and mutter like gamblers who cannot stop betting. Scientists are buffoons, not because they are rational but because the cosmos is irrational. Or perhaps it is not because the cosmos is irrational but because they are rational. Who can say which, in an acausal world? (p. 3)

Is this the world of the infant or does the infant come predisposed to perceive or understand simple causal relationships?[1] In this chapter we shall attempt to answer this question. For the past several years a few infant laboratories, including our own, have been exploring infants' reactions to one type of causal event, a situation in which one inanimate object moves across a screen until it hits a second inanimate object that then moves the remaining way across the screen. This relatively simple and prototypic example of physical

[1] We shall not draw a particularly sharp distinction in this chapter between infants' perception and their understanding of causality. Some possible differences between the two will be discussed at various points in the chapter, but we realize that for many, including ourselves, a sharp distinction between perception and cognition may be difficult to defend.

causality, referred to by Michotte (1963) as a “direct launching”, is uniformly perceived by adults to be causal. By comparing the reactions of infants of different ages to direct launchings versus other similar events, we, and others, have been exploring the origin and development of infants’ perception of causality.

Much of that evidence will be covered in this chapter. But the chapter is intended to be more than just a summary of our research and the research of others. We shall also mention a number of different theoretical views about the origins of infants’ causal perception. Some of these views should be considered more philosophical than psychological and may be primarily of historical relevance. Other more contemporary views, a modular approach and an information processing approach, are more directly related to current psychological and developmental issues. When possible, we shall attempt to evaluate these views based upon how consistent each view is with the available evidence.

We shall pay particular attention to modular explanations. To some of those with nativist leanings, evidence that young infants can respond to simple events on the basis of causality seems sufficient to demonstrate the existence of an organized, self-contained perceptual module for causality. In part because of inconsistencies in use of the term “module” (Carey, 1995), it may be impossible either to prove or disprove such a position. But certainly any explanation of infant causal perception should require more than just the demonstration that at some age infants can respond in terms of the causality of an event. The nativist-modular position, especially when taken to its extreme, reduces to a patently circular form of argument. Throughout this chapter, our central thesis will be that this type of modular account of causality perception is premature and actually contrary to the experimental evidence as a whole. It is our position that, regardless of one’s overarching philosophical position, causality theories, to be useful, must be amenable to falsification, and relevant experiments must be amenable to replication.

Our evaluation of the evidence indicates that the nativistic concept of causality perception is problematic at best, and probably counter-productive. First, we have found that there appear to be developmental precursors to the perception of causality. By around 6 months of age some evidence of causal perception exists. Younger infants, those under 5 1/2 months of age, do not respond to causal events in the same way as those over 6 months. Instead, they appear to respond on the basis of simpler, perceptual characteristics of the event. Yet these perceptual characteristics may become ingredients in infants' later perception of causality. Second, we have discovered two quite different and compelling examples of older infants, at 10 to 12 months of age, who, under one set of circumstances, do respond in terms of causality, but under other very similar circumstances respond in terms of simpler perceptual differences rather than causality. According to our understanding of a modular approach, the infants should be responding the same way under both sets of circumstances. Finally, additional evidence from infants between 10 and 14 months of age demonstrates a close link between the perception of causality and certain aspects of language comprehension and semantics. Although this link between perception (or perhaps cognition) and language is not precluded by the notion of a causal module, it certainly does not receive sufficient emphasis by an approach that assumes the perception of causality is an autonomous, self-contained entity.

A Working Definition of Causality

As indicated above, the experiments we shall be discussing in this chapter typically employ stimulus events in which one inanimate object either collides with a second inanimate object, at which point the first object stops and the latter object moves (a direct launching event), or a similar event, but one in which a spatial gap or temporal delay is inserted at the point of object contact. For adults it is clear, at least, that the first event promotes the "illusion of causality" (Michotte, 1963), while the gap and delay events are both perceived as not being causal. These prototypical events trace their origins at least as far back as Hume (1777/1993), who offered the example of one billiard ball striking another as the simplest example of a sequence of events giving rise to the inference of "causation". In the next section, we shall discuss Hume's philosophy of causality in more detail, but for now the point is simply that when we talk about infants' perception of causality in this chapter, we are talking about their tendency, at least at some point in development, to distinguish between or to organize these sorts of stimulus events on the basis of causality, rather than on some other basis. Thus, for our purposes, an infant who treats the gap event and the delay event as more or less the same, but who treats the direct launching event as quite different from either the gap event or the delay event, is responding on the basis of causality.

Historical Views and Distinctions

More than any other investigator, Leslie (1984; 1986) has emphasized the similarity between infants' perception of simple causal events and adults' perception of those same events as reported by Michotte (1963). In addition to establishing a simple working definition of causality, it is essential that, for the most part, we limit our discussion conceptually to what Leslie referred to as "mechanical causality" (Leslie, 1995) and Piaget (1954) referred to as "physical causality". The limitation is crucial because, as discussed below, a distinct body of psychological literature and philosophical discourse has grown up around two distinct types of cause and effect relationships. Although the literature on this subject is vast, we will limit most of our discussion in this section to Hume and Piaget, the two major figures against whom Leslie seems to direct most of his criticism.

The mechanical causality referred to by Leslie is the sort of causality that obtains to the relation between two or more objects external to the observer. Hume's billiard ball collision is perhaps the best example. A distinct, but perhaps not totally separable type of causality obtains to the relation between the observer as agent and other objects as recipients of action from the observer. Perhaps the best examples of this type come from Piaget, who stressed the young child's interactions with his environment, and his or her growing awareness of "psychological causality", i.e., the notion that the child is volitionally bringing about consequences in an external world.

The notion of causality as an inductive inference, derived originally from our own sense of power over our own limbs and organs, can be seen explicitly in Piaget (1954), who distinguished among various stages of causal understanding. The earliest stage is characterized by a combination of what Piaget called causal efficacy and phenomenological causality. At this stage the infant has no understanding of the concept of object or of self, and cannot have any meaningful understanding of psychological or physical causality. Even in the next stage of development of causal understanding, in which Piaget proposed that the infant begins to have some dim sense of his power over his world, Piaget was emphatic that the child still has no understanding about the true nature of this power. The infant merely has some vague "magical" sense of his power to bring about pleasurable results. Later in development, however, as the infant learns to distinguish between himself and his environment, and to understand about the permanence of objects, the infant begins to differentiate between different sorts of cause and effect relationships. Finally, in the second year the infant comes to understand as distinct concepts psychological or internal causality, or knowledge about power over one's actions, and physical or external causality, or knowledge about the physical relationships between external objects.

Like Piaget, Leslie (1995) also made a distinction between mechanical (physical) and actional (psychological) properties of causality. Unlike Piaget, however, Leslie (1995) assumed that mechanical and actional causality are based upon different mechanisms, a theory of body, ToBY (based upon the notion of force) and a theory of mind mechanism, ToMM. Furthermore, he assumed that both ToBY and ToMM serve as bases for development rather than being products of development. These theories seem to be more descriptive than explanatory, with little or no indication from Leslie about how they might arise in the first place.

More than two centuries ago, in An Enquiry Concerning Human Understanding (1777/1993), Hume wrestled with the meaning of causality and where it originates. Indeed, he stated at the outset: “There are no ideas, which occur in metaphysics, more obscure and uncertain than those of power, force, energy, or necessary connexion... “ (p.40) (emphasis in original). In the course of his analysis of causality, Hume entertained and rejected several arguments to the effect that we need not have repeated experience with physical objects in order to derive the notion of cause and effect in the external world. One of the arguments Hume rejected was that the idea of physical causality could be derived logically as an a priori truth by reasoning about the power we have to move our own bodies. Piaget later adopted the position that knowledge of causality in both the physical and psychological domains is derived from our prior experience of power over our own bodies. From Hume’s philosophical perspective, however, there was no fundamental difference between the origin of psychological and physical causality. The power of a causal agent over a causal recipient in both cases was, for Hume, “unknown and inconceivable” (p.44). The idea of power, or a “necessary connexion among events arises from a number of similar instances, which occur, of the constant conjunction of these events; nor can the idea ever be suggested by any one of these instances, surveyed in all possible lights and positions....[A]fter a repetition of similar instances, the mind is carried by habit, upon the appearance of one event, to expect its usual attendant” (p. 50). Thus, for Hume, the idea of cause and effect, in both its psychological and physical manifestations, was based upon experience. It was not an innate predisposition of the mind.

Whether one agrees or disagrees with the emphasis Hume placed on repeated experience, the significance of the distinction between physical and psychological causality remains controversial. This chapter is not an attempt to resolve that controversy. We shall restrict our discussion primarily to issues related to the development of physical causality, while at the same time being fully aware that Leslie's recent views do include aspects of causality beyond physical causality, and that Piaget may well have been prescient in speculating that awareness of physical causality may be dependent on the earlier development of a more self-centered version of the phenomenon.

But returning to the earlier comment that Hume's and Piaget's writings on causality take the brunt of the criticism from Leslie and others, what exactly do modern-day modular theorists find objectionable about the basic tenet, expressed in different ways by both Hume and Piaget, that an understanding of causality develops over time? Leslie argued that, "Hume was wrong to conclude that our idea of causal relation must therefore be based on statistical association" (Leslie, 1995), or in other words, learned over time. Yet in earlier writings Leslie was not just amenable, but emphatic about a distinction between the operation of a causal module in infancy, and an understanding of causality later in development (Leslie, 1988). He went so far as to call the output of the proposed causality module "COSE", in order to make it clear that its output was not the same as an understanding of the concept of causality. In more recent writings, Leslie (1995) says that Hume was wrong about inference because infants do not need to learn about basic cause and effect. They come equipped with a "sub-module" whose job it is to detect mechanical interactions in which force is transmitted (Leslie, 1995). Has Leslie backed away from his earlier distinction between "COSE" and an understanding of causality? Is he now assuming that an understanding as well as a perception of causality is part of some innate module?

Putting aside the issue of a distinction between "COSE" and cause, Leslie's idea of a causal module is borrowed explicitly from Marr (1982), who urged researchers in vision to adopt the computer science concept of a module in order to break down the dauntingly complex study of vision into more tractable pieces. Marr argued that if one can identify a process within vision, such as stereopsis, that appears to be relatively autonomous, hard-wired, and impervious to the influence of general knowledge, then it makes sense to approach the study of stereopsis as a separate problem. Marr was willing to call a process within vision a module only after experiments showed convincingly that it truly met these independence requirements. Marr also made it very clear that calling something such as stereopsis a module was merely the first step in attempting to understand the purpose and function of stereopsis: calling stereopsis a module was not a substitute for attempting to understand how stereopsis works. In keeping with Marr's rather strong admonitions in this regard, we respectfully question whether Leslie's proposal for a causality "module" is premature, and whether it comports with Marr's belief that calling something a module merely narrows the hypothesis space for formulating potential explanations.[2] We agree wholeheartedly with Marr's general proposition that processes typically must be isolated before they can be studied successfully, but we disagree with Leslie if he is arguing that calling something a causal module tells us very much about how the perception of causality works.

As a consequence of causality perception being characterized as the result of an innate module, there is no room in Leslie's formulation for causality perception to develop in stages. Accordingly, if anything relevant to causality develops, it must be causal understanding rather than causal perception. Is Leslie placing causal perception and causal understanding in separate compartments, and arguing that anything that changes after birth must be related to causal understanding? If so, then would a developmental progression in infants' treatment of causal and non-causal events count as evidence against a module, or just as evidence for the development of causal understanding?

The remainder of this chapter is about what infants actually do when confronted with the sorts of events described above in the working definition of causality. In the course of discussing these experiments, we hope to show that the arguments between Leslie, on the one hand, and Hume or Piaget, on the other, are not just quibbles over words. Instead, they

[2] This reference to Marr is even more problematic in light of the fact that Marr's work on vision was decidedly not developmental. It would be irrelevant to Marr's theorizing about the adult visual system whether the modules he identified for analysis were innate or the product of early development. In fact, we know that many of Marr's visual modules, such as stereopsis, are not functional early in development (e.g., Yonas and Granrud, 1995).

are getting at significant questions about the relevance of development. As we shall show, the evidence strongly suggests that whether one calls it causal perception or an understanding of physical causality, infants' reactions to causal and non-causal events are not static over age; they change dramatically during the first year of life and beyond.

Evidence from Occluded Events

As already discussed, in his most recent writings Leslie (1995) advances the strong view that causality is not a concept whose contours and complexities develop; on the contrary, it is a core cognitive property which must be in place at the outset in order for development to proceed. Causality, according to Leslie and other nativists, therefore is not something to study developmentally: it is a *non sequitur* to study the development of something that doesn't change. One simply needs to confirm its presence in young infants to verify that it is available as a building block for further development. In keeping with this position, experiments by Ball, Leslie, and others have attempted to demonstrate the presence of causality in infants during the first year of life.

In an unpublished experiment which may have been the first explicitly to advance the notion of an innate causal module operating in infancy, Ball (1973) presented infants across a wide age range (9 to 122 weeks) with a three-dimensional stimulus display in which a red block moved horizontally from right to left and passed behind an occluding screen. Half-exposed at the left edge of the screen, a white block was poised in the path of the red block. At the moment that the red block reached the right edge of the white block behind the screen, the white block was put into motion in a manner suggesting, at least to an adult observer, that the red block had caused the white block to move. Subjects were shown this "screen event" ten times. After being familiarized with the event, half of the subjects were placed in the contact condition. They were shown ten more presentations of the same sequence, from an adult perspective, but with the screen absent throughout. In other words, they were shown the red block actually contacting the white block, and then the white block moving to the left in response to this contact. The other half of the subjects, who were assigned to the non-contact condition, were shown the red block stopping 3 cm. short of the white block; then, after a 100 msec. delay, the white block nevertheless moved off to the left in the identical manner as in the contact condition.

There are numerous problems with the Ball experiment, including an extremely small sample size and a wide range of subject ages, a failure to produce habituation, an improper control group, and numerous marginal or statistically insignificant results that were over-interpreted[3]. Nevertheless, Ball's central finding was that infants in the non-contact condition appeared to show an increase in looking time compared to their performance during the familiarization trials, while in the contact condition, no such increase was apparent. Ball interpreted this pattern of results as support for the notion that infants come into the world with at least some limited form of causal perception. His argument was that subjects were treating the non-contact event as novel, and therefore looking at it longer than at the familiarization event, because the familiarization event was perceived as causal, while the non-contact event was not. Ironically, Ball also suggested that the older subjects in his experiment appeared to be showing less of a tendency to look longer in the non-contact condition. He offered no explanation for why this might be so, and one wonders how such a result, if replicable, could be squared with Ball's conclusion that the younger infants were perceiving the various events in the adult-like way proposed by Michotte (1963), i.e., in terms of some automatic system that perceives causality.

Three recent studies raise additional questions about Ball's conclusions. In one report, Van de Walle, Woodward, and Phillips (1994) claim to have replicated Ball's results with 6-month-old infants. They tested a reasonable number of subjects and did make certain that habituation had occurred prior to the test phase, both improvements over the original Ball study. They also included a control group that was habituated to two stationary blocks, one

[3] Spelke et al. (1995) noted that when they reanalyzed Ball's data for infants under 7 months of age, the preference for the inconsistent (non-causal) test event was significant relative to baseline. We too reanalyzed Ball's data. The appropriate comparison would be the difference in preferences, relative to their baselines, of inconsistent (non-causal) vs. consistent (causal) test events. This difference did not approach significance for the subjects as a whole, nor for the subgroup under 7 months of age.

on either side of the occluder. Unfortunately, their only significant effect seems to be in this control group, and one could reach the reasonable conclusion from their data that infants who had been habituated to objects that are initially separated from one another, will look longer at a test event when the objects touch one another.

Oakes (1992) also reported an attempt to replicate Ball's study, in this case with 10-month-old infants. She not only habituated one group of infants to a causal, direct launching event as Van de Walle, et al. (1994) had done; she also habituated a second group to a delayed launching event, and a third group to a no collision event. As we have mentioned earlier, these latter two events are considered to be non-causal by adults. Since an occluder was used, the defining moment for each type of event was hidden. The only perceptible difference between the events was the time interval between the disappearance of the first ball behind the occluder and the subsequent appearance of the second ball from the occluder. These times were 0.75 s for the direct launching event, 0.0 s for the no collision event, and 1.5 s for the delayed launching event. Each group was then tested with all three types of events, for the first time shown in full view, without the occluder, as Ball had done. Oakes found that unlike adult subjects, who had no trouble distinguishing occluded causal from occluded non-causal events, all three groups of infants treated their occluded habituation events as causal. All three looked longer at both non-causal events in the test than at the causal event. Thus, although the 10-month-old infants seemed to be responding on the basis of the causality, they were over-generalizing that causality to events that were not actually causal, and were certainly not responding in the same way as adults.

Finally, Lucksinger, Cohen, and Madole (1992) also presented infants with causal and non-causal events behind an occluder. Their procedure closely followed that of Baillargeon (1986). In the portion of the experiment most relevant to the present discussion, 6- and 10-month-old infants were habituated to a car that ran across a track, went behind one side of an occluder, and then reappeared at the other side of the occluder. During test trials, a second, distinctly <u>different</u> car was placed either on the track or behind the track, and then this part of the event was obscured by the occluder. As in the habituation phase, the first car traveled across the track and went behind the occluder, but now the second car reappeared from the other side. This event would be possible--a causal event, in fact--if the second car had been placed on the track, but it would be impossible, or at least improbable, and non-causal if the second car had been placed behind the track.

Based upon Baillargeon's previous work, the prediction was that if infants were inferring the causality of the event; i.e., that the first car should have hit and pushed the second car, then they would look longer at the impossible event than at the possible event. Ten-month-olds performed as predicted, but 6-month-olds looked equally long at the two events. As in the previously mentioned studies, this experiment examined infants' ability to infer causality from a launching event in which the critical contact between objects was obscured by an occluder. Reviewing all of these studies in which an occluder was used to investigate infants' reactions to causality, the inevitable conclusion is that although clear evidence of causal perception or understanding can be found at 10 months of age, the evidence is inconsistent, at best, at younger ages.[4]

Such a conclusion would be compatible with a Piagetian point of view, since by 10 months of age, infants should be able to infer an object's existence even when it is hidden behind an occluder. That inference must be a necessary ingredient in any subsequent inference about a causal or non-causal relationship between two hidden objects. Perhaps more to the point of the present discussion, the conclusion would also be compatible with a "causal module" view such as the one proposed by Leslie (1986). In order for Leslie's automatic, perceptual module to be activated, it would need to receive the appropriate input. That input, namely, the spatial contiguity and temporal continuity that occurs when the first object collides with the second object, is precisely what is obscured by the occluder. In fact,

[4]Spelke, et al. (1995) state that "... a comparison across different studies reveals a convergence between infants' reactions to events involving visible objects and infants' reactions to events involving hidden objects." (p. 51). Based upon the evidence we have cited, we disagree with their conclusion. As we shall indicate below, we believe infants respond to the causality of visible objects at a considerably younger age than they respond to the causality of hidden objects.

it is not apparent why occlusion should be employed in experiments examining causal perception. It would appear that simpler, more direct evidence of infants' causal perception can be obtained by allowing infants to see the collision, or lack of collision, between the two objects.

Evidence from Visible Events

Several experiments have now been reported in which the entire events shown to infants were visible. In general, these experiments compared infants' responding to a causal event and one or more non-causal events. Figure 1, illustrates the four types of events used in these causal perception studies: a direct launching event, in which one object collides with a second object that then moves immediately following the collision; a delayed launching event, in which a short time interval (e.g., 1 s) elapses before the second object begins to move; a no collision event, in which the first object never reaches the second object and a spatial gap (e.g., 5 cm.) exists when the second object begins to move; and a no collision plus delay event, in which both the gap and the delay are present.

Insert Figure 1 about here.

The logic behind most of these studies was to pit responding on the basis of causality against responding at a lower, perceptual level. The upper portion of Figure 2 represents schematically the psychological space if infants are responding to these events solely in terms of their independent spatial and temporal characteristics. Some might believe that the appropriate measure of psychological distance would be a city block metric. Others might argue for a Euclidean distance approach. According to a city block metric, the difference between the delayed launching and the no collision would be obtained by summing lines a + b in the upper portion of the figure, whereas the difference between the delayed launching and the direct launching would be only b. On the other hand, according to a Euclidean distance approach, the difference between the delayed launching and no collision would be c, but it would still be only b between the delayed launching and the direct launching. Thus, using either a city block metric or a Euclidean distance approach, and assuming that a and b are greater than zero, the independent features view would predict that a delayed launching event would be a greater psychological distance and should differ more from a no collision event (from which it differs both spatially and temporally) than from a direct launching event (from which it differs only temporally).

Insert Figure 2 about here.

In contrast, the lower portion of Figure 2 represents the case psychologically if infants are responding to these events solely on the basis of causality. The direct launching would be the only causal event. As a result, it should be perceived as qualitatively different from the other three non-causal events. On the other hand, these other three events should be perceived as equivalent. Two objects move sequentially in each event, but the objects are moving independently; in none of them is the first object causing the movement of the second object.

In a series of experiments, Leslie (1984) tested 6 1/2 month old infants on their ability to discriminate the events shown in Figure 2. His results clearly showed evidence of responding on the basis of causality, but that was not the whole story. He also found evidence of responding on the basis of independent features. These mixed results led Leslie to propose a one-dimensional “spatio-temporal continuity gradient” incorporating both types of responding. Presumably, Leslie’s infants were responding in terms of this gradient rather than solely in terms of causality. However, such a mixed bag of responding raises a number of questions about the modularity of causal perception. For example, if infants’ responding is based (in part) upon a causal module, why is it also based (in part) upon an incompatible perceptual system in which the spatial and temporal features are independent? If, as Leslie (1995) proposes, this causal module (or perhaps this “spatio-temporal continuity gradient”) is a core property that can serve as the basis for later development, but is not the product of previous development, then would one expect little if any developmental change in the gradient, or only in the modular part of the gradient? In short, it is unclear what, if any, predictions would flow from Leslie's model about developmental changes in infants' responses to simple causal events.

In contrast, Cohen (1994; 1997, in press) and Oakes and Cohen (1995) have argued on the basis of their information processing view that infants' perception of independent spatial and temporal features is a developmental precursor to later causal perception. According to this view, one should find developmentally, a decrease in responding in terms of independent features and an increase in responding in terms of causality. In fact, Oakes and Cohen (1994) also argued that the two types of responding found by Leslie (1984) in his 6 1/2 month old infants, and that Leslie assumed to be part of the same "spatio-temporal continuity gradient", may actually have resulted from summing over two types of infants: less advanced infants, who were still perceiving the events in terms of independent features, and more advanced infants, who had made the transition to causal perception.

Two recent studies lend support to this information processing view. In one experiment reported by Oakes (1994), 7-month-old infants (approximately two weeks older than those Leslie had tested) were presented with simple events involving moving red and blue balls. Infants were habituated to either a causal direct launching, a non-causal delayed launching, or a non-causal no collision event. The infants were then tested on all three events. Oakes found significant evidence of responding on the basis of causality, but no significant evidence for responding on the basis of independent features.

In a very recent study conducted in our laboratory, Cohen and Amsel [1997], the Oakes procedure was used once again, this time with 6 1/4 month old infants--infants just 1 to 2 weeks younger than Leslie's. The events involved moving red and green circles. The results, shown in Figure 3, closely replicated those of Leslie. At this age, just as in Leslie's experiment, there was significant evidence not only of responding in terms of causality, but also in terms of the independent features.

Insert Figure 3 about here.

Figure 3 presents the test data for infants habituated to the CAUSAL (direct launching), DELAY (delayed launching), and GAP (no collision) events. As would be expected from either a causal or independent features view, infants habituated to the causal event dishabituated to both the delay and gap events in the test. Infants habituated to delay or gap events dishabituated more to the causal event than to the other non-casual event (gap event or delay event respectively). This pattern is precisely what would be predicted by a causal perception view. If infants are responding in terms of causality, they should dishabituate more when the meaning of the event changes from non-causal to causal, than when it remains non-causal. However, clear evidence was also found for responding in terms of independent features. When infants who were habituated to one non-causal event (delay or gap) were tested on the other non-causal event (gap or delay) they also dishabituated significantly. Thus, the experiment replicated Leslie (1984) by providing reliable evidence of responding in terms of independent features as well as causality.

If one compares all three experiments, Cohen and Amsel at 6 1/4 months, Leslie at 6 1/2 months, and Oakes at 7 months, a developmental trend appears showing evidence of causal perception at all three ages, but also showing a systematic decrease in independent feature perception from 6 to 7 months of age. This is just the trend predicted by the information processing view.

We also had the opportunity to examine individual infants' performance in the Cohen and Amsel (1997) experiment. You will recall that Oakes and Cohen (1994) had argued that Leslie's results may have resulted from two subgroups of infants, one subgroup responding in terms of causality, and the other subgroup responding to independent features. In fact, Oakes and Cohen had shown that the two subgroup view predicted Leslie's results as well as his continuity gradient view. Accordingly, we examined the individual data for the 24 infants in Cohen and Amsel's (1997) study who had been habituated to a non-causal event. We were looking to see if these infants uniformly looked longer at the causal event than at the novel non-causal event (as predicted by the continuity gradient) or if some infants looked longer at the novel non-causal event than at the causal event (as predicted by the independent features view). Ten of the 24 infants looked at least 2 s longer at the causal test event than at the other non-causal test event, but 6 of the infants looked at least 2 s longer at the other non-causal event than at the causal event. Thus, some tentative evidence, at least, has been found for the existence of two subgroups rather than for one group responding to some overall “spatio-temporal continuity gradient”.

What obviously is needed to resolve the developmental issue is evidence from yet younger infants. Will these infants respond even more in terms of independent spatial and temporal features, or perhaps in terms of even simpler perceptual characteristics? And what will happen to their perception of causality? Will it continue to be evident at younger ages, or will it be preceded by simpler, non-causal modes of responding?

Evidence from Younger Infants

The causality experiments recently completed in our laboratory (Cohen and Amsel, 1997) tested infants not only at 6 1/4 months--about the same age as those tested by Leslie and Keeble (1987)--but also at 4 months and 5 1/2 months. Our results, which are shown in Figure 4, challenge Leslie’s position that causality perception is largely innate and hard-wired. Instead, the data indicate a developmental progression involving at least two distinct modes of processing prior to anything resembling processing in terms of causality. Ironically, it is the more primitive of these two modes which may be getting misconstrued as a form of built-in causality perception. Infants were presented with the same events 6 1/4 month olds had seen. Separate groups were habituated to either a direct launching, a delayed launching, or a no collision (gap) event. They were all then tested on all three events. The 4-month-old subjects displayed a pattern of post-habituation looking times that was dramatically different from the 6 1/4 month pattern described earlier. The key feature of looking behavior at 4 months, which is apparent from the white bars in the top graph of Figure 4, is that regardless of whether infants were habituated to the causal event or one of the non-causal events, they looked longer at the causal event during the test phase. Based on the logic of habituation, if infants are perceiving the events in terms of causality, then infants habituated to the causal event should be exhibiting exactly the opposite pattern of looking times. They should remain habituated to the causal test event, but dishabituate to either of the non-causal events. It is not clear why infants at 4 months showed such persistence in preferring to look at the causal event sequence, regardless of habituation. Lecuyer (1994) has reported the same overall preference for the causal event at 4 months when the objects were more realistic and complex than the red and green circles we had used.

Insert Figure 4 about here.

One possible explanation for this result is that the causal event was preferred at 4 months of age, not because of any conceptual distinction between it and the non-causal sequences, but simply because infants at this age were entrained by the uninterrupted, smooth movement of the two balls in the causal event. An analysis of the first four habituation trials shows that even prior to habituation, infants looked significantly longer at the causal event than at either of the two non-causal events. Obviously, much more work would have to be done to support a formal entrainment hypothesis, but it is offered here merely as one possible, albeit speculative, explanation for the tendency of infants at 4 months to prefer the “causal” event regardless of any habituation-induced novelty preference.

At 5 1/2 months, again contrary to what Leslie and Keeble (1987) would have predicted, there still was no causality effect. Indeed, infants habituated to the causal event still looked longer at the causal test event than at either of the non-causal test events. Again, this result is exactly the opposite of what a proponent of innate modularity would predict in an habituation experiment, and exactly the opposite of the result we obtained in the identical experiment at 6 1/4 months. Thus, even at 5 1/2 months, infants still seem to be processing the causal event in terms of something other than causality.

The other crucial development at 5 1/2 months can be seen clearly in the bottom graph of Figure 4. Infants habituated either to the delay or the gap event dishabituated significantly to the other non-causal event; i.e., to whichever non-causal event they were not exposed to during habituation. This effect is not hard to interpret if the events are considered in terms of their independent spatial and temporal features, instead of in terms of causality. Infants habituated to the gap event, for example, are seeing a spatial gap and continuous motion during habituation. In the delayed test event, they see two changes: no spatial gap, and discontinuous motion, whereas in the causal event, they see only one change: no spatial gap. Thus, the dishabituation the 5 1/2 month olds exhibited to the other non-causal event would be predicted by an independent features view. In fact, while infants at 6 1/4 months were beginning to show a pattern of results for the first time suggesting sensitivity to causality, it will be recalled that even these older infants were still showing a pattern of test responses indicating some sensitivity to the independent spatial and temporal features of the stimulus events. As we had indicated in Figure 3, infants at 6 1/4 months, who were habituated to one of the non-causal events, still showed significant dishabituation to the other non-causal event. Responding primarily in terms of something as simple as entrainment at one age, more in terms of spatial and temporal features at a later age, and then more in terms of causality at a still later age is problematic from an innate modularity perspective, but it makes perfect sense from a more traditional developmental perspective. Furthermore, the data support the developmental progression. Not only are the three distinct modes of processing visible in the three age groups studied in our laboratory, but remnants of the prior, simpler modes of processing are visible in the later age groups as well. In the data from 5 1/2 months, it is clear that superimposed on the processing of independent attributes is a remnant of something like entrainment to the causal event. Similarly, at 6 1/4 months, evidence for this entrainment has disappeared, but superimposed on what appears to be causal processing is a remnant of processing based on independent features. Finally, at 7 months of age, causal processing remains, but processing based upon independent features has decreased or disappeared. This simultaneous waxing and waning of more and less advanced forms of processing, respectively, is the hallmark of a more constructivist, information-processing perspective on development.

Furthermore, the evidence also seems consistent with, at least, some aspects of Michotte's (1963) view of causal perception in adults. For Michotte, a direct launching presents the perceptual system with a conflict. Continuity of motion is perceived but so are two distinct events, movement by the first object and movement by the second object. Michotte argued that the perceptual system resolves this conflict by perceiving the direct launching as causal. We are not certain whether Michotte's explanation of causal perception is totally correct. But assuming for the moment that it is, our results with 4-month-olds indicate their sensitivity to continuity of motion, and our results with 5 1/2-month-olds indicate their sensitivity to distinct events with different moving objects. Thus, the data supporting our information processing view of causality development are consistent with Michotte's conception of causality perception in adults. While Michotte did not emphasize developmental mechanisms, and may have even been a nativist (see Ball, 1973), he did assume that the perception of causal events required both the perception of continuity of motion and the perception of two distinct moving objects. We are simply proposing that the perception of these two aspects of an event develop independently at first, and then combine at some later age to form the perception of causality.

Evidence from Older Infants

Research presented thus far indicates a clear, three-step developmental progression in infants' perception of causality. It also indicates that infants can achieve causal perception of simple launching events by 6 or 7 months of age. Although evidence of developmental precursors to causal perception tends to undermine certain innatist, modular views such as those of Ball (1973), Leslie (1986), or Fodor (1983), it does not necessarily undermine all modular views. Karmiloff-Smith (1992), for example, draws a reasonable distinction between the notion of "pre-specified modules" and the process of "modularization", by which she means that self-contained, encapsulated modules may be the products of development rather than be present full blown at the outset. We are generally sympathetic towards Karmiloff-Smith's approach, and the evidence we have presented so far could be considered consistent with it. In fact, if we were to end the chapter at this point, it would be tempting to conclude that we had found evidence for the "modularization" of infant causal perception at 7 months of age.

But modularization implies encapsulation of whatever is being modularized. Just because, under some circumstances, 6- or 7-month-olds can respond on the basis of causality, does not necessarily mean that 6- or 7 month-olds have developed, and are using, a self contained, encapsulated module to perceive that causality. Presumably being self contained, or encapsulated, refers to the fact that the module should be sensitive to certain relevant information , but impervious to irrelevant background information. But what should count as relevant and irrelevant information for a causal module? We have already noted that, at least according to Michotte, the relevant information should be the spatial and temporal relations between two objects that produce the perception of continuous movement, on the one hand, and the perception of two moving objects on the other. This conflicting information should be sufficient to trigger this causal module and produce the automatic perception of causality.

What should count as an example of irrelevant information? Michotte (1963) provides some guidance here as well. In his discussion of the direct launching event he says, "From all this we may conclude *that the causal impression which appears in the Launching Effect is independent in principle* (if we disregard the possibility of gradual differences) *of the phenomenal aspect of the objects."* (p. 85, italics included in original article). In other words, according to Michotte, in a simple launching event the nature of the objects should be irrelevant to the perception of causality.

Almost without exception, the research we have reviewed thus far has shown infants events that included only uniform, extremely simple objects such as red and green blocks or red and blue circles. Would the same results obtain if, instead, more realistic, complex objects were used in these events? We believe modularists ought to predict that the type of object should not make any difference. As long as movement of the objects produced the appropriate spatial and temporal information, infants should perceive the event as causal. Thus, even with complex objects, the module should trigger the perception of causality in 6- or 7-month-old infants.

In contrast, the information processing view proposed by Oakes and Cohen (1994) would predict that the complexity of the objects could make quite a difference. According to this view, before infants can perceive a causal relationship between any two objects, they must discern that the moving stimuli being presented in the event are, in fact, distinctly different objects. With simple objects, such as green and blue blocks, even 6- or 7-month-old infants should have little difficulty making this distinction. But with more complex or realistic objects, integration of each of the objects' structural features into unified percepts of particular objects should be quite difficult for 6- or 7-month-olds. Thus, even though infants may be capable of perceiving a causal relationship between two simple objects at a relatively young age, they should be considerably older before they can perceive the same type of causal relationship between two complex objects.

As we have noted, in this chapter we have concentrated on studies using simple objects, but several additional studies have examined infant causal perception when the events included more complex objects. In general, the evidence from these studies is unambiguous. Infants have to be quite a bit older than 6 or 7 months of age before they can perceive the causality of these events. In one study that already has been mentioned, Lucksinger, Cohen, and Madole (1992) found, using an occluded object task with drawings of a toy car and a toy truck, that 6-month-olds did not respond on the basis of causality, but 10-month-olds did. Of course, from the present point of view, a comparison of the Lucksinger results with those of others, such as Leslie's (1984) or Cohen and Amsel's (1997) that reported 6-month-olds could respond to visible events on the basis of causality, confounds the complexity level of the objects with the presence versus absence of occlusion. It would be more appropriate to compare two studies that differed from one another only in object complexity.

A study reported by Oakes and Cohen (1990) meets that criterion. They examined 6- and 10-month-old infants, using exactly the same design as Cohen and Amsel (1997), but with objects that were realistic toy vehicles. Examples of these type of vehicles are shown in Figure 5A. Infants were habituated to a direct launching, a delayed launching, or a no collision event, and then tested on all three types of events. Clear evidence of causal perception was found at 10 months, but no evidence, at all, of causal perception was found at 6 months. Oakes and Cohen (1990) also showed that the 6-month-olds were not totally overwhelmed by the sight of realistic toys. The 6-month-olds did dishabituate when novel toys replaced the familiar toys. Apparently, at that age, they just did not notice the critical spatial or temporal differences between the causal and non-causal events.

Insert Figure 5 about here.

The failure of 6-month-olds to respond in terms of causality when realistic objects are used could be considered an embarrassment to a modular view, but it certainly should not be considered a fatal flaw of that view. One might simply counter that although the toys may not have overwhelmed the infants completely, they may well have distracted the infants from other aspects of the events. One might even argue that the 6-month-olds were attending to certain interesting attributes of these toys, and not even processing them as unified and distinct objects. Although this latter argument might well be the explanation for the failure of the 6- month-olds, accepting it would be tantamount to accepting the information processing view. A more definitive test of the modular view will be described below.

As Leslie (1995) has noted, a more critical test would be to find an instance in which infants show sensitivity to the spatial and temporal characteristics of the event, but not to the causality of the event. We have already presented such evidence with 5 1/2 month old infants; but by some accounts, that would not be the most telling evidence since the infants have not yet developed their causal module. A more definitive test would be to show that infants who, under some circumstances, do respond to the causality of an event, under other circumstances, respond to the spatial and temporal characteristics of the event, but not to the causality.

Cohen and Oakes (1993) provided that evidence. In their first experiment, they described what was basically a replication of the Oakes and Cohen (1990) study with 10-month-old infants, but with one small change. Once again different groups of infants were habituated to a direct launching, a delayed launching or a no collision event. However, instead of using a single toy vehicle as the agent and a second toy vehicle as the patient, as Oakes and Cohen (1990) had done, each infant saw five different pairs of vehicles during habituation. Thus, although the infants were receiving consistent spatial and temporal information, the objects producing that spatial and temporal information changed from trial to trial. Figure 6 shows, for comparison purposes, the test data from the original Oakes and Cohen (1990) study and below it, the test data from this Cohen and Oakes (1993) multiple object study. As one can see from the figure, the main difference between the two studies occurred with those infants who were habituated to a non-causal event. In Oakes and Cohen (1990) the infants dishabituated most to the causal event, a finding consistent with a causal perception view. In Cohen and Oakes (1993), on the other hand, the infants dishabituated most to the other non-causal event. This finding, which is consistent with an independent features view, indicates that the 10-month-old infants in the multiple object study <u>were</u> sensitive to the spatial and temporal characteristics of the event, but nevertheless not to the causality of the event. In other words, under circumstances in which infants saw multiple objects, the requisite spatial and temporal characteristics were processed, but apparently, no causal module was activated. To us, this result appears to be in direct contradiction to what would be predicted from a modular view of causal perception.

Insert Figure 6 about here.

But the interpretation of Cohen and Oakes' (1993) first experiment goes beyond just demonstrating the inadequacy of a modular approach. From a more positive point of view, it also demonstrates that the specific objects involved in an event were included in the infants' percept of that event. In other words, 10-month-old infants who see a direct launching repeatedly with the same two objects, A and B, are not perceiving that somehow in the abstract, "causality is going on" or that, "this is a causal event". They are perceiving a causal event that involves objects A and B. Furthermore, Experiments 2 and 3 by Cohen and Oakes (1993) indicated the infants were actually parsing the events. They appeared to be able to group the type of action (causal or non-causal) with the particular object used as agent (A), but not with the object that served as patient (B).

The idea that infants may be doing more than perceiving causality, that they may also be distinguishing between agent and patient, is important to Leslie's (1995) theoretical position. He has argued that infants perceive or understand the concept of "agency", and that a study which demonstrates infants can distinguish between the roles of agent and patient would be the clearest evidence that the infants are actually perceiving causality. Therefore, we shall turn next to studies examining infants' ability to distinguish between agent and patient.

Evidence on the Agent - Patient Distinction

Thus far, we have been discussing experiments employing one sort of logic. Infants are either exposed to one of two non-causal events or to a causal event during habituation, and then tested on all three events. Leslie, (1995), however, has proposed that the most definitive test for causal perception would be to familiarize infants to events that are either causal or non-causal, and then to test their reaction when the familiarization event is shown in reverse. He argued that if infants are sensitive to causality, then those in the causal condition should show greater dishabituation than those in the non-causal condition. This would be the prediction because reversal of a causal sequence reverses the action roles of the agent and patient, whereas in a non-causal sequence, the two objects do not have different roles, so a reversal would not create a significant change in those roles.

We disagree with Leslie that reversal experiments are necessarily a better test of causal perception than the sort of experiments we have just described in the preceding sections. It certainly could be the case, for example, that infants come to appreciate the causality of an event prior to the time that they key in on the specific roles of the agent and patient. Nevertheless, Leslie's idea of reversing action roles is intriguing, and if infants do respond more to role reversals in a causal event than in a non-causal event, it almost certainly would indicate that the infants possess some degree of causal perception.

Golinkoff reported some of the earliest research on infants' reactions to action role reversals. In one experiment Golinkoff (1975), showed 14- to 24-month-old infants a man pushing a woman from left to right across the screen, (M→W). Infants subsequently watched a direction of action which entailed a role reversal, (M←W), more than just a direction of action reversal alone, (W←M). In another experiment Golinkoff and Kerr (1978) habituated 15- to 18-month-old infants either to a film of one man pushing a second man or to a film of a man pushing a chair. In both types of events the direction of action was varied from trial to trial during habituation. She found that infants dishabituated in the test when either event was reversed. Although both studies indicated that infants above 14 or 15 months of age notice something about the reversal of action roles, unfortunately, one cannot conclude from either study that infants had a true understanding of agent-patient relationships because the studies did not include a non-causal condition in which the conceptual roles remained the same in spite of the action reversal.

Leslie and Keeble (1987) did include the required non-causal control condition. They reasoned that if young infants do, in fact, perceive causality they should respond to the reversal of a causal event more than to the reversal of a non-causal event because only in the causal event would there be a reversal of the role of agent. They habituated infants, ranging in age from 24 to 32 weeks, to a direct launching event or to a non-causal, delay event in which a .5 s delay occurred between time of contact of the objects and movement of the second object. As Leslie had done in earlier studies, the objects used in the events were a green and a red block. During habituation these objects moved from one side of the screen to the other (either left or right). For the critical test event the film was reversed so that the order of the objects in the events as well as the side of the screen from which the first object originated were reversed. Leslie and Keeble reasoned that in the non-causal event, a reversal would not be particularly interesting because the two blocks had not changed roles. In the causal event, however, a reversal of the film also reversed the causal roles of the red and green blocks. The agent now became the patient, and vice versa. They hypothesized, therefore, that infants in the causal group should dishabituate far more than those in the non-causal group. That is exactly what they found. Their infants showed greater dishabituation for reversal of the causal sequence than for reversal of the non-causal sequence. Thus Leslie and Keeble (1987) provide rather convincing evidence that at approximately 6 1/2 to 7 months of age, infants do, under some conditions, notice when the agent and patient in a causal sequence are reversed. It remains to be seen whether, as Leslie (1995) argued, this result also provides evidence for an active causal module at 6 1/2 months.

Redford and Cohen (1996) were specifically interested in the age at which infants acquire some understanding of agent and patient and what infants might perceive or understand prior to that age. As in Leslie and Keeble (1987), one group of infants was habituated to a direct launching event in which one object "pushed" another object. Unlike Leslie and Keeble, however, a second group received a no collision event, rather than a delay event, in which an 8 cm spatial gap was inserted into the direct launching event. During habituation the event sometimes proceeded from left-to-right and other times from right-to-left. In the test the infants were shown both the familiar event and a novel event in which the two objects were switched. Thus, in the novel test event, the order of the objects was reversed from what had been presented in habituation, but the direction of movement was not. Also, the objects were much more complex than in Leslie and Keeble (1987). They were scanned-in color photographs of stylized Lego toys. Examples of these toys are shown in Figure 5B. Because the objects were more complex and because Oakes and Cohen (1990) had demonstrated that younger infants may be distracted to some extent by complex stimuli, the infants tested in Redford and Cohen (1995) were 10 and 14 months of age.

It was predicted that if infants had the concepts of agent and patient, they should dishabituate to the reversal of the causal event, in which one object (the agent) “pushes” another object (the patient), but not to the reversal of the non-causal, no collision event, in which the objects move independently and therefore could both be considered agents. If, on the other hand, the infants were discriminating between familiar and test events on a simpler perceptual basis, such as that the first object (and/or last object) to have moved changed from habituation to test, without taking into account changes in the agent/patient action roles of objects, then they should dishabituate equally to both test events.

The results are shown separately for 10- and 14-month-olds in Figure 7. The developmental shift between these two ages should be apparent. The 10-month-old infants dishabituated as much or more to a switch of objects in the non-causal, no collision condition as they did to a switch in the causal condition. This pattern of responses indicates that the 10-month-olds were processing the switch at a simpler, perceptual level, or at least not in terms of the action roles of agent and patient. The 14-month-olds, in contrast, dishabituated only to a switch in the causal, direct launching, condition. The fact that at 14 months of age the infants responded only when the switch entailed a reversal of roles suggests that by this age the infants did recognize that a causal event involves an action relationship between objects such that one object, an agent, "does" something to another object, a patient.

Insert Figure 7 about here.

One may be tempted to argue that the reason 10-month-old infants in the present study responded at only a perceptual level was that they, like the 6-month-olds in Oakes and Cohen (1990), were overwhelmed by the complexity of the objects in the events. After all, the 7-month-olds in the Leslie and Keeble (1987) study appeared to respond to a role reversal when the stimuli were simple red and green blocks. However, this argument does not appear to be valid for the 10-month-old infants in the present experiment. For one thing, Oakes and Cohen (1990) also reported that by 10 months of age, infants were able to process the causality of an event that involved complex objects. For another, the 10-month-old infants in the Redford and Cohen (1995) study were paying attention to the change in the location and/or the relationship between the objects. But the fact that they discriminated the switch in the order of the objects during the test events of both causal and non-causal conditions indicates that whatever aspects of the event the 10-month-olds were attending to, it was not the action roles of agent and patient.

What then does the research on infants' understanding of agents and patients reveal about infants' use of some encapsulated perceptual module for causality? The conclusion appears to be quite straightforward and quite similar to what was reported in the previous sections of this chapter. If the objects are very simple, such as red and green blocks, then there is clear evidence that infants as young as 7 months of age perceive or understand the different roles of agent and patient. However, if the objects are more realistic or complex, there also is clear evidence that infants do not perceive these roles until 14 months of age. Furthermore, they fail to do so at 10 months even though they apparently have processed the requisite spatial, temporal, and object information. Thus, once again we seem to have evidence that tends to counter the notion of a perceptual module for causality.

Meeting Fodor's Conditions

Fodor (1985) asserted that three conditions must be met to provide a legitimate counter-instance to the modularity of a perceptual system. We question Fodor's tactic of putting the burden on those who would disprove modularity, and there may be disagreement over the necessity of all three of Fodor's conditions; nevertheless, it seems worthwhile to consider them in the present context.

The first condition is that background information should exert an influence that is exogenous from the point of view of the module. Clearly, the complexity of the objects represents just such background information. From a Michottean (1963) point of view, at least, as we noted earlier, the phenomenal nature of the objects is explicitly stated to be exogenous to the perception of causality. Nevertheless, as we have shown in this chapter, the nature of the objects appears to play a central role in whether infants of a particular age do or do not perceive an event in terms of causality.

The second of Fodor's conditions is that the effect of the background must be distinctively perceptual. Of course, this condition depends upon what is meant by perceptual. But if proponents of a causal module believe that responding on the basis of causality is perceptual, then certainly responding on a more primitive basis in terms of the same elements that are supposed to be the required inputs to the causal module should be perceptual.

Fodor's final condition is that the system should be one that functions in normal circumstances and not some backup mechanism that operates only when the stimulus is too degraded for the module. One might be able to use this condition to argue against the Oakes and Cohen (1990) result that 6-month-olds do not process causality or spatial and temporal information when the stimuli are complex. As we noted earlier, their result represents weak evidence, at best, against a modular view. For example, one could argue that the complexity of the stimuli so distracted the 6-month-old infants that their perception of the remaining aspects of the event became degraded. The same argument, however, would not apply to the Cohen and Oakes (1993) multiple object study, nor to the Redford and Cohen (1996) agent-patient study. In both cases, the relevant input information for the proposed module was available, yet in neither was the proposed module activated.

Thus, to the extent that one can ever disprove the existence of a module, we believe we have done so with respect to the causal module proposed by Leslie (1986) to explain infants' perception of causality. We have shown developmental changes in the acquisition of causal perception, and significant effects of object complexity that are much more compatible with a developmental information processing view (e.g., Cohen, 1988; 1991; Oakes and Cohen, 1994) than with an innate modular view. For example, according to the three-step developmental sequence proposed by Oakes and Cohen (1994), infants must first come to process objects as independent entities. Next, they should come to relate objects with their actions, and be able process simple relations between objects, such as spatial contiguity or temporal continuity. Finally, they should be able to use these relations to perceive or make inferences about the causality of an event. Based upon the results reported in the present section of this chapter, we would also propose a fourth step. Once infants do perceive or understand the causality of simple events, they then should be in a position to distinguish between different action roles, specifically the roles of agent and patient.

One still could assume that at some age the perception of the causality of simple events becomes modularized in the manner Karmiloff-Smith (1992) suggests. Certainly Michotte (1963) has shown the automaticity of such a perceptual system in adults. However, to assume some innate causal module, present in early infancy seems to us to be counter-productive. Not only does it fail to explain the developmental pattern we have reported, but by assuming that causal perception is a self-contained or autonomous module, investigators are directed away from exploring important links between the perceptual or cognitive development of such a core concept as causality and development in other domains. In the final section of this chapter, we shall speculate on one of these links, on the possible connection between the acquisition of causality and the acquisition of related concepts in the language domain.

Extensions to Language

So far in this chapter we have outlined a developmental progression in the understanding of causality that is consistent with a constructivist-information processing view of cognitive development. This progression proceeds from a perception of the individual elements of an event, such as the objects and the spatial and temporal relations between objects, to a more general conceptualization of the whole event as either causal or non-causal. In addition to processing an event as either causal or non-causal, older infants also begin to recognize meaningful roles for the objects in these events. The transition from distinguishing that an event is causal or non-causal to formulating meaningful categories for the elements of the event, such as agent and patient, can be considered an important step in the elusive transition from perceptual analysis to conceptual representation, or as Mandler (1992) refers to it, the transition from perceptual analysis to image schemas. However, as we have reported elsewhere in this chapter, processing the event on a causal and/or a meaningful level depends upon the information processing load placed on the infant. For example, if complex objects are introduced into the event, or the use of multiple objects transforms the task from a single event into a category problem, infants who may have been able to perceive causality under simpler conditions, can no longer do so, and attention is shifted back to the individual elements of the event.[5] But even when infants are able to perform a conceptual analysis of the causality of an event with complex objects at 10 or 14 months of age, it is important to note that our evidence so far indicates that the analysis is still tied to the particular objects seen in the event. An additional step is still required to form an abstract conceptual representation or an image schema independent of the specific objects producing that representation. It is attractive to contemplate such an abstract redescription, and we are continuing to investigate when it may occur but, as of now, we have no good evidence for one.

As previously noted, a nativist-modular perspective would not predict the type of developmental progression we have found, nor would it predict that infants may be distracted from perceiving causality if they are challenged with assimilating additional, complex, information. At the end of the last section, therefore, we concluded that the nativist-modular view was not supported by the evidence. But we also noted that there is yet an additional reason to question the value of a nativist-modular approach. Because a nativist-modular approach conceives of causality as an autonomous, self-contained mechanism, exploration of parallels and possible connections between different cognitive domains is de-emphasized. Yet, with reference to causality, one significant avenue for exploration is the parallel between cognitive development of causality and that of language development. Of the research already presented in this chapter, the most obvious parallel between causality and language is the development of concepts for the action roles played by objects in a causal event and the development of the linguistic notions of 'agent' and 'patient'.

[5] A similar "regression" to a simpler level when there is an overload of information has been noted by Cohen (1991) in his discussion of infants' ability to organize perceptual features into objects and to form categories of objects.

A number of researchers have posited some type of correspondence between semantic roles and general cognitive concepts. And some believe that the general cognitive concepts are a prerequisite to language learning (e.g., Bates, 1979; Tomasello and Farrar 1984; Mandler, 1992). If it can be shown that certain concepts that form part of the perception of causality are acquired prior to their presumably related linguistic concepts, then some indirect support may be provided for the connection posited by those researchers who perceive a cognitive basis for language acquisition. Redford and Cohen (1996), for example, have already demonstrated that the cognitive concepts of ‘agent’ and ‘patient’ are available between 10 and 14 months of age, even with complex objects. But we know from research on child language that the related linguistic concepts are not used until later, at around 24 months or the beginning of the two-word stage (e.g., Bloom, 1973; Brown, 1973).

The fact that the acquisition of the cognitive concepts of agent and patient precede their use in language suggests to us that the observed parallel between the domains might actually be the manifestation of a connection between cognition and language whereby concepts must first be acquired in the general cognitive domain before they are acquired and expressed in the linguistic domain. We are, however, aware of the likelihood that a number of other steps must intervene between when an infant is first able to conceptualize action roles like agent and patient and when the infant acquires the corresponding linguistic concepts. For example, our work demonstrates that 14-month-old infants respond in terms of agent and patient, but as we mentioned previously, we have not demonstrated that these infants have concepts that extend beyond the particular physical event in which they occur. Note, however, that even though the infants’ incomplete concepts of agent and patient are not fully comparable to the linguistic concepts of agent and patient, these fledgling concepts may still serve as the cognitive basis for those linguistic concepts.

In light of the obvious complexities associated with the transition from cognition to language, our purpose here is just to present some initial evidence for possible cognitive bases of language acquisition, not to theorize in detail about the exact progression from cognition to language. We have already shown that infants are sensitive to action roles of agent and patient well before they demonstrate a linguistic understanding of these concepts. Next, we shall examine another aspect of high-level perception or cognition of causality and how it may relate to language. That aspect is infants' ability to distinguish between perceptually similar, yet meaningfully distinctive types of causal action.

The ability to understand different types of causal actions represents a more complex and advanced form of causal understanding since infants must not only perceive the existence of a causal relation between the objects, but must also note the type of causal relation that is occurring. In an experiment that examined this more advanced causal understanding, Cohen, Bradley and Casasola (1995) presented 10- and 14-month-old infants with two different types of causal actions between inanimate objects. Infants were habituated to either a pushing or pulling event, and were subsequently tested on both events, as well as on a totally novel event. In each event, a Lego toy rolled part of the way across a television screen and stopped. A toy can, with a picture of a cow on it, then dropped from the top of the screen either directly in front of or directly behind the Lego toy, which proceeded to either push or pull the can across the screen. The direction of movement varied from trial to trial so that discrimination of the two events could only occur on the basis of the action relation between the objects. In order to heighten infants' attention to the events and to facilitate any possible discrimination, instrumental music accompanied the actions.

The Cohen, Bradley and Casasola (1995) experiment yielded results that were consistent with a developmental progression in the perception of causality. These results are shown in Figure 8. As can be seen from the upper portion of Figure 8, at 10 months of age infants provided no evidence of being able to discriminate between the pushing and pulling events. They did not look longer at the unfamiliar event (pushing if they had been habituated to pulling, or vice versa) than at the familiar event. The 10-month-olds, however, paid attention to some aspects of the events since they looked longer at a totally novel control event than at either the pushing or pulling event.

Insert Figure 8 about here.

On the other hand, as can be seen from the lower portion of Figure 8, 14-month-old infants looked longer when the action changed from pushing to pulling or vice versa. These results indicate that the ability to discriminate between two perceptually similar causal events, solely on the basis of the type of relation between the objects, develops between 10- and 14-months of age. Thus, discriminating pushing from pulling appears to be a more sophisticated ability than just perceiving causality, since 10-month-old infants can discriminate causal from non-causal events, whereas 14-, but not 10-month-old infants, can discriminate between two different causal events.

How might the ability to discriminate between different types of causal events be related to language? One possibility is that infants recruit their prelinguistic understanding of causality during language learning. Many transitive verbs (i.e., verbs that take a direct object, such as “hit”, “push”, and “pull”) encode simple causal relations between two objects. The ability to perceive and discriminate between a wide range of physical causal events should aid in the acquisition of the related linguistic terms. Consequently, one component that should be needed for the eventual attainment of the syntactic category of verbs could well be a cognitive understanding of the different causal relations between objects. The study by Cohen, Bradley and Casasola (1995) demonstrates that 14-month-old infants comprehend the causal actions of pushing and pulling, although the production of the verbs “push” and “pull” may not appear until a much later age. In the section that follows, research is presented that examines whether 14-month-old infants can also learn to comprehend language labels for specific causal events.

In a series of studies by Casasola and Cohen (1996), the relationship between the understanding of a causal event and the ability to associate and thus comprehend a linguistic label for those events was investigated. In these experiments, the same pushing and pulling events from the Cohen, Bradley and Casasola (1995) study were presented, but nonsense language labels replaced the instrumental music, and a modified habituation procedure, known as the “switch design”, was adopted (See Cohen, in press). Infants were habituated in alternation to two events. In one event, repeated presentations of a nonsense label, “neem,” was paired with the initiation and for the duration of a pushing action while in the alternate event, a second nonsense label, “lif,” was paired with a pulling action. After habituation, infants were tested with one event that maintained the familiar pairing between the action and language label presented during habituation (e.g., push + “neem”) and a second event that included a “switch” in the action-word combination (e.g., push + “lif”). The results indicated that the 14-month-old infants did not dishabituate to the event that presented the new combination of word and action. Evidently they had not formed an association between the word and type of event. These results are intriguing particularly since Lloyd, Cohen, Werker, Foster and Swanson (1994), using the same procedure and same nonsense language labels, found that 14-month-olds could form an association between a word and a single moving object. What then is the reason that 14-month-old infants have so much more difficulty forming a word - type of action association?

In an effort to find out, Casasola and Cohen (1996) next examined 14-month-old infants’ ability to discriminate a change in just the nonsense label or a change in just the action. 14-month-old infants were habituated to a single event, either pushing or pulling paired with a nonsense label (either “neem” or “lif”). Following habituation, infants in the constant action group were tested with a change in the nonsense label while the action remained the same as in habituation. Infants in the constant label condition, were tested with a change only in the action (e.g., from pushing to pulling) while the label remained the same as in habituation.

In light of the Cohen, Bradley and Casasola (1995) findings, that when music was playing in the background infants this age could discriminate pushing from pulling, the results from this second Casasola and Cohen (1996) experiment revealed an interesting and unexpected pattern. These results are presented in Figure 9. First, as shown in the upper portion of the figure, infants who observed a change in the nonsense label in the test, did dishabituate, indicating that they did notice the change in the word. However, as shown in the lower portion of the figure, infants in the constant label condition, who observed a change in action while the label remained constant, did not dishabituate to the change in action.

Insert Figure 9 about here.

Because 14-month-old infants in the Cohen, Bradley and Casasola study had previously discriminated between the pushing and pulling events when these actions had been presented with instrumental music, it was surprising that the 14-month-old infants in the constant label condition of Casasola and Cohen (1996) did not dishabituate to the change in action.

The above experiments revealed that 14-month -old infants have considerable difficulty learning the association between a particular novel language label and a particular causal action. For some reason, not only are the labels not associated with causal actions, their mere presence seems to disrupt the infants' ability to discriminate between the two actions.

This difference in infants' ability to discriminate two causal events in the presence of music versus the presence of nonsense language labels might be explained in a number of ways. Tomasello and Kruger (1992) have noted that children are more likely to attach verbs to actions when the label is presented either before or after the completed action, but are least likely to do so when the label is presented simultaneously with the action. According to these researchers, the simultaneous presentation of word and action most likely creates an attentional overload since children must attend both to a novel label and the action. Perhaps, in Casasola and Cohen (1996) the presence of language labels presented too great a cognitive load on infants who had to process both the linguistic terms and the causal relations simultaneously. As a consequence, infants in the current experiment should have been able to attend either to the language labels alone or to the causal events alone, but not to both. This explanation is consistent with the present results but it does not explain why the infants did attend just to the language labels in the presence of a single action, but did not attend just to the actions in the presence of a singe label.

As a second alternative, the presence of linguistic constraints may have biased infants to associate the language labels with the individual objects in the event as opposed to the type of causal action (Markman, 1991). Constraints such as the whole-object and taxonomic constraints are believed by some to bias children to interpret a novel label as referring to an object in its entirety and lead children to reject relations between objects or actions as possible referents. Thus, the presence of a novel label during the causal events may have led infants to direct their attention away from the type of causal relation occurring between the objects and toward focusing on the individual objects in the events. In addition to explaining why infants could not associate a language label with a type of action, a whole-object constraint would explain why Lloyd et al. (1994), who used the same procedure as Casasola and Cohen (1996), found that infants could associate a language label with a particular object.

A third possibility stems from our more general information processing viewpoint. It does not necessarily preclude the other explanations mentioned above. As noted earlier, increasing the amount of information to which the infant must attend causes the infant to process that information at a lower developmental level (Cohen, 1991). For example, we have already reported that 10-month-old infants can respond on the basis of the causality in an event, but only if the objects in the event remain constant. If the objects change from trial to trial, the infants drop down to processing spatial and temporal perceptual characteristics (Cohen and Oakes, 1993). In light of the differential effects of cognitive load on the information processing capabilities of infants at different developmental stages, a possible reason that 14-month-old infants are able to associate labels with particular objects, but not with particular causal actions is that action discrimination is a higher level task for infants at this age than is object discrimination. Action discrimination subsumes object discrimination and requires other additional steps as well. Infants must perceive the objects and their movements, the causal relation between the objects, and finally the type of causal relation that is occurring. Further support for this view is that, on a perceptual or cognitive level, the ability to discriminate individual objects as unique "wholes" emerges at a younger age, at about 5 - 7 mos. (Cohen, 1988), than does the ability to discriminate between different types of actions of an object, at about 14 mos. (Casasola and Cohen, 1996). Attaching a particular label adds an additional cognitive load. Therefore, infants at 14 months of age may be able to associate a language label with an object, but not with an action because of the additional processing required with actions.

The finding that infants are able to associate language labels with objects before they can associate labels with actions implies a developmental progression in the acquisition of language that is intimately tied to cognitive development. A number of researchers have explicitly addressed this probable tie between cognitive development and language development by showing that specific words, which encode specific concepts, emerge only once a child understands the concept (e.g., McCune-Nicolich 1981, Gopnik & Meltzoff 1985, Tomasello & Farrar 1984, 1986; Gopnik 1988). Gopnik (1984), for example, has shown that the relational word “gone” emerges in the one-word stage once the infant demonstrates an advanced understanding of object permanence. With respect to the developmental progression in the acquisition of infant causal perception, we would propose the following parallels to the progression in the acquisition of certain key aspects of language.

An early step in the development of an understanding of causality is the conceptualization of individual elements such as the objects and the spatial and temporal relationships between objects. This step parallels the first major stage in language production, the one-word stage, in which infants use nouns and relational words, but not verbs (Smiley and Huttenlocher, 1995). Conceptualization of objects should be a prerequisite for object naming (Markman 1991, Gentner 1982) and conceptualization of spatial and temporal relations should be a prerequisite for linguistic encoding of these and other relations with relational words such as “up” and “more” (Tomasello and Farrar 1986).

A next step in understanding causality is the conceptualization of the event as causal or non-causal. This step from processing the spatial and temporal characteristics of objects to processing the concept that one object is causing (or not causing) another object to move, might parallel the shift proposed by Gopnik and Meltzoff (1985) from the pragmatic use of relational words to the more conceptual use of these words. Pragmatic uses of relational words indicate that the infant understands the relationship between the use of the relational word and the action, but not the abstract concept. Not until later in the first word stage does the infant begin using certain relational words in contexts that demonstrate a conceptual understanding of these words. The conceptual understanding of relational words is a less sophisticated conceptual understanding of dynamic events than the conceptual understanding of verbs (Smiley and Huttenlocher 1992), and therefore nicely parallels the initial perception of gaps and delays between objects before acquiring the conceptual understanding (i.e., the causality) implied by those gaps and delays.

A later step in the development of infant causal perception is the one in which infants begin to formulate meaningful categories of objects' roles (e.g., agent and patient) and the types of actions (e.g., pushing and pulling) in the event. This step may parallel the second major stage in language production - when words are combined - where it is thought that grammatical concepts are first demonstrated (e.g., Brown, 1973; Bloom 1973). For example, when infants begin to combine words they are said to demonstrate linguistic equivalents of concepts such as agent and patient, and of verbs such as push and pull (Brown 1973, Bloom 1973, Smiley and Huttenlocher, 1992).

The parallel in the progression of causal understanding and linguistic use set forth in this section is, admittedly, highly speculative and undoubtedly overly simplistic. It suffers, in particular, from leaving any direct causal links between cognition and language implicit and unspecified. Nevertheless, we feel that it is important to search for these types of parallels in order to help guide research that could make explicit causal connections between the general domains of cognition and language. An explicit theory of the causal connections between cognition and language could provide the beginnings of an explanatory account for how humans acquire the abstract representational structure that is language. Once again, a research program that proceeds with the assumption that knowledge is innate and that the domains of knowledge are modular and encapsulated is not motivated to pursue such explanatory accounts for how knowledge develops, or to examine parallel processes and wonder whether one process can inform us about another.

General Conclusion

Throughout this chapter we have argued for a developmental view as opposed to a nativist-modular view of infants' perception of causal events. We believe the evidence we have presented supports our position. It indicates that infants under 6 months of age process these events in a very different way from those over 6 months of age. The evidence also indicates that even when infants show the first signs of causal perception, that perception is quite limited. It is limited to events with simple objects, and it is tied to the specific objects that serve as agent and patient. It seems to us to be rather arbitrary whether one wishes to assert that infants' processing first passes from the perceptual realm to the conceptual realm when the infants first respond to the causality of an event produced by simple objects, or when they can do it with complex as well as simple objects, or when they can clearly distinguish between agent and patient, or when they can clearly distinguish between different types of causal events, or when they can first understand that an event is causal, or involves pushing or pulling, independent of the objects producing that event. Labeling one or more of these achievements as "cognitive" seems less important to us than specifying the entire developmental progression.

We are particularly intrigued by the fact that although infant causal perception may be thought of as a specific domain, or sub-domain, if not a module, the development of causal perception seems to demonstrate some of the same general information processing principles that are hallmarks of the development of other domains of infant perception or cognition. For example, at each stage development appears to be constructive, taking elements or features that are independent at one stage and integrating them to form some higher-order unit or element at the next stage. In this way, at each succeeding stage, infants appear to be capable of processing and assimilating more information than in the previous stage. Furthermore, if infants are faced with an information load that is above their current level of processing, they will tend to "drop down" and process the information at a less conceptually or perceptually sophisticated level. In the past these principles have been used to describe the development of infant form perception, object perception, and categorization. (Cohen, 1988; 1991; 1997, in press). In this chapter we believe we have shown that the same "constructivist-information processing" framework applies to the development of infants' perception of causality.

We have also made an initial attempt to connect both our research on infant causal perception and our more general framework with processes that occur in the development of language. We have also emphasized that a research program, theoretically motivated by a nativist-modular position, would not attempt making such connections across domains.

Finally, although this chapter has dealt exclusively with infant causal perception, we hope that what we have learned will be applicable to other areas (or domains) within infant perception and cognition as well. Perhaps there is one general lesson to be learned from the research described in this chapter. It is that just because under certain circumstances, and at some age, infants perform in what appears to be a relatively sophisticated cognitive manner, one should not necessarily assume that the infants have at their disposal some pre-specified, fully formed, innate module, immune to development change or improvement. On the contrary, what we have shown in infant causal perception, and what we hope researchers will discover when investigating other areas of infant perception and cognition, is that these areas (or as some call them, "domains") develop in significant ways throughout infancy. Although there may well be specific constraints on how each domain develops, there undoubtedly will also be critically important, non-specific information processing principles that apply across domains. It is these principles that guide development in general and tie specific domains together.

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Figure Captions

Figure 1: Schematic examples of causal and non-causal events, adapted from Leslie and Keeble (1987). The open circle represents a green ball, the closed circle, a red ball.

Figure 2: Two models of infant perception of causal events: The Independent Features Model assumes infants are responding solely on the basis of spatial and temporal characteristics of the events. The Causality Model assumes those features are integrated into the perception of causality. Adapted from Oakes and Cohen (1994).

Figure 3: Responses of 6 1/4-month-old infants in the test to direct launching (CAUSAL), delayed launching (DELAY), and no collision (GAP) events: All events used simple red and green circles as objects.

Figure 4: Responses of 4 and 5 1/2-month-old infants in the test to direct launching (CAUSAL), delayed launching (DELAY), and no collision (GAP) events. All events used simple red and green circles as objects.

Figure 5: Types of complex objects used in causal perception studies. The upper portion of the figure, (A), provides examples of actual toys. The lower portion of the figure, (B), provides examples of experimenter designed, Lego toys.

Figure 6: Comparision of 10-month-old infants' performance in a standard causal perception task (Oakes and Cohen, 1990) versus a task in which the objects change from trial to trial (Cohen and Oakes, 1993). Log fixation times were used in Oakes and Cohen (1990) to normalize the data. For comparison purposes, therefore, log fixation times are also presented for Cohen and Oakes (1993).

Figure 7: Responses of 10- and 14-month-old infants in the test to familiar events versus events in which the first and second objects were switched.

Figure 8: Responses of 10- and 14-month old infants in the test to a familiar event (either pushing or pulling), an unfamiliar event (either pulling or pushing), and a totally novel event. The same music is playing in the background during each event.

Figure 9: Responses of 14-month-old infants to familiar, unfamiliar, and novel test events. In the upper portion of the figure, the unfamiliar event retains the same action (pushing or pulling) as in habituation, but the verbal label ("neem" or "lif") changes from habituation to test. In the lower portion of the figure the unfamiliar event retains the same verbal label, but the action changes from habituation to test.

Figure 1

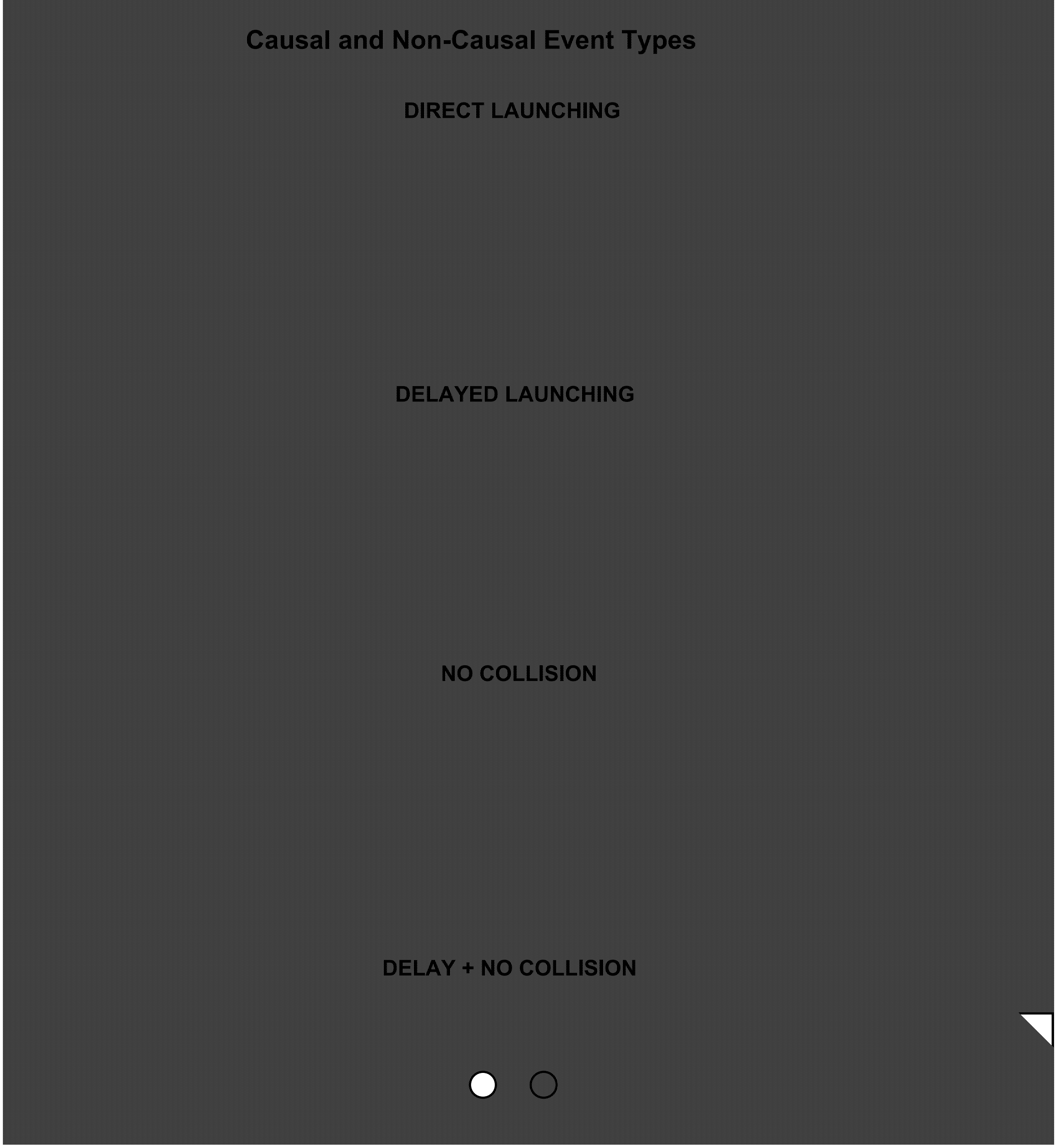
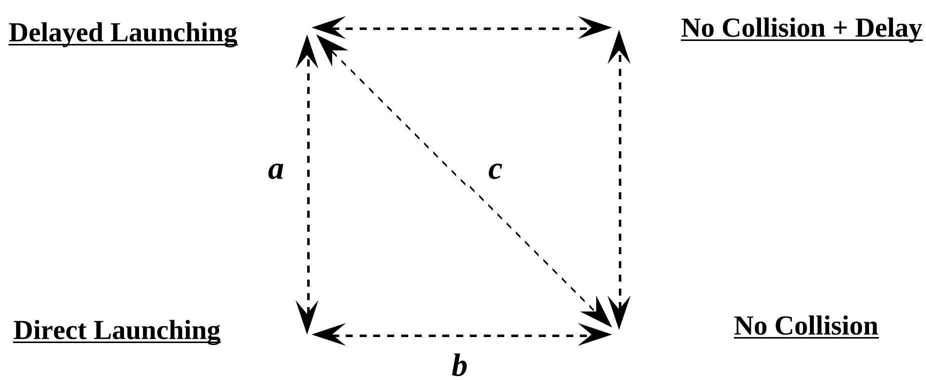

Causal and Non-Causal Event Types
DIRECT LAUNCHING
DELAYED LAUNCHING
NO COLLISION
DELAY + NO COLLISION

Figure 2

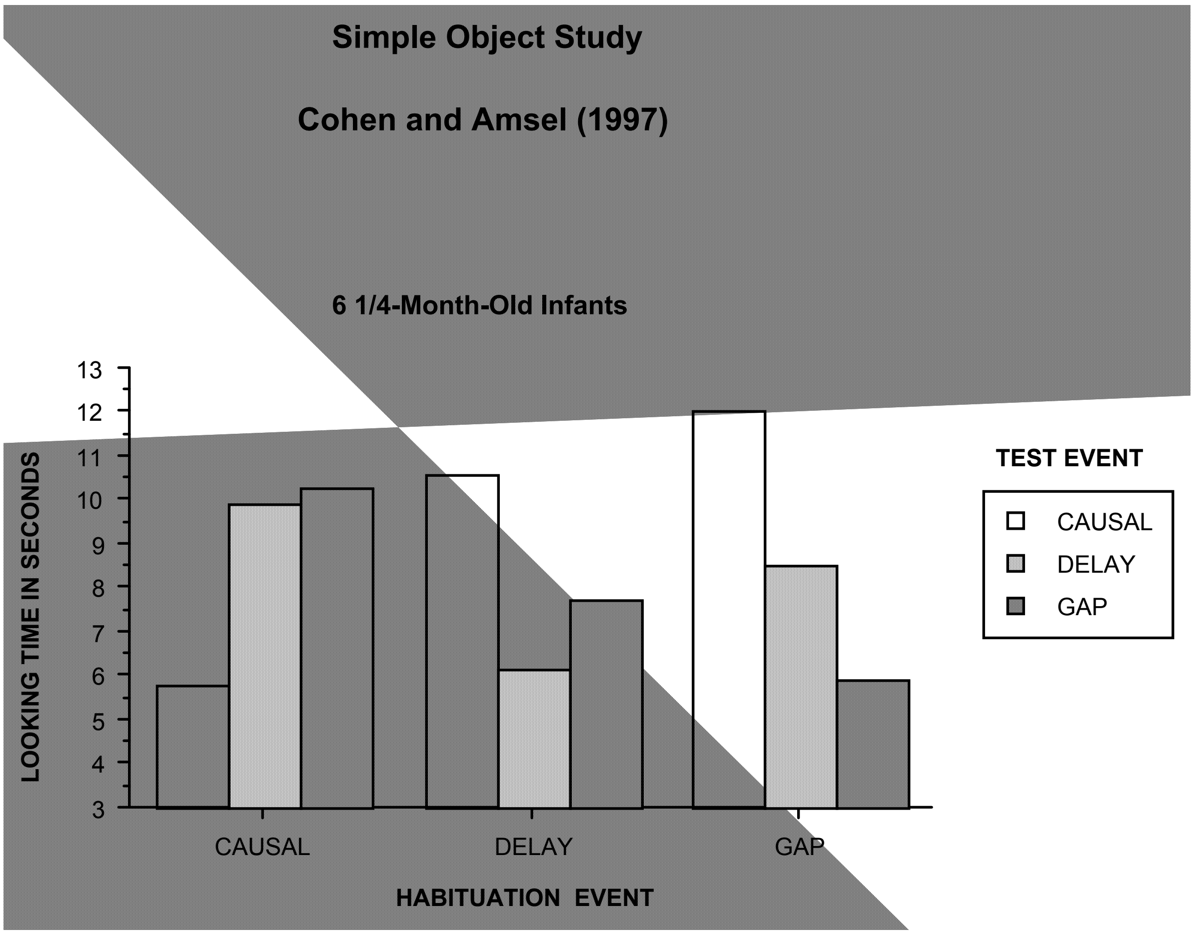
CAUSAL EVENT STUDIES

INDEPENDENT FEATURES MODEL



CAUSALITY MODEL

Figure 3



Simple Object Study
Cohen and Amsel (1997)
6 1/4-Month-Old Infants
LOOKING TIME IN SECONDS
13
12
11
10
9
8
7
6
5
4
3
CAUSAL
DELAY
GAP
HABITUATION EVENT
TEST EVENT
CAUSAL
DELAY
GAP

Figure 4

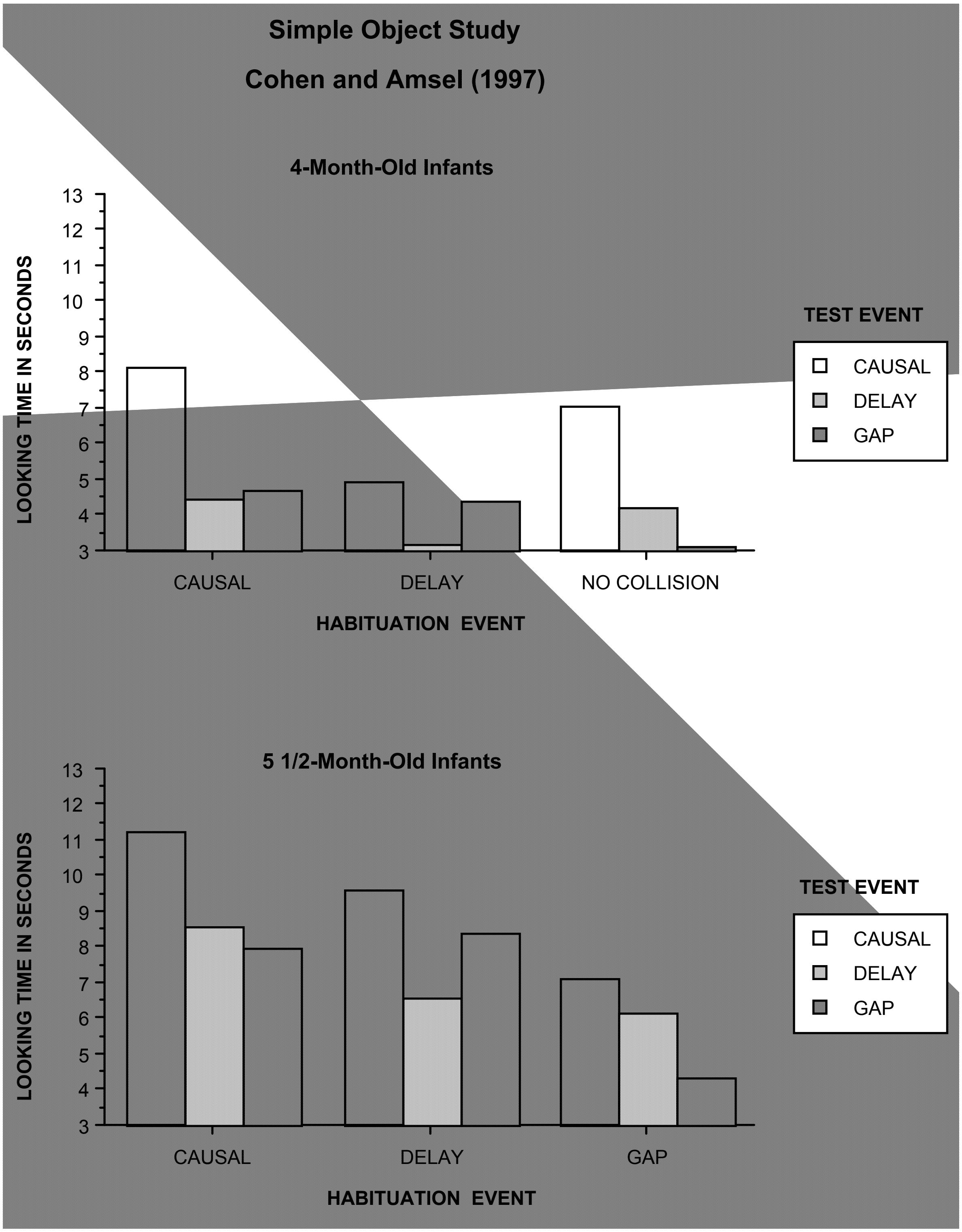

Simple Object Study
Cohen and Amsel (1997)
4-Month-Old Infants
LOOKING TIME IN SECONDS
13
12
11
10
9
8
7
6
5
4
3
CAUSAL
DELAY
NO COLLISION
HABITUATION EVENT
TEST EVENT
CAUSAL
DELAY
GAP
5 1/2-Month-Old Infants
LOOKING TIME IN SECONDS
13
12
11
10
9
8
7
6
5
4
3
CAUSAL
DELAY
GAP
HABITUATION EVENT
TEST EVENT
CAUSAL
DELAY
GAP

Figure 5

Examples of Complex Objects

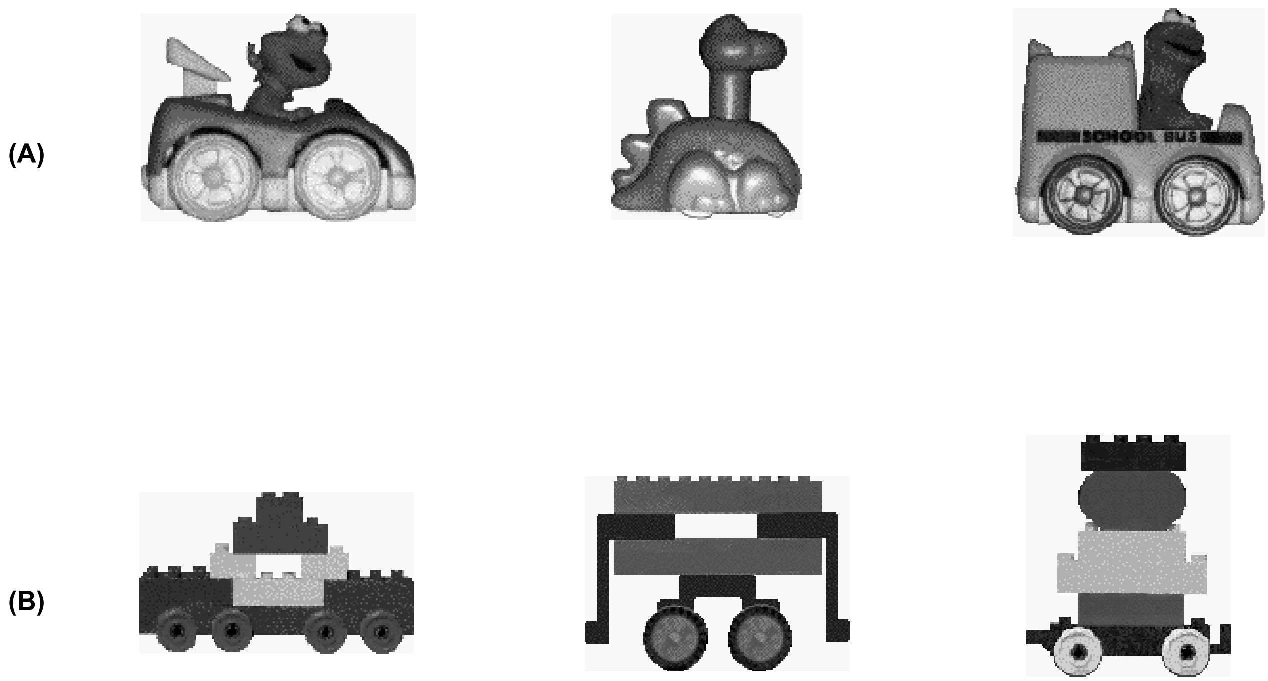
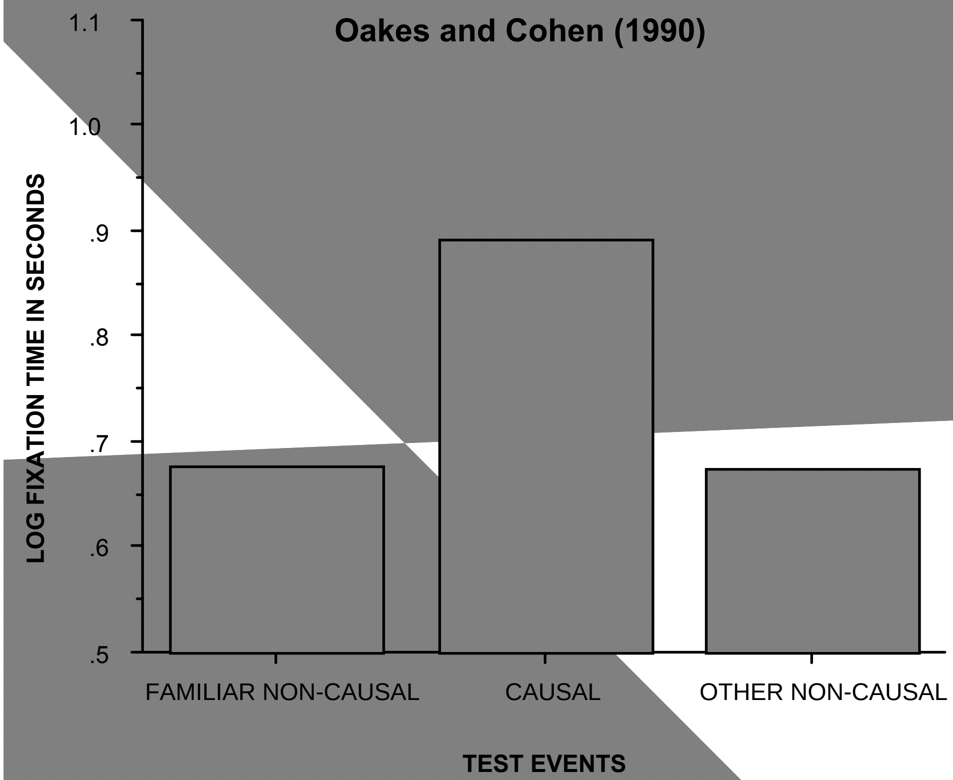


Figure 6


Oakes and Cohen (1990)
LOG FIXATION TIME IN SECONDS
1.1
1.0
.9
.8
.7
.6
.5
FAMILIAR NON-CAUSAL
CAUSAL
OTHER NON-CAUSAL
TEST EVENTS

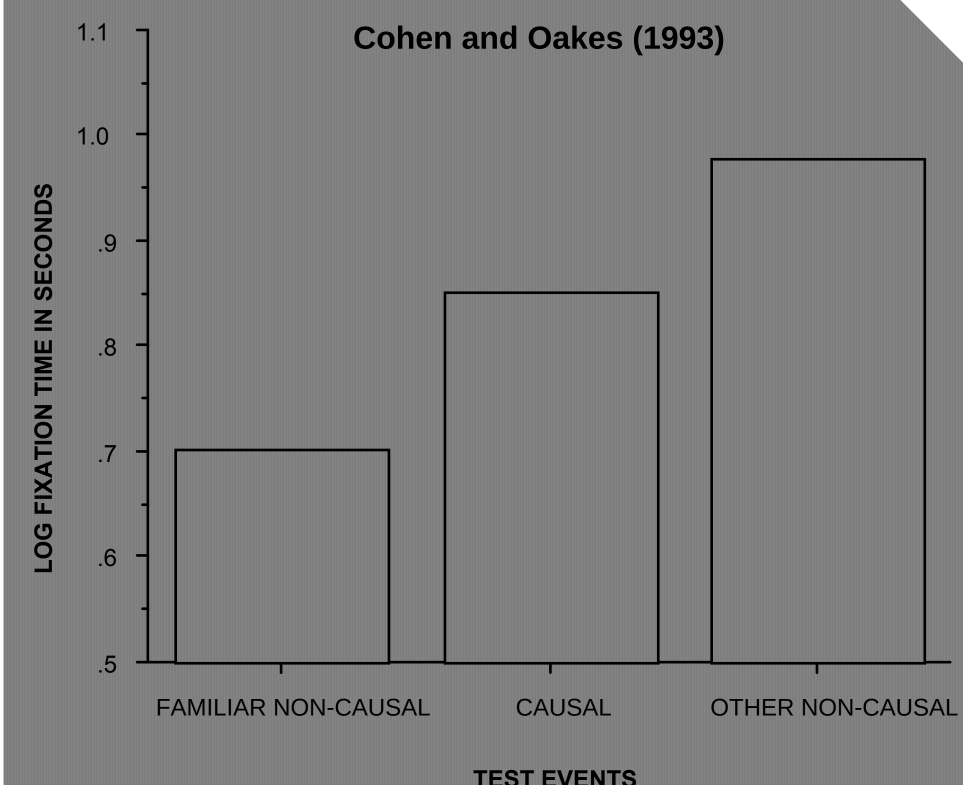

Cohen and Oakes (1993)
LOG FIXATION TIME IN SECONDS
1.1
1.0
.9
.8
.7
.6
.5
FAMILIAR NON-CAUSAL
CAUSAL
OTHER NON-CAUSAL
TEST EVENTS

Figure 7

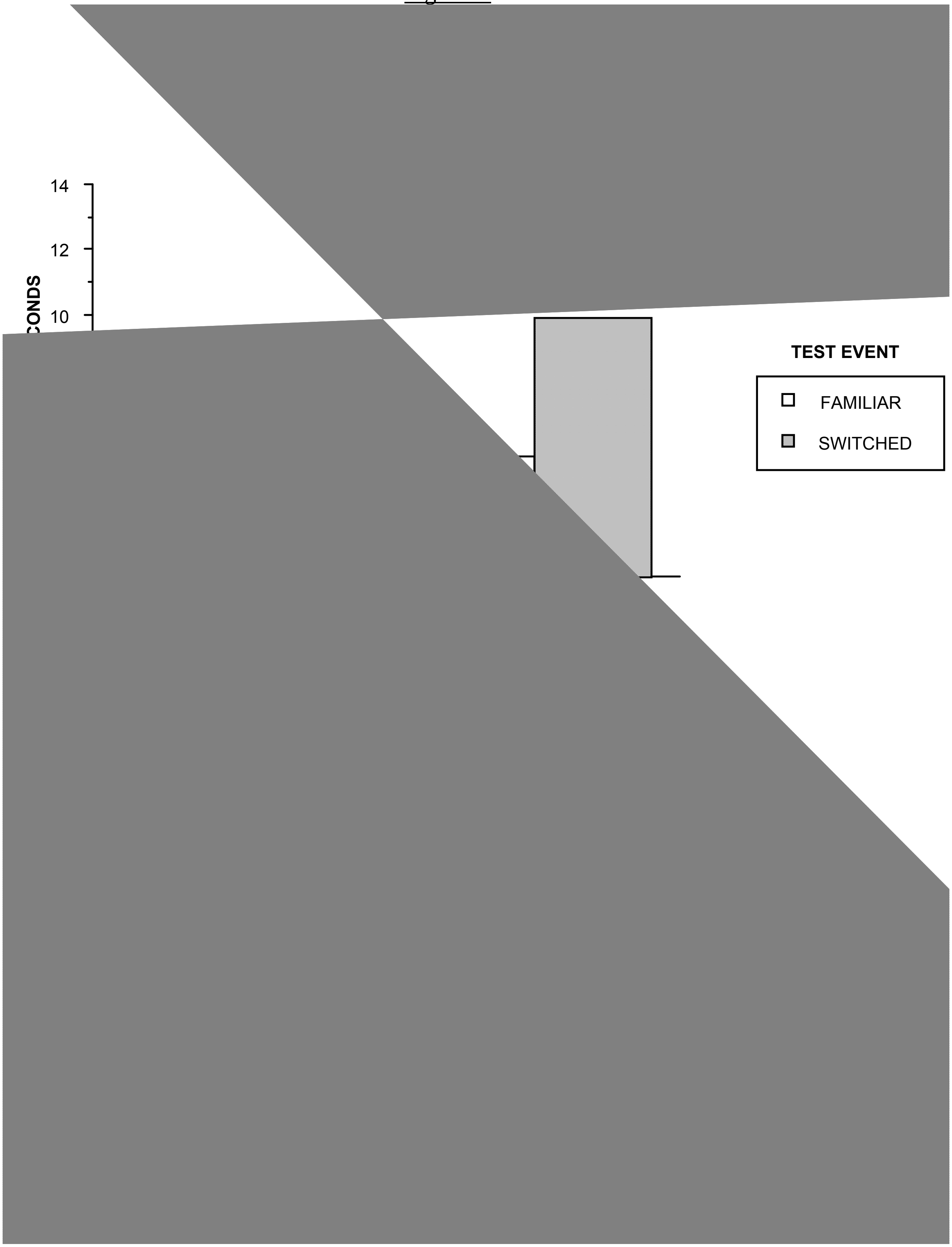


Figure 8

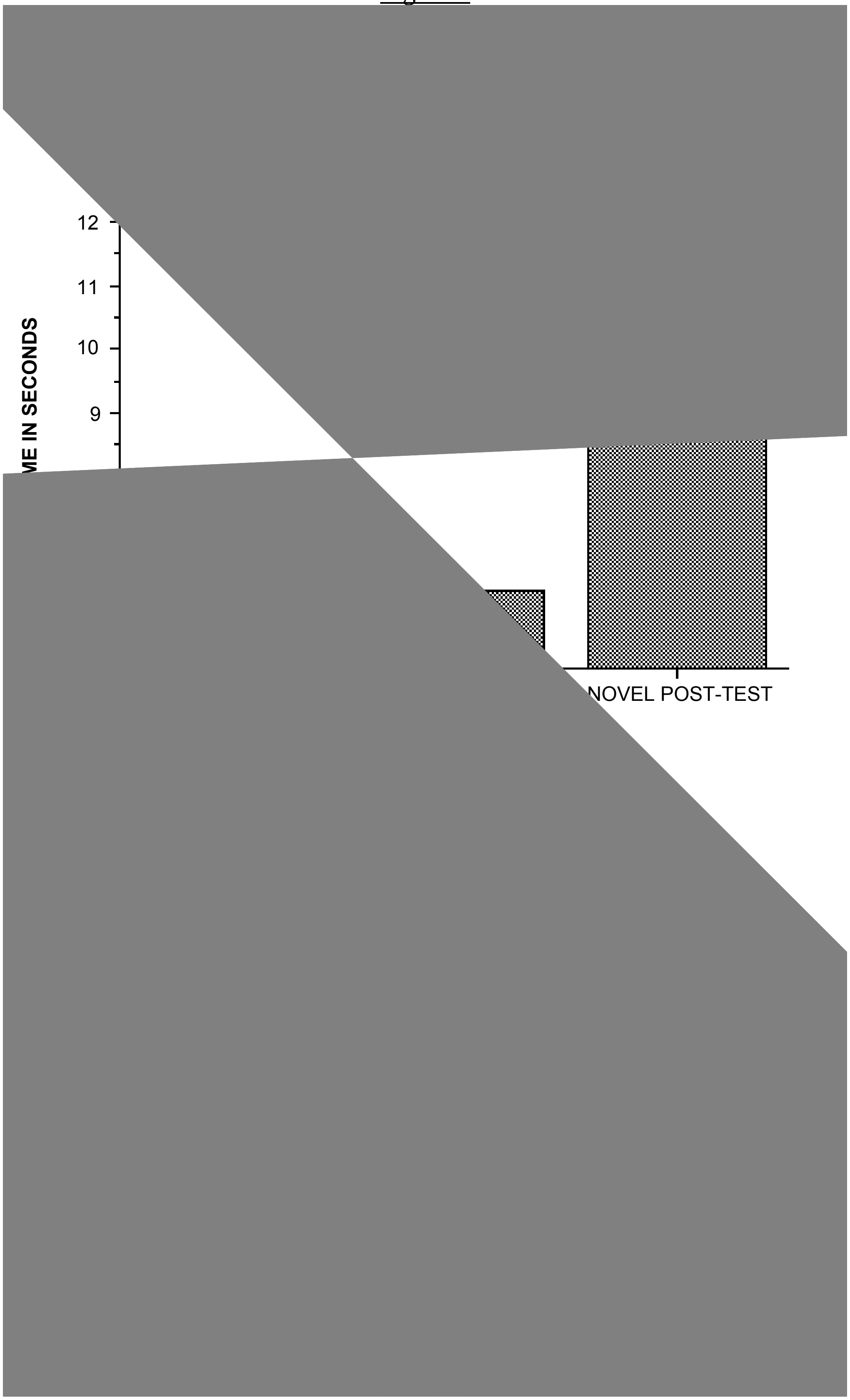


Figure 9