AN INVESTIGATION OF THE RELATIONS AMONG
OBJECT SEARCH SKILLS, CROSS-LANGUAGE SPEECH PERCEPTION,
AND VISUAL CATEGORIZATION IN INFANCY

By
CHRISTOPHER EDWARD LALONDE
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Department of Psychology
The University of British Columbia
Vancouver, Canada

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ABSTRACT

The present research was designed to assess the extent to which three different cognitive/perceptual abilities become integrated during the second half of the first year of life. Forty infants, aged 8 to 10 months, were tested on measures of object search skill, cross-language speech perception, and visual categorization. The object search task tested the infants' ability to retrieve an object, after a 3 second delay, hidden under one of two identical cloths placed in front of the infant. The cross-language speech perception task tested the infants' ability to discriminate both native English (bilabial /ba/ and dental/alveolar /da/) and non-native Hindi (dental /da/ and retroflex /Da/) speech contrasts. The visual categorization task measured the infants' ability to detect and use correlations among the attributes of a set of line drawn stimuli in category formation. Subject performance on the three tasks was examined to test the hypothesis that previously reported changes in task performance occur in synchrony. Results indicate that while infant performance would be expected to change on all three tasks at about 9 months of age, the pattern of individual subjects' performance suggests a systematic relation among the changes. This finding suggests that the acquisition of an ability to mentally coordinate separate sets of information emerges at approximately 9 months of age and permits the expression of at least these three more sophisticated skills. The results raise the possibility that cognitive and perceptual capabilities become related in more substantial ways as the infant develops, allowing increasingly accurate application of these skills to a broader range of cognitive and perceptual phenomena.
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INTRODUCTION

The research presented here assessed the extent to which three previously reported changes in infant development represent a systematic integration of perceptual and cognitive abilities. Infants were tested on measures of object search skill, cross-language speech perception, and visual categorization chosen as representative of achievements in cognitive and perceptual development previously thought to be independent of one another. The tasks used have been characterized as measures of conceptual, perceptual, and information-processing skill respectively. The specific changes examined were: i) the ability to overcome a 3 second search delay in a two-location object search task, ii) the ability to discriminate a Hindi speech contrast, and iii) the ability to make use of correlational information in a visual categorization task. Previous research has shown that major changes in performance on each of these tasks occurs between 8 and 10 months of age. By replicating previous findings in a repeated measures design, it is possible to determine: i) whether these changes appear in a fixed sequence; ii) whether it is possible to infer from the timing of these changes that successful acquisition of one of these skills is necessary or sufficient for the expression of the other capabilities (i.e., is the relation one of developmental dependence); and iii) whether the present assessment of this relation is sufficiently precise to permit the prediction of individual subject performance. The main hypothesis tested concerned whether the changes observed in task performance are wrought by the attainment of a single cognitive-developmental capability, or by the happenstance confluence of three independent and unrelated developmental pathways.

It is argued here that changes in task performance at around 9 months reflect a more pervasive capacity to form and then manipulate a higher order relation among the products of separate processes. Previously task-specific skills become
coordinated and applied across several domains permitting a more sophisticated set of skills to emerge. Specifically, the ability to overcome search delays in the object search task signals the emergence of a more general capacity to coordinate cognitive and perceptual processes in the service of intentional action. Since this coordination is also a prerequisite to success on the speech and categorization tasks, the ability to succeed on one of the tasks should ensure success on all three.

In 1790 Laurence Stern made the following observation about hypotheses: "It is the nature of an hypothesis, when once a man has conceived it, that it assimilates everything to itself as proper nourishment; and, from the first moment of your begetting it, it generally grows the stronger by everything you see, hear, read or understand. This is of great use." Stern's words capture more about this work than the private vacillations of a graduate student alternately loving and loathing his thesis. The bitter-sweet utility of such hypotheses is evident both in the science from which this work issues and, if the thesis is correct, in the lives of the subjects it investigates.

The field of infancy research, like all of social science, is shaped by the vision researchers hold of the inner lives of their subjects. The hypotheses generated, the procedures devised, and the interpretations given research findings, reflect the way we conceptualize the perceptual and cognitive capacities of infants. But this is not news, nor should it be considered a cautionary note. The dependence of knowledge on prior assumptions about a phenomenon of interest need not taint the knowledge generated, nor discourage the researcher. Often the assumptions themselves become the subject of investigation. Such investigations are particularly appropriate when, as reflected here, two contradictory conceptions - two hypotheses 'of great use' - appear. The present research assesses the validity of two such competing views of the nature of cognitive and perceptual development in infancy. On the one hand is

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the view that the changes under study result from a single developmental event, on
the other, that the changes are unrelated.

The work centres on an exploration of meaning making -- on the question of
how and when in the course of their development infants first coordinate their
perceptual and cognitive abilities in the service of intentional action. While it is
clear that infants arrive armed with a set of perceptual capabilities that help bring
order to the 'blooming, buzzing confusion' of their sensory experience, for the most
part these perceptual systems seem simply to do what they were 'designed' to do. The
products of these processes do not constitute an active construction of reality, nor are
they yet intentional as consciously aimed by the infant at resolving a particular
sensory phenomenon. At some later point in development, however, it becomes
obvious that infants are bringing both perceptual and cognitive capacities to bear on
more specific and sophisticated problems in a deliberate and focussed manner. As a
result, they are able to extract information which is not inherent in the sensory
display, to 'go beyond the information given', and to make sense of the previously
insensible.

Much of this may seem conceptual hair-splitting since there is ample evidence
that infants are capable of directing and modifying their perceptual processes from
birth. But it is nevertheless true that the ability to coordinate the products of these
perceptual processes in the service of a higher order intention arrives somewhat
later. It is a matter of some contention, however, exactly when and how this feat of
infantile meaning-making is accomplished. The aim of this work is to shed some
light on how it is that infants come to form the specific relations among the products
of their perceptual and cognitive processes that afford them this greater success in
their commerce with the world. The research outlines one possible solution to the
developmental problem of harnessing separate abilities with respect to these three
developing processes. In essence, I argue that at about 9 months of age, infants

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acquire a new and imminently 'useful' hypothesis which 'assimilates everything to itself', and in doing so, changes what they see, and hear, and understand about the world around them.
The literature review is divided into three sections which describe, respectively, the development of object search, visual categorization skills, and cross-language speech perception. The present concern is to introduce some of the theoretical and empirical issues which arise from the use of the tasks I have chosen. The following section on the development of object search skills will proceed from a summary of Piaget's notions through a review of some of the task variations which have been shown to affect infant performance, to a discussion of alternative theoretical accounts.

**The Development of Object Search Skills**

Piaget (1952) describes the fourth stage of his sensorimotor adaptations as comprising "the first actually intelligent behavior patterns" (p.210). These patterns are distinguished from their predecessors by the "intercoordination of the secondary schemata...the subject must aim to attain an end which is not directly within reach and to put to work, with this intention, the schemata thitherto related to other situations" (p.211). This achievement, which results in the universe becoming "objectified and...detached from the self" (p.211), arises out of the successful negotiation of barriers which appear between the infant and the goal toward which she strives. What distinguishes stage IV behavior is "keeping in mind the 'goal' to be reached and of trying different known means of surmounting the difficulty." (p.213)

With reference to object search, Piaget notes:

"It is to the extent that the child learns to coordinate two separate schemata - that is to say, two actions until then independent of each other - that he becomes capable of seeking objects which have disappeared and of attributing to them a consistency independent of the self. Searching for the object which has disappeared is, in effect, to set aside the screens which mask it and to conceive it as being situated behind them; it is, in short, to think of it in its relations with things seen at the present time and not only in its relations with the action." (p.211)
It is noteworthy that throughout his discussion of object search, Piaget seems to take for granted what later researchers do not: that what limits the infants' ability to overcome the barrier is not that she has forgotten where the object is, nor that she lacks a means of removing the obstacle. I will return to these issues again below, but suffice it to say that in Piaget's scheme at least, a child may be possessed of both these capacities and yet fail to recover the object of her desire. The blame for failing to search successfully is laid on the inability to coordinate the separate schemata related to the goal (grasping the object), and the barrier (removing the obstacle) rather than on simple forgetting. In addition, while attempting to remove the barrier (that is, prior to the reappearance of the object) the infant may, in fact, have forgotten about the object entirely. Despite forgetting what it was that he had intended to do, once the object has been partially revealed, the infant is nevertheless 'successful' in his search as the mere sight of the partially uncovered object is sufficient to elicit the initial schema 'grasp the object'. Something more is required, therefore, to resolve the issue of whether or not the infant can retain knowledge of the ultimate goal while grappling with the problem of removing the barrier.

Piaget provides something more by giving the infant the opportunity to fail, and in the bargain, opens the door to memory based explanations of object search errors. Faced with two identical locations at which the object may be hidden (A and B), the infant, in order to successfully retrieve the object, must now avoid the twin pitfalls of forgetting the goal or the location at which the object now resides. If the infant can remember both the goal and the location success is assured. If the infant can remember the goal, but forgets the correct location, search will be random and thus the infant will be successful only by chance. If, on the other hand, the infant is somehow able to retain the correct location but loses sight of the goal, the infant will always be successful (despite having forgotten what she was looking for), given that
the sight of the object will revive the desire.\(^1\) Finally, if the infant forgets both the goal and the location, search and success, again become random. In the AB task, where two hiding places are involved, in order to show-case her new found ability to coordinate previously separate schemata, the infant must overcome the additional problem of remembering where to look.

Given these possibilities we might predict either correct or random search. A third possibility, however, is systematic, incorrect search - the AB error. After having successfully recovered an object hidden at one location (A) an infant will return to search at A when the object is hidden at a second location (B). Piaget's finding has been the subject of hundreds of studies using dozens of variations on this basic two-location theme. In addition to Piaget's explanation of the error in terms of the infant's growing understanding of the permanence of physical objects, the source of the perseverative error has been sought in the infant's memory capacity (eg., Kagan, 1974), in the maturation of certain brain centres (eg., Baillargeon & Graber, 1988), and in a brain-based inability to suppress a previously reinforced motor response (Diamond, 1985). The extent of this literature precludes an exhaustive discussion here. For the present purpose a short description of the development of object search skills, a discussion of the main classes of theoretical accounts of this sequence, and a summary of the factors which most strongly affect object search performance is offered.

Piaget's interest in object search was but a single item on a much broader agenda of investigation into the development of intelligence. Within this framework his description of the development of object search skills can be seen as a demonstration of the changing nature of representational and spatial abilities. The emerging understanding of physical causality which underpins these

\(^1\) If this is seems an unlikely combination, imagine that you find yourself in your office suddenly unable to remember what it was you were looking for. When you catch sight of a book sitting on your desk, you immediately recall that you intended to read it that evening.
demonstrations is the link between the various search tasks and Piaget's interpretations of search behaviour in infancy. The results of this investigation can be laid out in a sequence of stages which provide the basis of the empirical wrangling surrounding the AB task.

From birth until the age of 4 months (i.e., the sensorimotor substages of reflexive activity and primary circular reactions), infants exhibit no overt search behaviour. The responses observed by Piaget to the movement, occlusion, or disappearance of an object were limited to continued gazing in the same direction the object occupied prior to the motion, or at the point at which it vanished. At best, the infant is able to track the object but shows little reaction to its disappearance.

At 4 to 8 months of age (secondary circular reactions) infants begin to develop what Harris (1983) terms a "minimal set of adjustments to the disappearance or movement of objects" (p. 715). In addition to groping along after a suddenly stolen toy, partially covered objects now present little problem. Though these adjustments are minimal in the sense that the infant is unable to retrieve a fully hidden object, substantial progress has taken place. Still, the infants' search skills seem tied either to direct (if partial) perception of the object, or to an extension of actions initiated prior to its complete disappearance.

Search for fully hidden objects begins with the onset of substage 4 (coordination of secondary schemata) at 8 to 12 months. Though the infant is now able to retrieve a fully hidden object, which suggests that she can mentally 'set aside the screens that mask' the object, a crucial restriction attends this ability -- the AB error. The phenomenon of perseverative search renders the attribution of full representational powers questionable. Nevertheless, the infant can now initiate an active search for the missing object in the absence of direct perceptual cues, and can even overcome short delays between the object's disappearance and the onset of search.
By 12 to 18 months of age (tertiary circular reactions), the degrees of difficulty which the infant is able to overcome have increased. The duration of delays required to disrupt search has increased, as have the number of sequential hidings the infant is able to tolerate. While no longer susceptible to the effects of a second hiding location, the infant may still be thwarted by an experimenter's sleight of hand. Thus, remnants of the AB error persist when, for example, the experimenter conceals the object during the hiding, leading the child to search in the experimenter's hand. Visible displacements, however, even across several containers, present little difficulty. By the final substage of the sensorimotor period, from 18 months of age onward, even these invisible displacements are overcome with ease.

Given the many and varied replications of these findings, few researchers would question the validity of this sequence. Piaget's interpretation of the sequence, however, has not fared so well. The infants' failure to search in stages 1 and 2, which Piaget attributed to a lack of object permanence, has been interpreted as reflecting a motor skills, rather than a conceptual deficit (Bower, 1967). It has been suggested, for instance, that the tracking ability and the expectation of reappearance seen in stages 1 and 2 evince an early form of search and a precocious grasp of object permanence (eg., Bower, 1967). Piaget maintains that "true search is active and causes the intervention of movements which do not solely extend interrupted action, whereas in the present behavior patterns either there is simple expectation, or else the search only continues the earlier act of accommodation" (1954, p. 10). Still, these perceptual expectancies which allow the infant to anticipate the reappearance of a vanished object have been exploited as a possible challenge to Piaget's explanation of search behaviour. Several researchers have noted that prior to the development of active search, infants are surprised by 'impossible' events which violate their expectations. Such events include perturbations of the expected trajectory of a
moving object (Mundy-Castle & Anglin, 1974), the unexplained absence of an object seen hidden behind a screen when the screen is later removed (Bower & Patterson, 1972), and the apparent simultaneous occupation of a single location by two objects (Baillargeon & Graber, 1988).

The implication from these findings is that an important distinction between competence and performance may exist. The contribution of these early arriving expectancies to the development of search skills is a matter of debate, however. To Piaget, the utility of these responses is secondary to the cognitive capacities which he imputes to the infant. Acknowledging these abilities does not necessarily imply that the infant is cognizant of the permanence of objects. Indeed, rather than attributing an early understanding of physical causality, Piaget interprets such behaviour as evidence of a mistaken belief that the existential status of the object remains at the mercy of the infant's action. What is at issue here is whether or not such capacities signal a change in the conceptual status of the object. The AB error, seen long after infants show perceptual expectancies, indicates that, however helpful these capabilities may prove in search tasks, they cannot be taken as evidence for a well developed concept of object permanence. An analogy to adult behaviour will serve to press home this point. Though I may rightly expect to hear a voice when I answer my ringing telephone, we would be mistaken to infer from this that I have anything but the faintest notion of how the voice I will hear got into the phone. Similarly, perceptual expectancies tell us little about the infants' notions of object permanence.

In sum then, Piaget is less interested in strategies that increase the likelihood of successful searches than in the development of object permanence. The presence of the AB error so late in the object search game, therefore, remains a crucial component in Piaget's explanation of search behaviour. It is to this error that we now turn our attention.
The proto-search behaviours described above merely head a list of factors which have been investigated as operant in the development of object search. With reference to the AB error itself, several factors have been shown to influence the likelihood of perseverative search. Among these, age is the most obvious -- the likelihood of the AB error decreases with age. In a meta-analysis of 89 conditions from 30 studies, Wellman, Cross, and Bartsch (1986), report an overall correlation of -.49 between age and perseverative error. Also obvious is the effect of delay. At every age, the probability of error increases as the delay between hiding and search onset increases. Wellman et al. (1986) report a correlation of +.56 between delay and proportion of AB errors. Diamond (1985) found that the delay necessary to produce the error increased at a constant rate of approximately 2 seconds per month from under 2s at 7.5 months to over 10s by 12 months. Increasing the delay which produced the error by 2s led to random search, while a 2s decrease resulted in correct search.

Interestingly, Diamond (1985) also reports a significant sex difference in AB performance. Baby girls are able to find a hidden object sooner than are boys, and begin showing perseverative errors at a younger age. Overall, girls precede boys by approximately 2 weeks in task performance. Diamond (1985) reports that, "although age is the single best predictor of the length of delay an infant can tolerate, knowing both the sex and age of an infant significantly improves one's ability to predict the delay that will produce the AB error in that child" (p.878). This finding mirrors a general trend for infant girls to outperform their same aged male peers on most measures of infant development.

Several variations on the standard two-location version of the task have revealed the effects which the number and nature of particular locations have on the probability of error. In some cases Piaget seems to imply that the number or distinctiveness of the locations should carry no weight, that is, search should proceed
either correctly or erroneously dependent on the infants' degree of conceptual sophistication ("Go look in my room and see if I am there" Piaget, 1954, p.59). With regard to number, Wellman et al. (1986) report a decrease in the proportion of error with an increasing number of locations. An important restriction on this finding applies: the direction of errors is predominantly toward A rather than to the 'far' side of B. Some controversy attends this finding, however, (see Harris' reply in Wellman et al., 1986), and Diamond (1989) has recently shown that the effect of multiple locations may be an artifact of the hiding procedure. When the correct location is covered last (typical of multiple location procedures) performance is enhanced, but when all locations are covered and uncovered simultaneously, the probability of the error matches two location tasks.

More urgent are the results concerning the nature of the locations. Perhaps not surprisingly, the more distinctive or discriminable the locations are, the less likely error becomes (Wellman et al., 1986), though this effect is much weaker than that of age or sex. In addition to differences between the hiding places in two-location tasks, the type of concealment also plays a role. Dunst, Brooks, and Doxsey (1982) found that infants were more often successful when the object was concealed behind a screen or beneath a cloth than when it was placed under a cup or in a box. The authors contend that the first two events are interpreted by the child as 'barrier between self and object' while the latter two constitute 'barrier replaces object'. Piaget also notes the effects of more 'difficult' hiding places:

"Gerard, at 13 months, knows how to walk, and is playing ball in a large room. He throws the ball, or rather lets it drop in front of him and, either on his feet or on all fours, hurries to pick it up. At a given moment the ball rolls under an armchair. Gerard sees it and, not without some difficulty, takes it out in order to resume the game. Then the ball rolls under a sofa at the other end of the room. Gerard has seen it pass under the fringe of the sofa; he bends down to recover it. But as the sofa is deeper than the armchair and the fringe does prevent a clear view, Gerard gives up after a moment; he gets up, crosses the room, goes right under the armchair and carefully explores the place where the ball was before." (1954, p.59)
The linear effect for age and delay, and the fact that perseverative search can be demonstrated in children over one year of age, suggests that the attainment of substage 4 is no guarantee of error free-search. In addition, procedures which don't require active search, relying instead on measures of looking time, suggest that the infant may have the wherewithal to know *where* to look long before they know *how* to go about retrieving the object (eg., Baillargeon & Graber, 1988). Furthermore, Corter, Zucker, and Galligan (1980) demonstrate the importance of the object itself. When the 'object' in an AB task is the infants' mother, search is more often successful though perseverative errors are still seen. Though Piaget acknowledged a 'subjective or affective permanence' which could account for the early appearance of person permanence, the relation between active search and non-search equivalents is not fully specified.

For Piaget, the AB task and the resulting AB error reveal the limits of the child's conceptual understanding of objects. The fact that increasing the complexity of the task may prolong the life expectancy of the error should do little to disuade the faithful of the idea that infants of less than one year have a fragile notion of the object. The stipulation that the infant must "aim to attain an end...and to put to work, with this intention, the schemata thitherto related to other situations" (1952, p.211), underscores the importance Piaget places on active search:

"...we do not believe that the coordination of schemata suffices to explain the permanence belonging to the object. So long as the child does not undertake special searches to find objects which disappear, that is, so long as he does not succeed in deducing their displacements in space when he no longer sees them, one should not yet speak of object conservation"(1954, p.90).

Without active search, and the reciprocal assimilation of secondary schemata it demands, the permanence of the object is "only practical and not substantial, because the universe is not detached from action nor objectified in a system of relationships" (1954, p.94). Just as the ability to anticipate the reappearance of the object adds only
a false cloak of sophistication to the infants' behaviour, so too would non-search equivalents to an AB task.

In the preceding discussion no distinction is drawn between object search tasks in general and the AB task in particular. The relation between the two is by no means a simple one. If Piaget is correct in attributing correct search to the coordination of two previously independent schemata, the somewhat later arriving ability to tolerate two locations should depend only on the added dimension of recalling the correct location at which to apply one's efforts. In both cases the imposition of a delay increases the probability of failure, though the type of failure and its causes are different. In the simple object search task, failure is restricted to not searching. In the AB task, the infant may, additionally, search in the wrong place.

The demands of the object search task are such that the infants may fail in two ways: by forgetting what they were doing (losing sight of the goal), or by forgetting how to do it (inability to coordinate secondary schemata). The AB task adds to this list the problem of deciding where to look. This is not simply a matter of remembering where the object is, otherwise there would be no reason for Gerard to return to the armchair when his search under the sofa is frustrated. While it is likely that errors are often attributable to confusion between the locations (made all the more likely when these are identical), other possibilities exist. Piaget contends that perseverative search implies an attempt to recreate the object through the application of the search activity which earlier produced the object. The infant may nonetheless know that the object disappeared at B. The ability to resolve the AB dilemma may not, therefore, require an improvement in memory capacity or processing efficiency, but rather, the 'special searches' Piaget describes.

Before taking up the alternative theoretical accounts of the AB error, it is of interest to speculate as to what happens during the delay to cause the infant to err. It
is conceivable that the specific coordination acquired during the A trial(s) is given priority over the location at which the object was found. Given that no change in the probability of committing the AB error is found with increases in the number of A trials (Wellman et al., 1986), we must conclude that the lesson learned once is learned well. The fact that the error can be made to 'float' between the locations over the course of a single session suggests that the infant is not simply one step behind the object, but rather, that they hold stubbornly to this inappropriate strategy. The finding that they abandon the search at A when left empty handed supports the contention that despite the ability to coordinate the schemata necessary to search for hidden objects in general (i.e., in object search tasks, or on A trials in an AB task), the infant is still bound by an egocentric search strategy. The persistence of perseverative search, albeit under an increasingly narrow set of conditions, may thus be seen as the persistence of a contextual understanding of the object:

"In order that these things really become objects the awareness of relations of position and displacement must be acquired. The child will have to understand the how of the appearance and disappearance of these objects and thus will have to abandon belief in the possibility of their mysterious reappearance at the place they have left and where action itself has discovered them. In short, a truly geometric rationalism will have to supersede the phenomenalism of immediate perception and the dynamism of practical efficacy." (Piaget, 1954, p. 65)

The inability of the child, otherwise able to find fully hidden objects, to overcome more complex hiding situations, merely indicates the length of the road yet to travel. Piaget's geometric rationalism begins with empirical success, that is, with the discovery of objects through action. The insufficiency of this strategy in the more demanding AB task reveals both the nature of the infantile concept of the object and the importance of active search in the construction of a more mature conception of its permanence. What then separates the three classes of performance on the AB task? The infant able to solve the AB task appears more sophisticated than one still plagued by the AB error, at least in terms of overall success. But the difference between these two is not in their ability to coordinate secondary schemata
, for both infants possess this skill. Indeed, the infant able to pass the AB task is not free of the potential to err until their belief in 'mysterious reappearance' has been quashed by 'geometric rationalism'. In Piaget's account, then, there is no conceptual difference between these infants unless the infant able to pass the AB has attained substage V, an achievement that is not measured by the AB task. For Piaget, the theoretical importance of the AB error lies in the conceptual limitations it reveals in infants able to find hidden objects - that empirical success may mask underlying deficits.

All of the alternatives to Piaget's account of the AB error inevitably reduce to variations on a single theme: memory. Such accounts burden the infant with a defect in memory capacity, efficiency, fidelity, or application which results in perseverative search. Memory based explanations are of two kinds: functional and structural. In both cases the infant is not necessarily limited by a faulty or immature concept of the object, but by an inability to cope with the specific memory demands of the task. Functional accounts seek an answer to the AB riddle in the inappropriate use of accurate memory for the location, while structural theories point to immaturities in the hardware of memory. One hybrid account (Diamond's) combines these two in an account that smacks of neurological fideism.

Piaget (1954) discusses the possibility of a memory-based explanation: "Gerard, having known perfectly well at first that the ball had left the armchair and was to be found under the sofa, little by little lost all memory of the events; no longer knowing very well what he was doing under the sofa, he remembered having found the ball under the armchair and immediately followed his impulse"(p. 60). An explanation of this sort relies on the decay of the memory for the B location without a corresponding decay for the A location memory. Sophian and Wellman's (1983) information-processing account proposes just such uneven memory decay. Where the memory for the B location does not decay, the infant is said to rely
inappropriately on prior rather than current information. The infant may remember both locations correctly, but fails to appreciate that current information (object at B) takes precedence over prior information (object was at A). Perseverative search then results either from the decay of memory for B or from reliance on improper information that is faithfully represented in memory.

Without a direct test of the relative strength of the memory for each location, one can only speculate about the adequacy of this explanation. If the memory for the B location does decay more rapidly, we should expect some effect to obtain when the number of A trials is increased. As noted above, no effect for A trials was derived from Wellman et al.'s (1986) meta-analysis. If the infant is prone to incorrectly choosing prior over current information, we should expect that increasing the number of locations would result in an increase in random search. On the contrary, Wellman et al. (1986) report an increase in correct search.

Kagan (Fox, Kagan, & Weiskopf, 1979; Kagan & Hamburg, 1981) proposes a two-pronged solution to the AB error: there is an improvement in recognition memory which facilitates a comparison of past with present across the interference of delay, and a concomitant increase in the desire to resolve discrepancies perceived between these two points in time. The infant of 10 months is now better able to retrieve the memory for an event (the image of the object) and is motivated to resolve the discrepancy between the present state of the world (no object) and the desired state (object in hand). This rather mystical motivational change seems to arrive on the scene rather late. Nonetheless, one must assume that it could not predate the ability to recognize and recall the event (i.e., to encode the event as the disappearance of the object) resulting in an infant 'all dressed up with no where to go'. Further, it is not clear how the increase in motivation is a separable component in the development of search skills. An increase in the ability to resolve discrepancies would necessarily presuppose the coordination of schemata, and thus Kagan would be forced to attribute
the same motivational change to both the AB 'pass' and 'error' infants, rendering both infants equivalent where a difference is sought. Kagan's alternative cannot account for both successful search and the perseverative error without specifying two different motivational changes within the sequence from error to pass.

Bower's (1974, 1977, 1979) more radical alternative assumes that the very young infant has already solved the problem of object permanence and falters only with respect to object location. In support of this, Bower cites the surprise reactions which 3-4 month olds show when the anticipated reappearance of an occluded object fails to occur. The importance of these perceptual expectancies to the acquisition of a fully developed concept of the object was noted above. Though it is clear that the AB error has much to do with the infant's immature notions of object location (why else would the error be of any interest), Bower is unconvincing in his attempt to persuade this reader that the child possessed of a concept of object permanence would exhibit such fundamental search errors.

Moore and Meltzoff (1978) offer a more detailed account of the problem of object location by suggesting three problems related to identifying objects which must be overcome prior to the onset of successful search. First, the authors argue, infants must grasp the continued identity of an object that either moves or remains stationary. Second, they must recognize the continued identity of an object that changes its state (from stationary to moving or vice versa). Finally, they must be capable of maintaining the identity of the object across disappearances. While there is little in this account that directly depends on the extent or strength of the infant's memory for location, rephrasing the problem in terms more local to the hidden object does little to explain the mysteries of infant search. In order to 'maintain the identity of the object' the infant must represent it in its absence and thus, Moore and Meltzoff presuppose the memory component. The fact that infants rarely err when allowed to search without delay, supports the contention that the AB error is
indicative of a failure more complex than this loss of identity. Additionally, this account suffers from a disturbing silence with respect to the direction of errors in multiple well versions of the task - when faced with many alternative possibilities, infants invariably err in the direction of A rather than to the 'far' side of B.

Butterworth (1978) and Bremner (1980) opt for an even more detailed listing of the abilities which underpin successful search. Butterworth proposes that infants may deduce the identity of an object by linking together its various successive positions or manifestations through a third, more stable term. The infant may use the position of the object relative to herself, within the room etc., as a means of overcoming the less predictable behaviour of the object. This triangulation is refined by Bremner (1980) who describes a 'self-related code' and a 'framework code' which the infant develops to locate the object in space. The self-related code maintains the object's location relative to the infant's position and, for infants not yet able to crawl, this code provides the only means of locating the object. Once able to move relative to the object the infant may begin to code for position relative to landmarks - the object 'under the chair'.

It must be stressed that alternative accounts such as these hold that the infant fully expects the object to be found at the location where search is applied. In other words, the infant searches where he believes the object to be. Piaget's account, on the other hand, allows the infant to search where he believes his efforts will be rewarded but where the object need not, at present, be located. The infant may know that the object disappeared at B but believe that effort at A will reproduce the object. In this sense, the memory accounts grant the child greater recall ability than does Piaget's. The acquisition of rules by which to search, of location codes, and object identification aids do not relieve the child of the necessity of object permanence. Indeed, these are merely reformulations of the concept of the object, for the infant
must be able to do all of these things if search is to be successful at levels above chance.

In all of these alternative accounts there is an implicit admission that the child is capable of remembering things for more than 3 seconds, but is somehow tripped up by the demands of overcoming a barrier to immediate search. If it is not memory per se which fools the tot, it is certainly something more than simply a lack of mobility (Bremner) or rules for maintaining the identity of objects through occlusions (Moore & Meltzoff). Were the limiting factor in object search the ability to locomote, there should be no difference between an object search task and the AB task. If one blames failure on a lack of rules it is not at all clear why infants show perceptual expectancies prior to the onset of successful search. How is it that infants can anticipate the reappearance of an object for which they have no re-identification rules?

Adele Diamond (1985; 1988) offers what I have called a hybrid account that attributes the AB error to a combination of neuronal immaturity and an action/memory interaction. Diamond begins her analysis with a comparison of infant AB performance to primate behaviour in a Delayed Response (DR) task. The limiting factor in infant performance is an inability to inhibit a previously rewarded motor action. The infant is rewarded by finding the object at A and becomes unable to inhibit the act of reaching toward A even when aware that the object is no longer there. This lack of control is in turn blamed on immaturity of the prefrontal cortex.

Diamond's argument depends on a combination of primate studies and evidence from specific forms of organic brain damage in adults. The story runs like this: until the prefrontal cortex is mature (approx. 9 months in humans) or if it is damaged (e.g., by dorsolateral prefrontal lesioning or localized cooling), primates,
and by extension human infants, are unable to coordinate the processes of memory with actions necessary to solve the AB task.

To suggest that this is a sort of neural fideism is not simply to nay say the importance of brain maturation in developmental progress. It is obvious that some large contribution is made in this regard, but my objection is a familiar one. The maturation of some portion of brain tissue may be necessary but it is hardly sufficient to account for the behaviour. While Piaget's 'special searches' may not be possible without some degree of prefrontal maturity, they need not be caused by the advent of this activity. The argument can even be run in the reverse, that it is the application of search behaviours which sculpt the brain in the manner suggested by Diamond's account. In any case, even if Diamond is correct (and I have no reason to believe otherwise), the only restriction on a Piagetian interpretation of search behaviour is that it be consistent with this underlying neurological event. Since there are no compelling reasons to think that it is not, we can cling to the belief that whatever the contribution of brain maturation to object search skills, the result is more general than AB success. The question of interest concerns just how general this contribution might be.

The precision added to the discussion by these alternative accounts goes some distance toward a statement of the prerequisites to successful search. Infants must do more than simply anticipate the reappearance of a vanished object - they must deduce and predict its location, form some plan to retrieve it and implement this across a disruption of some kind. To Piaget this represents the beginnings of intentional action and presupposes some knowledge, albeit limited knowledge, of the permanence of objects. The accounts discussed above do little to shake this conceptual foundation. Whatever developmental miracle one chooses to explain the onset of successful search, it must involve the coordination of the processes of memory and planful action. The goal of the present research is to determine the
extent to which this new found ability influences other domains of infant functioning.
The Development of Visual Categorization

The purpose of the present review is to provide a framework for a discussion of the developmental changes evident in the form and structure of the categories formed by infants across the first year of life. Again, the section will introduce some of the theoretical and methodological issues which arise out of the use of a categorization task. Following a definition of categorization, the evidence of categorization in infancy will be examined both for its content (what is it that infants categorize) as well as its empirical measurement, with emphasis on the latter. Attention then turns to the relationship between categorization and other related cognitive abilities which are present and develop during infancy, specifically representation and memory. The section ends with a discussion of the theoretical underpinning’s of research on categorization in infancy.

The ability to categorize objects and events is fundamental to intellectual functioning. Thought, language, perception, learning, all rely on the ability to form and manipulate categories. Categorization is commonly defined as the treatment of discriminable entities, properties, objects, or events, as equivalent. At least one rider is typically attached: that the differences among the members of a category be recognized yet ignored. It is important for what follows that we understand exactly what this definition implies.

First, consider the word ‘treatment’. The common usage of the term implies action: 'to act or behave toward in some specified way' (Oxford Dictionary). In contrast to representation, which may be an entirely private, mental process, categorization involves action. The act of categorizing is public. While it is true that I may sit quietly and mentally sort through a hypothetical pile of imaginary objects, what I do is rooted in action. Even at its most subjective, categorization implies a change in attitude or mental posture toward something based not on its individual or
unique character (as with representation) but, rather, on its larger implied character as a member of some group.

The provision in the definition that the entities be discriminable - that the differences are recognized yet ignored - allows a critical distinction to be drawn between appropriate action given an exemplar of some category, and the recognition of category membership in this exemplar. To construct true categories, one must ignore still perceptible differences among members of the same category. The category does not exist outside of this recognition - my car acts appropriately in the presence of unleaded gas but does not recognize it as a member of the category 'gases'. The issue is whether the basis for discrimination retains any 'cognitive reality' (Nelson, 1985). The key is that we are acting as though these things were the same while we are fully aware that they are not. In essence we're playing a sort of pretend game in which we are pretending that one thing is equivalent to some other thing. The equivalence created among members, that is, the structure of the category, must produce both the criteria of category membership as well as some means of holding perceptible differences among exemplars in abeyance.

If categorization is, as I have suggested, a kind of pretend game, then what are the rules by which it is played and how do we know when infants are playing it? If categorization implies action, we can demand some act on the part of the infant. Though infants may sit and hypothetically sort imaginary objects we can safely ignore this possibility in favour of overt behaviour. Still, some difficulty may attend the specification of which behaviours will count as evidence. We may also demand some evidence of pretending. That is, not only some evidence that the infants can discriminate among exemplars, but that they are doing so while categorizing. We need be sure that the infant is not either incapable of detecting such differences or has forgotten them and is treating all exemplars as a single object or event. Finally, and most important, evidence concerning the manner in which within-category
differences are suppressed - evidence of the structure of the category - must be given. In summary, evidence of categorization in infancy must include: 1) an observable, unambiguous response that signals the formation of a category(s), 2) discrimination among within-category exemplars, and 3) a description of the structure of the category formed.

Since the great bulk of the research on categorization in infancy has been carried out using variations of habituation/dishabituation techniques, a short discussion of this methodology is in order.

Habituation procedures designed to assess categorization generally involve the repeated presentation of a set of stimuli, until measured responding drops below some absolute (preset) or relative (subject defined) level. At this point habituation is said to have occurred. If, on presentation of a novel stimulus (or member of a contrasting category), responding increases (in absolute or relative terms) the subject is said to have dishabituated. To ensure that the infant has not merely forgotten the habituation stimuli, most procedures reintroduce the original stimulus and again show a decrement in response. In a variation of this procedure, infants are presented with a fixed number of 'familiarization' trials followed by presentation of test stimuli. In this familiarization procedure, differences in response levels to different test stimuli are used to infer category acquisition.

Two inferences are made on the basis of these changes in response level. The first is that the infant recognizes the difference(s) between the habituation and test stimuli, and the other that the change in responding results from the perceived discrepancy. In the first case, the decrement in responding is due to familiarity - after an initial period of processing, the infant sees the repeated presentation as 'old news' unworthy of continued attention. At dishabituation the infants' increased responding to the novel stimulus reflects renewed processing. The 'novelty' of the novel stimulus is thus defined in terms of the habituation stimuli. In other words, it
is not simply new, but new when compared to the stimuli which produced the habituation.

When properly designed, studies which employ this technique can easily satisfy the set of rules developed above. Since the measures of habituation and dishabituation are, without exception, behavioural, the infant's response is rarely ambiguous. The most common measure in visual categorization studies, fixation time, clearly satisfies this criterion. In order to satisfy the discrimination requirement most studies include a control condition or group in which infants demonstrate the ability to detect and respond to the critical differences between exemplars used in the habituation phase. Finally, the use of multiple test or dishabituation stimuli allows us some insight into the structure of the category, though specific interpretations remain open to debate.

The stress placed in the definition of categorization on the ability to discriminate among category members should be recalled here. It was noted that this discrimination be made while categorizing in order that categorization be distinguishable from simple recognition of a formerly encountered event or object. One clever variation of the habituation procedure provides some assurance that this requirement is met. By presenting the infant simultaneously with two test stimuli, only one of which is novel, researchers have claimed that systematic preference for one stimuli over the other may be taken as evidence of categorization. This paired comparison technique is particularly persuasive since a consistent preference for either stimulus is taken as evidence of categorical responding. The logic behind the use of these two techniques requires some explanation.

In studies using the habituation procedure the explanation for the initial decrement in responding is given in two stages: 1) the infant encodes, assimilates or processes the information in some unstated way and, 2) having completed that task, exhibits a lack of attention to further presentations. The problem is that the infant
may have detected or constructed the category prior to the decrement in responding and, having validated this over the course of subsequent presentations, is now bored with the game. The beauty of the paired comparison procedure is that it allows the infant to evidence categorical responding in continued attention to category members. While the habituation technique relies solely on the preference for novelty, in a paired comparison the infant may prefer the familiar and still please the experimenter. Although this sounds a bit like having your cake and eating it too, the logic is difficult to fault since it is not a necessary consequence of the acquisition of a category that the preference for a completely novel stimulus ensue. The great advantage of a paired comparison procedure is that it provides some insight into the structure of the category. Giving the infant a choice between something completely different (novel) and a variation on a newly acquired theme (new exemplar), we can decide whether the infant has simply forgotten the differences among the 'memorized' set of category exemplars or has formed the desired category but is not yet bored with the game. If the infant has somehow memorized the previous stimuli, there should be no systematic preference for one of the test stimuli over the other since both are equally novel. Preference for one over the other (regardless of which) indicates category formation.

Thus armed with a definition of categorization, techniques for testing infants, and a set of rules by which to judge the results, we move to an examination of the research. In any literature review, one must of necessity neglect some large portion of the published research. The justification given for particular exclusion rules rarely satisfies many readers. Recognizing this, the present review confines itself to demonstrations of developmental change in category structure between 6 and 12 months, forsaking investigations of basic perceptual categorization skills (for example, colour perception), which emerge early in development and remain essentially stable into adulthood. The exclusion rule follows, unapologetically, from
Neisser's (1967) observation of an "unmistakable difference between seeing that two things look similar and judging that they belong in the same category" (p.95).

Rosch and her colleagues (eg., Rosch, 1978; Rosch, Mervis, Gray, Johnson & Boyes-Braem, 1976) have argued that not all attributes by which objects and events may be categorized occur together with equal frequency. Instead, natural categories exist around collections of correlated attributes. For example, feathers and wings occur together more frequently than do wings and fur. Where discontinuities between such clusters of attributes occur, category boundaries form. Studies of adults show that the acquisition of abstract or 'unnatural' categories are guided by such considerations. The attraction of using stimuli the subject is unlikely to have encountered outside the laboratory lies in the kinds of information that can be manipulated by the experimenter. By eliminating the possibility that the subject is bringing the category into the lab (which may not be possible with perceptual, or natural kind categories), we can be sure that the category formed is based only on the stimuli made available in the procedure. In addition, the strategies the subject employs to form a category can be teased out from the problems of familiarity with the invariant features of the stimuli.

The process that allows us to take advantage of such discontinuities, natural or otherwise, is a matter of debate. One phenomenon which has fueled this debate is the prototype effect: some exemplars are reported as 'familiar' even when they have not been previously experienced. One explanation for this effect is that categories are formed around prototypes that summarize the crucial information about a particular category. By this account, the features of exemplars are counted, averaged, or in some way calculated to produce a 'best' exemplar, a central tendency, or a family resemblance which is prototypical of the category. The prototype is regarded as a mental representation formed through an analysis of the attributes of exemplars. Members are added to a category by virtue of their distance from the centre of the
category - that is, from the prototype: "Prototype theory construes membership in a concept's extension as graded, determined by similarity to the concept's 'best' exemplar (or by some other measure of central tendency)" (Lakoff, 1987, p.43). Thus the prototype is often experienced as 'familiar' even when it has never been seen previously.

An alternate explanation is offered by Medin and Schaffer (1978) who argue that prototype effects result from a much different process, one that does not depend on prototype abstraction. In this view, all instances are stored individually and each new exemplar is compared to the previously encountered stimuli. The new exemplar is then judged a member or non-member according to its similarity to these previously remembered stimuli. The comparison is not with a single, abstract, representation of the best member, but with every member already in the set. In this case, the familiarity of the 'prototype' results not from the abstraction of a central tendency, but from the higher number of previously stored exemplars it resembles. The prototype appears more familiar because it is similar to more stored exemplars of the category than any other.

The question of which, if either, of these interpretations should be applied to infant categorization depends in part on the sorts of categories one asks infants to form. Categorization tasks that make use of unnatural or unfamiliar stimuli are designed to determine the specific properties of the stimuli that are employed in category formation. By the instance model of categorization, the infant should be limited only by the complexity of the stimuli and memory capacity, that is, by what constitutes an 'instance' to the infant, and the number of such instances they are able to store. By the prototype model, there are at least three possibilities or strategies available to the infant presented here in ascending order of complexity: 1) form a global impression focussing on featural invariants, 2) average or count selected features, or 3) take advantage of correlations among attributes. The
acquisition of these strategies has been chronicled by Leslie Cohen and his colleagues and demonstrates a clear developmental sequence from 4 to 10 months of age (Hussain & Cohen, 1981; Strauss, 1979; 1981; Younger, 1985; Younger & Cohen, 1983; 1985).

The progression in categorization strategies suggested by Cohen and his associates may be summarized as follows. What changes over the course of development is the level of abstraction at which infants can process relational information. Part of the explanation for this change lies in the changing nature of the basic unit of information being processed. For the newborn this basic unit may be only figure-ground relations. Later, the unit becomes specific features such as colour, size, texture etc., and still later, as these lower order elements and relations become themselves the units of processing, patterns, objects and classes of objects are processed. The ability to form categories that match in complexity the discontinuities between clusters of attributes, which Rosch contends exist in the real world, does not appear until this last step. Categorization of the type Rosch has in mind should demand the ability to average attributes and to detect correlational structures.

If, prior to 10 months of age, infants show basic perceptual categorization skills in selected domains but little else, and after 10 months, begin to generalize habituation to stimuli which represent subordinate categories, one is tempted to suggest that the infant has arrived at a watershed in the development of categorization skills. It is my task to convince the reader that this temptation should not be resisted. The attempt will be made through a more detailed analysis of the Younger and Cohen (1983) task and the proposed sequence of categorization strategies which might account for the developmental changes found in categorization tasks in general. The remainder of the discussion of research is taken
from this research programme and will compare the ability of the two models described above to account for this set of data.

In a series of studies, one of Cohen's students, Marc Strauss (1979; 1981), has shown that at 10 months of age, infants begin to respond categorically to photographs or drawings of human faces. Using a police 'Identikit' to construct faces varying along four dimensions (eye separation, nose width, nose length and head length) Strauss reports that 10-month-olds can categorize these stimuli by averaging selected features. Like adults, infants treat a previously unseen face composed of averaged features (i.e., prototype) as more familiar than previously encountered or novel exemplar faces. Although younger infants, 5-6 months, are able to discriminate faces quite easily, they are unable to form a category comprising these stimuli. The 10 month old is distinguished by the ability to construct a prototypical representative of category membership from the set of exemplars by averaging the attribute values experienced during familiarization.

This finding is telling for two reasons. First, it suggests, not surprisingly, that the ability to discriminate among exemplars of a category is not in itself sufficient to allow category acquisition. One wonders how an infant able to discriminate between exemplars is yet unable to store these instances in the manner proposed by Medin and Schaffer (1978). Second, it suggests that a developmental component independent of experience with faces is required to account for this ability. Again, using an instance model it is not immediately clear why the younger infants, though able to recognize particular faces, are unable to form the category.

Using line drawn 'nonsense' animals composed of features which can be interchanged to produce variations on head, tail, ear, body and leg type, Younger and Cohen (Younger, 1985; Younger & Cohen, 1983; 1985), document the appearance in infancy of another adult-like categorization skill: the ability to detect correlations among attributes. Younger and Cohen (1985) argue that younger infants (4 and 7
months) fail to take advantage of such correlations not because they cannot discriminate among the stimuli, for they clearly can, but because their overriding strategy pertains to specific features. From their data it is impossible to determine whether the subjects relied on a single or multiple features. It is nevertheless clear that even if these infants were sensitive to more than one of the features, they were not responding on the basis of the correlations among those features.

The ability of the 10 month olds to form a category on the basis of correlations among attributes represents a significant improvement over this earlier strategy since it allows the formation of more complex categories. The performance differences between the age groups are characterized succinctly in Husaim and Cohen's (1981) contention that 10 month olds apply their new strategy with relative ease to such tasks.

The stimuli used by Younger and Cohen (1983) are nonsense animals composed of five different attributes, each of which can take on one of three values as shown in Table 1. The advantage of this design lies in the ways in which these attribute values can be combined to produce stimuli that bear a quantifiable 'family resemblance'. The resemblance is produced by correlating the attribute values across the stimuli.

<table>
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<tr>
<th>Dimension</th>
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<td>1</td>
<td>Giraffe</td>
<td>Feathered</td>
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<td>2</td>
<td>Cow</td>
<td>Fluffy</td>
<td>Club</td>
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<td>3</td>
<td>Elephant</td>
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<td>Hoofed</td>
<td>Human</td>
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Table 1: Stimulus dimension values from Younger and Cohen (1983)

Table 2 lists the dimension values for experimental stimuli used in the 1983 study, the stimuli are shown in Figure 1.
Table 2: Dimension values of experimental stimuli used by Younger & Cohen (1983)

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<th>Stimulus</th>
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<table>
<thead>
<tr>
<th>Stimulus</th>
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<td>CORRELATED</td>
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<td>UNCORRELATED</td>
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<td>NOVEL</td>
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In the procedure, infants are shown the habituation stimuli in two randomized blocks of four trials. Thus, each stimulus is seen twice. The habituation or familiarization phase is followed by presentation of the three test stimuli (order is randomized across subjects). During each of the 20 second trials, the infant's fixation time to the stimulus is recorded. The correlated test stimulus conserves the correlation present in habituation stimuli 3 and 4 among dimension values a, b, and c. The uncorrelated test stimulus violates the correlation, and the novel stimulus is composed of features absent in the habituation stimuli. The results of their investigation suggest that the stimuli are too complex to be reliably categorized by infants under 7 months of age. These infants typically show low fixation times to the correlated and uncorrelated stimulus and recover to the novel stimulus. A very generous interpretation of the data would grant that 7 month olds are able to form a large and ill-defined category that encompasses all of the habituation and test stimuli, save the novel test animal. More likely, they are simply concentrating on one or two specific features. In that case, both the correlated and uncorrelated test animals are equally 'familiar', and looking time should rise only to the novel stimulus.
In contrast, 10-month-old infants show high looking times to the uncorrelated as well as the novel stimulus (Younger & Cohen, 1983). The older infants, it can be argued, are capable of forming two categories, one containing habituation stimuli 1, 2, and the correlated test stimulus, the other habituation stimuli 3 and 4 (see Figure 1). The uncorrelated and novel test stimuli belong in neither category and are accorded equally high levels of visual attention. But the uncorrelated and novel stimuli may garner the infants' attention for very different reasons. The uncorrelated stimulus is a more attractive candidate for category membership given the familiarity of its features, while the novel stimulus is, by definition, novel. The increased looking time to the uncorrelated stimulus could, therefore, be construed as continued processing in an attempt to determine its status relative to the two categories formed during familiarization. The novel stimulus attracts equally high visual attention by virtue of a novelty preference inculcated in the familiarization phase.

The ability to form these two categories rests on a recognition of the underlying correlational structures of the stimuli. It will be argued below that such recognition should be taken as indicative of a more general cognitive ability to make use of relational information and to coordinate this with intentional action. For the moment, it is enough to claim that the ability to form these two categories is an instance of a new sort of categorization. The 10-month-old infant is now able to judge that the uncorrelated stimulus belongs in neither category by applying, in serial fashion, the correlational information detected during the familiarization phase of the procedure. Indeed, Younger (1985) has demonstrated that by 10 months of age infants are able to segregate a series of items into two distinct categories based on correlations among the attributes of the items.

To return to the issue of prototype versus instance models of categorization, two types of findings argue against the instance view. First, an instance model would
demand memory of the specific exemplars seen during the familiarization phase. There is considerable evidence weighing against this explanation. When tested on their memory for specific items presented during the habituation phase of Strauss' (1981) study, infants displayed no evidence of memory for previously seen exemplars after delays as brief as 15 seconds. Nevertheless, these infants showed evidence of prototype effects with 5 second stimulus presentations. In addition, Sherman (1981) has shown that infants fail to show prototype effects when forced, through overtraining, to remember more than two or three specific items. As Cohen notes: "The evidence as a whole, then, seems to indicate that formation of a prototype accompanies incomplete processing of many exemplars, rather than complete processing of only a few" (in press, p.32).

Second, instance theorists would contend that infants in the correlated attribute studies are recalling the specific exemplars seen in the familiarization phase rather than the correlation. When the task is simplified such that stimuli vary on only three attributes, it is possible to construct a set of test stimuli which directly test the instance theorists' contention. Younger and Cohen (1985) report a variation of the 1983 study in which infants were shown more simple stimuli composed of only three attributes which took on one of three values. The infants were given 9 familiarization trials with 3 stimuli having the attribute values 111, 112, and 221. Infants were then tested with a correlated stimulus (222), an uncorrelated stimulus (211), and a novel stimulus (333). If the infants responded on the basis of the correlation between the first two attributes, the looking times should be low for the correlated stimulus and high for the uncorrelated. On the other hand, if the infants responded on the basis of the similarity to previous instances, the uncorrelated stimulus should be more similar to the habituation set, and the looking times reversed. The results conformed to the first prediction. The infants generalize
habituation to the correlated stimulus and look longer at the uncorrelated and novel stimuli.

Two findings from the research by Cohen, Younger and Strauss should be re-emphasized. First, infants of 10 months, but not younger, are sensitive to correlations among stimulus attributes and are able to use that information in forming categories. Like adults, they can use discontinuities in the variability of attributes to group discriminally different entities into a single category. Second, infants of this age, but not those younger, are able to segregate items into one or the other of two such categories. Given exposure to items which preserve the correlation of one category but not the other, 10 month-olds generalize habituation to further presentations of exemplars from either category. In both cases the feat depends on the ability to process relational information. Infants must be able to detect the correlation and use that information to form a category, and must then compare subsequent exemplars to both category structures.

Having established that this new categorization ability appears near the end of the first year and that its appearance depends on the ability to process relational information, the theoretical implications of these findings need to be addressed. Since much of Cohen et al.'s explanation of categorization derives from an information processing model, the relations of categorization to representation, memory, and concept acquisition - particularly Piaget's concept of the object, is left unstated. The remainder of this section will address these concerns.

To acquire and use a category based on correlational information, the infant must make the decision to respond based on a prototype they have never seen. To segregate items into one of two such categories, the infant must compare a new item to both prototypes or structures. Two questions arise immediately. First, does this necessarily imply that the infant has formed a representation of the object or event similar in complexity to that of an adult's, and second, does the demonstration of these
categorization skills in infancy challenge Piaget's contention that the 10 month-old possesses a still immature concept of the object? The response I propose to both questions is no, and offer the following defense.

First, impressive though the infant's categorization skills may be, they do not require the concept of object permanence. As Sophian (1980) points out, memory for the object may be such that the infant "recreates" the object in the decision to respond. Success, whether in object search or in the categorization of objects, validates this fragile notion of the object without entailing its permanence. Further, the category resides in the acknowledgement and disregard of within category differences, and, therefore, infants need only concern themselves with the criteria of category membership and not the permanence of any particular exemplar. The decision: is X a member of Y, is made with X present, thus relieving the infant of the burden of X's existence beyond this moment. To be sure, these feats require memory for objects but not their permanence.

The reasoning is similar with regard to concept acquisition. The infant need not have an abstract notion of category membership, only the criteria by which membership is determined. A demonstration of categorization based on numerosity (Strauss, 1979) serves to illustrate this point. That infants can discriminate objects based on their number and generalize this discrimination in a habituation procedure does not demonstrate the acquisition of the mathematical concept of number. The stimuli presented are simply instantiations of the concept and can be properly treated as such without resorting to explanations that require the infant's understanding of the abstract concept upon which the category is based. My cat becomes visibly perturbed when robbed of her favourite toy, yet I am confident in denying her any appreciation of the concept of justice.

Categorization in infancy is an impressive achievement indeed. That preverbal infants can respond categorically to events and objects by processing
correlations among features seems, on the surface at least, to suggest that we have seriously underestimated infant capabilities. One is tempted, perhaps, to remove categorization from the list of the adult abilities which infants lack. A closer look, however, reveals a different picture. Looking from the 'top down', we may simply be more likely to interpret categorization in infancy as formally identical to categorization in adulthood. This is clearly not the case. The infant, though able to acquire categories, is, unlike the adult, unable to form an abstract, conceptual representation of the principles by which category inclusion decisions are made.

While adults may have some trouble describing the ways in they make membership decisions, infants require the continued presence of category exemplars. This distinction is important in understanding the limitations of the infants' new found categorization skill. The 10 month-old's ability rests on the recognition of category membership only in specific here-and-now exemplars, but one cannot claim any 'cognitive reality' for the concepts which underpin this recognition. Such knowledge is beyond these infants though they can categorize using what appear to be highly sophisticated information-processing strategies. It must be stressed, however, that the potential for realizing these concepts exists even at this early stage. The understanding of such concepts depends jointly on the infant's ability to recognize instantiations of a particular concept and the later arriving, and more general, ability of conceptual representation.

Categorization of the kind available to these infants allows them to dissect their experience in qualitatively new ways and likely serves to further development in other domains. It is possible, for example, that categorization of the type Cohen and his colleagues report is a necessary prerequisite to mapping knowledge of objects and persons onto emerging language capabilities. The acquisition of a receptive vocabulary and a functional phonology may depend on the ability to recognize abstract categories of precisely this kind. Further, the ability to apply
language labels to category exemplars, which arrives much later, helps to define and fix category boundaries. In this sense, language both profits from and enables this type of categorization. The possibility that language may, at once, provide an anchor and a sail for the realization of the conceptual potential of these categorization skills will be reprised in a later section. It is also likely that conceptual knowledge grows out of such abilities. The 'cognitive economy' that categorization allows may be a crucial step toward the acquisition of the concept of the object. I will return to this notion as well, but from the preceding review it seems evident that, whatever the developmental implications of this emerging ability, infants are capable of processing such information in importantly adaptive ways.
The Development of Cross-Language Speech Perception

The purpose of this section is to introduce some of the theoretical and methodological issues which arise out of the use of the cross-language speech perception measure. The review will outline some of the research in the area of adult perception, the developmental implications of these findings, and some of the more recent results from work with infants.

One of the most intriguing aspects of speech perception is that we are able to treat acoustically distinct instances of a single phoneme as equivalent. This categorical - rather than continuous - perception of language allows the listener to effortlessly divide an acoustically ambiguous continuum of speech sounds into discrete, language appropriate categories. Early research with adults painted a clear picture of categorical perception for speech, but not non-speech, sounds. Perhaps not surprisingly, more recent results have complicated this simple picture. Nevertheless, where stimulus characteristics and processing demands match those found in everyday speech processing (ABX procedures, long ISI, Go/No-Go procedures with multiple tokens), categorical perception remains the rule for speech and continuous perception for non-speech (see Repp, 1983 for a review).

More fascinating still (for those of a developmental bent) is the fact that the benefits of this rapid and accurate processing of speech sounds are enjoyed by pre-linguistic infants. As young as one-month of age, infants have been shown to discriminate speech stimuli according to adult phonetic category boundaries. In a classic study by Eimas, Siqueland, Jusczyk, & Vigorito (1971), infants one- and four-months of age, presented with three pairs of stimuli from the /ba/-/pa/ voice onset time continuum, only one of which straddled an English phonetic boundary, were shown to reliably discriminate only those pairs of stimuli which crossed the English boundary. Similar results have been reported for place of articulation, voice onset,
stop, lateral, and fricative consonants (e.g., Aslin, 1987; Eilers, Wilson, & Moore, 1977; Eimas, 1975; Holmberg, Morgan, & Kuhl, 1979), as well as vowels (Trehub, 1973). Importantly, when non-speech counterparts to the speech stimuli have been included, infants show continuous discrimination. Together these findings suggest that infants possess broad based, linguistically relevant, discriminative capacities.

These demonstrations of infant sensitivity to phonetic information in single syllable utterances begged the question of sensitivity to higher order aspects of speech perception. Adults, for instance, show sensitivity to context effects such as rate of speaking. To the adult English speaker, one of the principle acoustic cues differentiating /ba/ from /wa/ in synthesized speech is the duration of the formant transitions. Typically, these transitions are much shorter for /b/. When a speaker is talking slowly, however, the formant transitions for /ba/ will lengthen, reaching well into the range of the formant transitions for a normal /wa/. Rather than perceive this slowly spoken /ba/ as /wa/, adults compensate for the rate of speaking (Miller & Liberman, 1979). Eimas and Miller (1980) have shown that young infants are also sensitive to this kind of contextual cue, indicating that their processing of speech sounds is determined by the relational rather than absolute acoustic parameters of what they hear.

A similar sensitivity extends to vowels. Young infants can categorize vowel colour across different speakers and intonation contours (Kuhl, 1979). Recently, Greiser and Kuhl (1989) have shown that young infants can even generalize to novel instances of a single vowel category. As with phonetic contrasts, infants easily discriminate between categories but show little sensitivity to the differences among category members, even when the acoustic differences between two category members are greater than those between two instances which cross a category boundary.
The discovery of such unexpected and remarkable sophistication on the part of the infant led to a shift in research focus. Attention now turned to the developmental fate of these skills in an attempt to determine if the perceptual constancy of phonetic segments was simply given at birth, or whether evidence of further perceptual development could be obtained. The similarity of these feats to perceptual categorization as discussed in the previous section cannot escape comment. While the infants' perceptual skills are remarkably sophisticated, the absence of within category discrimination and the exhaustive nature of the categories, suggest that the categorization of speech demands little effort.-- it is the nature of the beast. On the agenda of the present section is the extent to which the categorical perception of speech follows a developmental course similar to that of perceptual categorization in becoming co-opted to serve a different sort of ability.

The first indication that developmental changes occur in the perception of the formal aspects of speech came from studies of cross-language speech perception showing that adults often have difficulty discriminating phonetic contrasts that do not have phonemic status in their native language. Japanese speakers, for instance, have difficulty discriminating between the English /r/ and /l/ (Goto, 1971; MacKain, Best, & Strange, 1981; Miyawaki, Strange, Verbrugge, Liberman, Jenkins, & Fujimura, 1975). Studies using different contrasts have revealed similar results (for reviews, see Burnham, 1986; Strange & Jenkins, 1978; Strange, 1986).

The finding that adults have difficulty discriminating non-native contrasts suggested that both adults and infants might have to learn to discriminate phonetic contrasts, and that by 1-4 months of age infants have already had enough experience to have acquired this ability. To remove the potential confound between nature and nurture, researchers began testing infants prior to their first exposure to a non-native phonetic contrast. The goal of such investigations was to determine whether
young infants show sensitivity to the universal set of phonetic contrasts, or are sensitive only to those contrasts present in their language environment.

The rewards of this approach have been plentiful. Two month old Kikuyu-learning infants, for instance, are sensitive, to the English /ba/-/pa/ voicing distinction (Streeter, 1976), as are Spanish-learning 4-6 month olds (Lasky, Syrdal-Lasky, & Klein, 1975). The comparison between the infants' broad-based phonetic sensitivities and the more limited (language-specific) capabilities of adults led to the hypothesis that infants may have a biological predisposition to discriminate the universal set of phonetic categories, and that there is a decline in this sensitivity as a function of acquiring a particular language (Eimas, 1975). Effort now focussed on the timing of this developmental change.

To assess the effect of experience on cross-language speech perception, Janet Werker and her colleagues began by comparing English-speaking adults, English-learning infants aged 6-8 months, and Hindi-speaking adults on their ability to discriminate the English /ba/-/da/ distinction (which is also used in Hindi), as well as two pairs of syllables (unvoiced, unaspirated retroflex versus dental stop /ta/-/Ta/, and the voiceless, aspirated dental stop versus the breathy, voiced dental stop /tʰa/-/dʰa/) that are phonemic contrasts in Hindi but not in English (for a full description see Werker, Gilbert, Humphrey, & Tees, 1981). While virtually all of the infants could discriminate both Hindi contrasts as well as the Hindi-speaking adults, most of the English-speaking adults failed both the non-English contrasts.

The developmental change between infancy and adulthood was subsequently replicated using a contrast from Inslekampx (Thompson), an Interior Salish Northwest Indian language (/ki/-/qi/). Again, English-learning infants aged 6-8 months and native Inslekampx-speaking adults were able to discriminate this distinction, but the majority of English-speaking adults were not (Werker & Tees, 1984a).
Werker originally (and incorrectly) predicted that the developmental change in the ability to discriminate non-native phonetic contrasts would occur around puberty, the age at which Lenneberg (1967) had claimed that the flexibility to learn a foreign language without an accent declines. Contrary to expectation, her work indicated that 12-year old, and even 8- and 4-year old English-speaking children were no more able to discriminate the non-English syllables than were English-speaking adults. Even more surprising, the 4-year olds actually had more difficulty on the Hindi voicing contrast than did the older children and adults (Werker & Tees, 1983).

A further set of experiments revealed that when adult English-speakers were tested under more favourable testing conditions, they did show some latent sensitivity to the non-native contrasts. For example, when presented with truncated portions of the contrasts, discrimination of these now non speech-like stimuli improved markedly (Werker & Tees, 1984b). Thus the ability to discriminate the acoustic cues differentiating these non-native contrasts had not disappeared, it was simply not as readily accessible when the stimuli are language-like sounds. Further, adult English-speakers were able to discriminate the full-syllable Hindi retroflex/dental contrast when given sufficient practice and tested in a more sensitive procedure (Werker & Logan, 1985).

These studies suggest that the apparent decline in perceptual sensitivity is evidence of a reorganization within the language system rather than an absolute loss or simple decline in sensitivity. It may be that performance depends on the extent to which the task demands and stimuli resemble the natural speech environment. When the testing situation most closely mimics the natural environment, and the stimuli are perceived as speech-like, discrimination is poor. As the stimuli become less speech-like discrimination improves, thus subjects show evidence of discrimination in some testing procedures and not others. The reorganization may
represent a developmental shift in the level of analysis applied to speech and non-speech stimuli, with each level affording its own set of boundaries.

Having ascertained that children as young as age 4 perform as poorly as adults on non-native contrasts, Werker and her colleagues next (again incorrectly) predicted that the reorganization would be apparent at 18-24 months of age to coincide with the "explosion" in productive vocabulary. However, in pilot testing children between 8 months and 4 years of age, it quickly became apparent that something was happening by the end of the first year of life.

At this point the investigation narrowed, concentrating on infants under twelve months of age. Three groups of infants aged 6-8, 8-10, and 10-12 months were compared on their ability to discriminate both the Hindi retroflex/dental (/Ta/-/ta/), and the Inslekampx glottalized velar/uvular (/ki/-/qi/) distinctions.

Virtually all the infants aged 6-8 months were able to discriminate both non-native contrasts, whereas only one of the ten infants aged 10-12 months was able to discriminate the Inslekampx, and two of the ten the Hindi contrast. The performance of the infants aged 8-10 months was intermediate, 8 of the 14 infants able to discriminate the Inslekampx, and 8 of 12 the Hindi. This experiment was repeated (Werker & Tees, 1984a) using a longitudinal design yielding results consistent with those described above with all subjects discriminating both non-English contrasts at 6-8 months, and none at 10-12 months of age.

Finally, to make sure that the results were not due to a general decline in performance for difficult contrasts at 10-12 months, a few Hindi- and Inslekampx-learning 11-12 month olds were tested on these contrasts. These infants had no difficulty discriminating their native contrast.

We recently replicated this finding using a 16-step synthetic /ba/-/da/-/Da/ continuum which allowed precise control of the differences within and between phonetic categories. The continuum was constructed by varying the starting
frequency of the second and third formant transitions (see Werker & Lalonde, 1988, for a detailed description). English listeners were shown to divide this continuum into two categories, /ba/ and /da/, and Hindi listeners into three categories, /ba/, dental /da/, and retroflex /Da/.

We then tested infants aged 6-8 and 11-13 months and Hindi- and English-speaking adults on their ability to discriminate stimuli from the continuum according to both phonetically relevant and irrelevant boundary locations. Three exemplars from either side of three boundary locations along this continuum were presented using the Head Turn procedure. The first boundary location, called Common, corresponded to the boundary between bilabial /ba/ and dental/alveolar /da/ for both the Hindi and English listeners. The second location, called Hindi-only, corresponded to the boundary between dental /da/ and retroflex /Da/ for the Hindi listeners. A third location, called Neither, was chosen near the Da end of the continuum where no language is known to make a category distinction.

The results clearly indicated that infants aged 6-8 months and Hindi-speaking adults could discriminate the Common and Hindi-only pairings, but not the Neither pairing, whereas English adults and 11-13 month olds could only discriminate the Common pairing. This inability to discriminate a linguistically irrelevant boundary (Neither) confirms the phonetic specificity of infant speech perception.

Together with other studies of infant speech perception, this research strongly supports the contention that infants have special phonetic capacities which become reorganized by the end of the first year of life to match what is required by the native language.

Recent evidence indicates that important developmental changes to other aspects of infant speech perception may also be occurring in this first year. It has been shown, for example, that infants as young as 4-6 months can perceive clausal boundaries, and this ability is particularly striking when the clausal boundary is
exaggerated with the timing characteristics of "motherese" (Hirsh-Pasek, Kemler Nelson, Jusczyk, Wright Cassidy, Druss, & Kennedy, 1987). The ability to perceive phrasal boundaries, however, is not apparent until approximately 9-months of age (Jusczyk, Hirsh-Pasek, Kemler Nelson, Kennedy, Woodward, & Piwoz, in press) suggesting that the perception of phrases may build from the same kinds of abilities that facilitate the perception of clausal boundaries. In addition, Jusczyk and his colleagues have shown that infants as young as 4 months can perceive clausal boundaries in both native and non-native languages, but that by 6 months the capacity has narrowed to native language boundaries. This research further indicates that the broad based sensitivities present during early development become tuned in accord with specific linguistic input.

The advantages which these remarkable perceptual abilities hold for the task of acquiring language are self-evident: the ability to perceive speech contrasts in a categorical manner and the ability to segment speech into clauses and phrases allows the infant to bring some measure of order to the seeming chaos of her linguistic environment. But language learning demands more than the simple detection of the formal properties of language: the infant must harness these perceptual abilities to serve a communicative function.

I have argued that the newborn arrives armed with an impressive array of speech perception skills. The infant is able to categorize speech stimuli according to universal phonetic boundaries. Over the course of the first year of life these skills will narrow to conform to the demands of the infants' native language. It is also apparent that comparable changes are occurring in the perception of the suprasegmental aspects of speech. The perceptual biases that are evident in the newborn reflect a sensitivity to a broad base of linguistically relevant segmental and suprasegmental features. As noted above, this universal sensitivity far outstrips the formal requirements of the native language. These changes, evident before the
infant utters his first real word, represent a specific narrowing of perceptual abilities which match what is required of a native listener.

The intent of this review has been to describe some of the processes that may contribute to developmental changes in infant speech perception. It has been argued that the contribution of the infants' emerging cognitive abilities must also be considered. By highlighting some of the ways in which both contextual variables and developing infant competencies may influence the fate of early speech perception abilities, I hope to have set the stage for a discussion of the developmental relations among the three competencies I have chosen to study.
POSSIBLE RELATIONS AMONG THE TASKS

To suggest that the developmental changes evident in the object search, categorization, and speech perception tasks share a common origin, demands a description of the relations I see between each of the three possible pairings. These will be addressed by the following pair-wise comparisons: object search/speech perception, object search/categorization, and speech perception/categorization. The common theme in these comparisons is that success on each task requires a coordination of separate processes and the mental manipulation of their products across some form of interference or ambiguity. The coordination is carried out in the pursuit of a specific goal and represents the infants' first attempts to realize the potential which this coordination ability holds. The ability to coordinate what were once independent processes or separate sets of information becomes objectified, and made more general. The changes outlined in object search, speech perception and visual categorization reflect the emergence of this coordination as a general cognitive strategy.

Object Search and Speech Perception

The reorganization of cross-language speech perception capabilities can be characterized as a developmental transition in the processing of phonetic information. The finding that, although adults may have difficulty discriminating non-native speech sounds, they have not lost the ability, suggests that a change in the level of processing has occurred. To the distinction between speech and non-speech is added the distinction between 'universal' phonetic, and more narrow native phonetic perception (cf. Mehler, Jusczyk, Lambertz, Halsted, Bertoncini & Amiel-Tison, in press, with respect to the whole language). Further, if the speech/non-speech distinction is made by the machinery of perception (i.e., it is the nature of the beast), the initial speech processing capabilities represent a form of perceptual
overkill. While non-speech sounds are perceived in a continuous manner, with fine
grained discriminations easily made, speech is perceived categorically, making within
category discrimination difficult. The capacity to discriminate non-native speech
contrasts provides infants with more perceptual categories than their language
environments require. The frequency with which each category is activated by
exemplars from the native language differs -- some are virtually absent, others
subdivide a single native category, still others match the native phonetic distinction
exactly. The task facing the infant, if we were to formalize it, is to move certain
boundaries and erase others such that the set of possible perceptual discriminations
matches the phonetic set used in the native language. But the initial capabilities are
not entirely lost. The reorganization of these categories, therefore, involves a
sublimation of the extraneous categories which, interestingly, are most easily
revived under special conditions in which non-native speech begins to resemble
non-speech. Still, these findings in no way inform us as to whether the
reorganization arises out of an independent maturational/experiential process,
occurs within some encapsulated phonetic or phonetic/linguistic module, or is
somehow yoked to other developing abilities. In an effort to persuade the reader that
the latter is indeed the case, I offer a demonstration of a formal similarity between
the development of object search and native speech perception skills.

Consider as one of the goals of perceptual development in this domain the
recognition that sound is a cue to the localization of its source in space. If this is so,
we should expect intermediary steps prior to a full appreciation of the causal
relationships between the experience of sound and the nature of its source. The
observation that the newborn is equipped with an orienting response triggered by
sudden noises, must then be distinguished from later, more sophisticated forms of
localization. We can easily contrast the reflex nature of the newborn's response to
the very real sense that the 12 month-old not only correctly locates the sound in
space, but *expects* a specific source. While this older child understands, if incompletely, that sounds are 'caused' by persons and things, the newborn merely orients more or less correctly in the direction of the sound. Over the course of the first months of life infants begin to evince a perceptual expectancy surrounding sound, and will coordinate sound with events, perhaps beginning to expect mouth movements contingent with the speech directed toward them (Muir & Field, 1979).

The limits of such expectancies are found in the infant's inability to use that information as a guide to action beyond simple orientation. The connection of sound, and events or images in the infant's world to the differentiation of sounds from the objects that produce them, comes gradually. Clearly then, the transition from reflex, to perceptual expectancy, to an appreciation of causal relations (using whatever terms one wishes in which to couch this process) is intertwined with the child's conception of space, time, causality and, therefore, with her concept of the object. The crucial question then becomes: Can the same be said of the child's perception of speech?

Having acknowledged that speech is 'special' in the sense that it is processed differently than non-speech, I intend to argue that a similar process to that described above lies behind the reorganization of perceptual abilities. At the outset it must be stressed that I do not endow the 9 month-old with a large, functional, receptive vocabulary. All that is required for the argument that follows is that the infant have a sense of the correspondence between speech and events in the world. This sense of correspondence may more properly be termed a perceptual expectancy. The nature of the expectancy is that speech and events are correlated in time but not unitary -- that is, that speech may attend an event without being a causal or inseparable constituent of the event. The infant must have the beginnings of a sense that speech may precede, overlap, or follow events, but is not isomorphic with them. Speech is thus not simply background noise, nor does it yet have meaning.

Relations among the tasks
beyond the immediate context. In this way speech has no meaning unto itself, save that which attaches to it as a function of this loose correspondence with events. The content of any receptive vocabulary at this point may be restricted to simple recognition of the one to one correspondence of a word as a cue to an immanent object/event (e.g., "bye-bye"). The task is to explain the effect this expectancy might have on the perception of native and non-native speech sounds.

The utility of the speech/non-speech distinction is reinforced by the differing degrees of correspondence which emerge between the 'objects' of speech and non-speech related events. The key difference is that non-speech related events, to be localized in space and time, and understood as a cause-effect relation, must be conceived of as emanating from independent objects, and are, therefore, more obviously a part of the development of the concept of the object. Speech related events on the other hand, are more nebulous, the 'object' is the referent or the communicative intent of the speaker. If the infant has developed an expectancy that speech attends (i.e., is somewhat separate from) events, and couples this with a receptive vocabulary which contains only a single, even context-dependent, item, the process of constructing a concept of the speech 'object' has already begun. This is precisely the position of the 9 month-old with a simple and restricted receptive 'vocabulary', having acquired this sense of expectancy surrounding speech, and showing evidence of investing speech in general with a global, subjective measure of 'meaning'.

The recognition that speech may correspond to events in some specific way (as do the items in a receptive vocabulary), and that there are objects of speech, arises out of the coordination of the perceptual expectancies surrounding speech with the ability to differentiate between objects in general from the events that attend them. Just as the barking of the family dog always predicts his appearance, so the appearance may predict barking.
If this is indeed the case, we should expect that over time, the processing of speech as speech should come to predominate. In keeping with the theme of meaning-making, I take this to be a function of the infant's growing awareness of the relation between sound and referent in the domain of speech perception. This is not to suggest that the 10 month-old is aware of a direct correspondence between sound and meaning, only that the distinction between speech and non-speech sounds becomes reinforced by their differential correspondence to visual and tactile events. The emphasis of the relation between visual and kinesthetic events as speech and non-speech is elaborated by the relation that exists between native and non-native speech sounds as presented within the special character of infant directed talk. The absence of non-native speech contrasts in the speech of caregivers is thus made conspicuous by the specialized emphasis in the presentation of native contrasts. The increasingly 'palatable' relation between sound and the internalized 'referent' (images, events), bolstered by the special properties of motherese, reinforces the utility of the infant's developing capacity to categorically divide speech and non-speech and in the bargain reduces the overdetermination of their speech processing capabilities.

This process, as it becomes a sort of perceptual triage, consolidates the permanence of speech 'objects' and is thus self-validating: the investment in native speech categories pays off in a better correspondence between processing and experience. The mill adapts to the nature of the grist. The similarity of this transition to the consolidation of the permanence of physical objects across the tactile and visual domains evident in the ability to coordinate separate schemata in a successful search can now be established. What the infant is beginning to acquire in both instances, is an awareness that by triangulating the permanence they ascribe to these images, a more successful strategy for coping with the vagaries of object behaviour can be attained. Just as the coordination of the successes of tactile search
through the extension of manual searching with the successes of extended visual search leads to the ability to find a completely hidden object, so to placing faith in the distinction between native and non-native speech categories begins the process of refining the perceptual skills required for native speech comprehension.

But infants do more than simply ignore the unused categories available in their perceptual arsenal. Non-native phonetic categories are, in fact, consumed by the spreading native category boundaries. Something more than the acquisition of empirically useful speech 'objects' is required to account for this process. The validity of the analogy between physical and speech objects rests on certain assumptions about the process of speech perception. It could be argued that, as a result of the absence of input, the infant merely loses the ability to discriminate non-native speech contrasts through some form of perceptual atrophy rather than as a result of the construction of a native phonology. Research findings weigh against this argument however, and support the contention that adults are still capable of non-native discrimination but that speech, when perceived as speech, is processed using native phonetic categories only (Werker & Tees, 1984b; Werker & Logan, 1985). In the adult, the fact that speech contrasts signal linguistic meaning has resulted in the automatic application of a native phonetic analysis to speech-like sounds. The idea that some analogous dimension related to linguistic meaning is being imposed on the infant's abilities is made more plausible if one adds that the meaning apprehended by the infant consists of a more perfect match between their perceptual categories and the nature of the native speech they hear.

To suggest that the reorganization of speech perception skills is related to changes in object search skill implies that the coordination of schemata evident in object search, is a necessary condition for the emergence of the native categories. To add weight to the notion that it is a sufficient condition, requires an empirical demonstration of the simultaneous appearance of these changes.

Relations among the tasks
Object Search and Categorization

The relation between object search and visual categorization consists in the formal similarity of the intentional coordination required to solve the tasks. Both require the sequential application of distinct sets of information derived from experience. For the object search task, the infant must coordinate the information related to the goal or intention (and hold this intention at bay), with an appropriate barrier removal strategy (which is unrelated to the goal). Successful search is both evidence of this ability as well as a measure of the infants' concept of the object. This much was made clear in the review of the object search literature. The purpose of the following discussion is to convince the reader that a sufficiently similar process can be inferred from Younger and Cohen's (1983) categorization task.

In the visual categorization task, the infant must acquire a category structure that is not immediately apparent in either the present or previously experienced stimuli, but is abstractable from the set as a whole, a set which he never sees. In other words, he must acquire a category based on a correlation among stimulus attributes and, in order to succeed at this task, must form two such categories which are defined by two related correlational structures. Thus the category is not 'burned' into the infants' head by virtue of its featural redundancy, but is rather a product of the history of familiarization with both structures and the acquisition of category representations or prototypes which negate any category overlap. If the structure of either category is ambiguous or overlaps the other, the uncorrelated test stimulus would drop into one of the two categories formed during habituation. The resulting data pattern would (though for different reasons) be that observed for 7 month olds. If the structures have not been separated, that is, no accounting of category differences is made, there is no choosing between the correlated and uncorrelated test stimuli, and the infant will dishabituate only to the novel test stimulus.
In any case, the assumption that dishabituation results from an inability to match the stimulus to the category needs to be fleshed out. The dissimilarity of the novel test stimulus is readily apparent to the infant and this is the researchers' intent. This stimulus is meant to rule out the possibility that some form of fatigue could account for the decrement in responding and it is explicitly designed using novel features that bear no relationship to the other stimuli. The same, of course, cannot be said of the uncorrelated test stimulus. This stimulus is composed entirely of features familiar in both categories using no novel features. It seems plausible that the increased visual attention accorded this stimulus is the result of a sustained attempt to assimilate it to one category or the other rather than a novelty preference. For the 10 month old subject, the correlated stimulus is judged 'old news'; the novel, 'new news'; and the uncorrelated, a puzzlement.

Younger's (1985) demonstration of the segregation of items into two categories formed using correlations among stimulus attributes provides support for this interpretation. As Younger's 'segregation hypothesis' makes clear, the coordination required to resolve this puzzle involves the recognition that two categories are possible and that this stimulus shares enough of the attributes of each to warrant consideration for membership in either category. In truth, however, the uncorrelated test item belongs in neither. Any confusion about the correlational basis of the two categories, or mismatch of attributes will derail the child. Further, the infant must perform these comparisons in the absence of any true category exemplars.

In both tasks the infant must do the following: (1) access or recall two distinct sets of information which are not present in the display (goal and barrier schemata in the object search task; structures of two mutually exclusive categories in the categorization task), and (2) apply these sequentially to the problem at hand (barrier then goal in the object search; "member category A?", then "member category B?" in
the categorization task). Both tasks share the pitfalls of forgetting: the inability to recall crucial information leads to failure as readily as a lack of coordination between sets of information. And both tasks share red herrings. In the AB task the infant must surmount the problem of two identical locations at which search might be applied. In the categorization task there is the problem of shared features -- the uncorrelated test stimulus contains features common to both of the categories to which it might be assigned.

This is not to gloss over the differences between the two tasks, for there are many. The object search task is obviously similar to the problems of finding hidden objects that infants encounter in their everyday lives. The same claim cannot be made for Younger and Cohen's (1983) task. While the infant's 'real world' categorization tasks reflect a gradual apprehension of adult norms, of basic level categories etc., the application of such teleological significance to the task used here is tentative at best. The correspondence of the abstract stimuli to real world categories is structural and as such, allows the attribution of sophisticated structure to the categories formed by 10 month-old infants but no specification that it is the infants' intention to match this ability to the nature of some category per se. The infants' 'goal', to resolve the discrepancies among the exemplars can, nevertheless, be seen as an extension of the problems faced in real world categorization.

Still, the ability to detect and encode such correlations in 'real world' category formation is as a step toward a better grasp of the adult norm only from the adult's vantage point. The infants' seemingly sophisticated skill on this artificial task might, by some accounts, be the result of its comparative simplicity to the more complex demands of 'real world' categorization. We should recall however, that Younger and Cohen's task deprives the infant of access to category exemplars and provides only the structures of the now vanished exemplars as a guide. If the infant is to make any sense at all of the uncorrelated stimulus, he must do so by applying a
strategy which has no objective standard of success, for the infant gains nothing by categorizing the stimuli, and does so only as an extension of a strategy gained in his dealings with real world objects. The flexibility of this strategy, and the infants' realization of its potential in this situation results from the success of its application to real objects -- the creation of 'real' categories that carry subjective significance. The appearance of this change in the categorization of nonsense line drawings comes, therefore, at the precisely time the child has begun to realize the potential this strategy holds in more the more tangible pursuit of hidden objects.

**Categorization and Speech Perception**

That a logical relation exists between these two tasks is based on the contention that the speech task is a proper analogue of categorization skill. The purpose of this section is to convince the reader that s/he has been compelled rather than seduced by this analogy. This conviction will be sought in two stages: first by arguing that the speech task is not only a test of discrimination, but also of categorization, and secondly via an appeal for a formal equivalence of the processes that account for this categorical ability.

Investigators of the speech perception skills of young infants typically champion a pre-linguistic infant able to naively overcome the confusing babble of speech they hear through the wonder of categorical perception. In very young infants sensitivity extends to the universal set of phonetic distinctions. As outlined above, this ability undergoes a reorganization between 8 and 10 months of age resulting in a loss of sensitivity to speech contrasts not heard in the native language.

The speech stimuli from Werker's research programme are of exactly the kind necessary to prove that the task facing the infant subject is one of categorization as well as discrimination. Infants categorize multiple exemplars of speech tokens chosen at equally spaced intervals along a continuum of synthetic stimuli which cross adult phonetic boundaries. To be successful, the infant must ignore the within-
category variability and respond only to between-category differences. Using natural speech stimuli may reduce the within category variability with respect to phonetically relevant information but at the expense of increasing the variability of non-phonetic information. In both instances, however, the infant must categorize the stimuli. Still, the conclusion that Werker's speech perception task should properly be considered a measure of categorization may boil down to a semantic relation between the tasks. To accept the notion that an ontogenetic relation also exists between speech perception and visual categorization demands a small but vital leap of faith.

In the arguments presented above for an underlying equivalence between the tasks, I emphasized the ability to recruit information about the past in service of present needs and characterized this as the beginnings of intentionality: the formation of a plan in connection with a goal. The application of that same explanation to the relation between the speech perception and visual categorization tasks raises an issue which can be avoided no longer. The absence of the word 'memory' in the previous discussions now becomes conspicuous. What is it that infants are remembering in the speech task?

I have argued that the reorganization evident in speech perception follows from the attribution of a degree of 'permanence' to speech 'objects'. The permanence is characterized by a sense of correspondence between speech and physical events which exceeds a perceptual expectancy in an as yet unstated manner. If this correspondence demands an appreciation of the difference between past and current information and the ability to coordinate these sets in order to categorize present exemplars, the case for an underlying formal equivalence between the tasks can be made.

If the reorganization in speech perception occurs through the application of a second process of categorization based on the distinctions between 'native' and
'universal' speech, and then among the defining versus arbitrary features of native sounds, some means of coordinating these as analyses is required. It has been said, in another context, that: "...there must be just one principle of human conduct, for if there are two principles then there must be a superordinate principle to decide which one is in force at any moment, and it will the superordinate principle that becomes the one principle" (Loevinger, 1966). The one principle I wish to place over these processes is the ability to coordinate the separate results of this analysis with the growing awareness of the relation between speech and meaning.

Clearly, the 'meaning' of a fragment of speech, for example, /ba/, is not equivalent to the meaning of a word which contains it, like "ball". I am suggesting that the attribution of a sense of permanence to the sound /ba/ precedes an appreciation of the specific meaning of words. By reducing the likelihood that such fragments will fall alternately into native and universal speech categories, the infant acquires the building blocks necessary for the construction of a receptive vocabulary. The acquisition of this functional phonology requires the ability to coordinate the 'given' distinctions among the universal set of speech distinctions with the newly constructed categories (i.e., 'objects') of native speech perception.

Summary and predictions

The discussion of possible relations among the tasks reduces to a single prediction: that infants able to coordinate separate sources of information will respond differently to the three tasks than those who lack this coordination ability. To be more precise, infants who pass any one of the tasks are assumed to possess the required coordination skill, and are predicted to pass all three tasks. Infants who fail any of the tasks are assumed to lack the coordination skill, and are predicted to fail on all of the tasks.

On the AB task, three outcomes are possible: pass, fail, and error. For the present purpose, infants able to tolerate a 3 second delay in the AB task will be
assumed to possess this coordination skill and are predicted to pass both the speech and categorization tasks. Thus, infants who pass the AB task, or commit the AB error are considered to possess this coordination skill, while those who fail the task will be said to lack the skill. Though the ability to coordinate secondary schemata is typically measured in a simple, one location, object search task, those infants who exhibit the perseverative search error are nonetheless capable of successful search at one location (A), and, by this measure, they too possess the required coordination skill.

'Passing' the categorization task is defined here as generalized habituation to the correlated stimulus and dishabituation to both the uncorrelated and novel stimuli. Failure on this task will be characterized by generalized habituation to both the correlated and uncorrelated stimuli, and dishabituation to the novel stimulus only. These performances are characteristic of the 10 month-old and 7 month-old subjects in the Younger and Cohen (1983) study, respectively.

Counter-intuitive, though this may appear, 'passing' the speech perception tasks is defined as the failure to discriminate the Hindi contrast. The logic of this definition is that infants who fail to discriminate the Hindi contrast may be considered "native listeners" (Werker, 1989), and thus more sophisticated than those still able to discriminate non-native speech sounds.

At bottom the differences between all three tasks seem more apparent than real. All three measure memory and categorization in one form or another. All three involve the coordination and sequential application of separate sources of information or action in the service of a goal. And all three can be characterized as the coordination of previously unrelated sources of information despite some form of interference, delay, or barrier. The argument that successful performance on one of these tasks should predict success on the others, rests on several rather large assumptions, however. First and foremost, there is the assumption that there is a
common ability or strategy which underpins successful performance on all three tasks. This, in turn, stems from my belief that the infants' more or less direct control of physical objects allows the formation of firm and reliable mental correlates of the relations between action and object behaviour (schemata) which permit the formation and successful execution of the intentional action sequences required to solve the AB task. Finally, there is the assumption that the empirical success of such sequences engenders a more confident application of the strategy to the other tasks than either should warrant on the basis of the immediate task goal. While it is obvious that the recovery of a hidden object is of some immediate and concrete interest to the infant, the benefits of the successful perception of speech segments and the categorization of nonsense figures are calculated only by the adult observer.

To demonstrate that infants able to overcome the demands of the AB task are also able to categorize visual and speech stimuli in the manner described above, would in no way validate these assumptions. Such a feat would merely rule out one pesky alternative: that the ability to coordinate separate sets of information is simply an epiphenomenon of my analysis of the research to date. Thus, despite all that I might wish to the contrary, positive results would merely form a petition for further research.
DESIGN

The study consisted of four experimental sessions per subject spread across two days of testing. Testing for each infant was completed within a 7 day period, with most sessions held within a two day period. Each subject was tested for three abilities: object search, cross-language speech perception (two sessions), and visual categorization. All testing sessions were held in the Department of Psychology, Infancy Research Laboratory, at the University of British Columbia.

Portions of the data were collected in March and April of 1986 (sample 1, n=14), with the remainder collected from April to August, 1989 (sample 2, n=26). Subjects in sample 1 were tested with the synthetic speech tokens used by Werker and Lalonde (1988). Subjects in sample 2 were tested with the natural speech tokens used by Werker and Tees (1984a). The data collection period for both samples continued until an equal number of subjects passed and failed the AB task. No procedural changes were made in the design or experimental protocols used with the two samples. The results of the two samples were compared and analyzed separately (see Results section), before being combined for further analysis.

Subjects

Seventy-eight full-term, healthy infants (36 male, 42 female) were recruited for participation in the study. The subjects were selected randomly from files of parents recruited at local maternity hospitals for the University of British Columbia Infancy Research Program. A total of 38 infants were excluded from the study. Twelve infants who would not perform in the Head Turn procedure, or failed to reach a pre-set criterion of performance on the English contrast (see below), were excluded from the study as it has been repeatedly demonstrated that infants of this age and younger are able to discriminate these sounds (e.g., Eimas, 1975; Mehler, 1985). Ten infants were unable or unwilling to return for the second testing session.
Nine subjects were eliminated for fussiness, 2 for equipment failure, and 2 for experimenter error. An additional three infants with histories of middle ear infections, which has been shown to adversely affect auditory development, were eliminated. The data reported here are from the final sample of 40 infants. Nineteen male and 21 female subjects completed testing. The mean age of the subjects was 9.2 months, range = 8.25 - 10.09, s.d. = .540 (male subjects: mean = 9.35, range = 8.28-10.09, s.d. = .526; female subjects: mean = 9.06, range = 8.25-10.09, s.d. = .527).

Object Search Measures

All infants were tested using the standard AB object search task (Piaget, 1954). Infants were seated on their parents' lap facing an experimental assistant (E1) across a small table (see Figure 2). A video camera (JVC GX-N7U camera, JVC BR-1600U video cassette recorder) recorded the infant's responses during the experimental session. The subject was presented with an object (set of plastic keys, small toy) by E1 who ensured that the infant was sufficiently interested in the object to warrant its use as the test object. E1 then placed the object under a cloth at location A, ensuring that the infant attended to this event. The parent was instructed to restrain the infant gently but firmly throughout the hiding. E1 then counted aloud from 1 to 3 in order to distract the infant from the display and to provide a 3s delay between hiding and search. An on-screen stop-watch was used to verify the length of the delay during later coding. At the end of the 3s delay, the infant was allowed to search for the hidden object for a period of 10s. If the infant was unable to retrieve the object E1 removed the cover and allowed the infant to play with the object for 5s prior to beginning the next trial.

Ten of these trials were repeated with the following constraints on object location. The object was hidden at location A for the first 3 trials, then at B on the fourth trial. If the infant was successful in retrieving the object on trial 4, the location of hiding on the next trial was switched to A on trial 5. This rule applied to
all trials on which the infant was successful. If the infant failed to retrieve the object, or initially searched at the incorrect location, on any trial after trial 4, the object was hidden again at the same location until the infant was successful, or three trials had occurred. The rule reduces to: switch location if successful or after three failed attempts. Search attempts were scored from the video tape record according to the criteria shown in Table 3 below:

<table>
<thead>
<tr>
<th>Score</th>
<th>Search description</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Loses interest in object once it is covered.</td>
<td>A B</td>
</tr>
<tr>
<td>1</td>
<td>Reacts to loss of object, but does not search.</td>
<td>A B</td>
</tr>
<tr>
<td>2</td>
<td>Pulls at cloth but does not uncover object.</td>
<td>A B</td>
</tr>
<tr>
<td>3</td>
<td>Uncovers but does not retrieve object.</td>
<td>A B</td>
</tr>
<tr>
<td>4</td>
<td>Makes errors 0 - 3 but corrects within 10s.</td>
<td>A B</td>
</tr>
<tr>
<td>5</td>
<td>Immediately searches for and obtains object.</td>
<td>A B</td>
</tr>
</tbody>
</table>

Table 3: Scoring criteria for AB task.

The video tape records of these sessions were scored by two raters, blind to the subject's age and performance on any other procedure. The following criteria were used: if the total score for the 10 trial session fell within the range 40 - 50, the infant was judged to have 'Passed' the procedure. Infants scoring 0 - 39 were judged to have 'Failed' the task. The occurrence of more than one perseverative search error (i.e., infant removes the wrong cover initially) on change trials resulted in a judgement of 'Error'. Since infants invariably correct their AB mistakes within 10 seconds, trials on which the AB error occurred were then scored as '0' rather than '4' to prevent their overall scores from falling within the pass range.

Speech Perception Measures

The cross-language speech measures were gathered using the Head Turn procedure. The procedure involves conditioning the infant to provide an operant head turn in response to changes in the phonetic category of a series of speech stimuli, and is used to measure the infants' ability to discriminate native and non-
native speech contrasts. Subjects were presented with a series of digitized natural
tokens of an English, and a Hindi language speech contrast. Two measures of
discrimination were used: the ability to reach a pre-set criterion, and the subjects' 
percentage of correct responses in the procedure.

Stimuli. The stimuli used in testing the first sample of infants (n=14), were 
identical to those employed by Werker and Lalonde (1988). The English contrast used 
was the place-of-articulation distinction, /ba/-/da/, in which bilabial and alveolar 
voiced stop consonants are differentiated. The Hindi contrast used for sample 1 was 
the unvoiced, unaspirated retroflex versus dental distinction /da/-/Da/. The Hindi 
language distinguishes four places of articulation, while English distinguishes only 
three. Thus, English speakers typically categorize both the retroflex and dental 
places as alveolar stops. The stimuli were taken from a synthetic place-of-
articulation continuum constructed with the Mattingly synthesizer on a VAX 11/780 
computer at Haskins Laboratories, New Haven, Connecticut. Multiple synthetic 
tokens were used, so that the subjects would have to ignore any within category 
acoustic variability and discriminate sounds according to phonetic category, in the 
same manner as in natural language processing. The stimuli were composed of 5 
formants with the starting frequency of the second and third formants varied to 
produce an eight-step continuum (see Werker & Lalonde, 1988 for a full acoustic 
description). The stimuli were presented from reel-to reel tape using a Teac 3340S 
tape recorder and a single driver Bose 101 loudspeaker. An Apple II+ computer 
controlled stimulus presentation, activation of the visual reinforcer, and collection 
and collation of subject responses using a computer program designed specifically 
for this purpose.

The stimuli used in testing the second sample of infants were identical to those 
employed by Werker and Tees (1984a). For this sample, multiple natural exemplars of 
each sound were used, since infants in sample 1 had more difficulty than expected
discriminating the synthetic English contrast (see Results section). For sample 2, the Hindi contrast used was the voiceless, unaspirated retroflex versus dental distinction /ta/-/Ta/. Four naturally produced exemplars of each sound were used. All exemplars were equated on intensity, fundamental frequency, duration, and intonation contour. An acoustic analysis by Werker and Tees (1984a), revealed that the main cues differentiating these speech sounds are the amplitude of the burst, and the slope of the second and third formant transitions (see Werker & Tees, 1984a, for a full acoustic description). The stimuli were digitized from audio tapes using an Analog to Digital conversion computer program interfaced with a Data Transmission 1801 analog-to-digital/digital-to-analog conversion board. The stimuli were digitized at a 10 kHz sampling rate, via a 4500 Hz low-pass filter, and presented over a single driver Bose 101 audio loudspeaker. A Compac Deskpro-286 computer controlled stimulus presentation, activation of the visual reinforcer, and collection and collation of subject responses using a computer program designed specifically for this purpose.

Procedure. In the Head Turn procedure the infant was seated on the parents' lap across a small table from an experimental assistant (E2), in a sound attenuated chamber (see Figure 3, page 84). A visual reinforcer and loudspeaker were located at a 90 degree angle to the infant. The visual reinforcer consisted of a smoked plexiglass covered box containing mechanical toy animals which were activated during conditioning and whenever a correct response was observed. The number of correct responses observed provides a measure of the infant's ability to discriminate the speech contrast presented.

The procedure consists of a series of conditioning and testing stages. During conditioning stage 1, the infant is presented with a speech sound, for example /ba/, which repeats at fixed intervals of 1500ms. The visual reinforcer is activated by the experimenter whenever the speech tokens change from one phonetic category to
another, for example, from /ba/’s to /da/’s. The reinforcer is turned off when the speech tokens return to /ba/. The infant is conditioned to turn his/her head toward the reinforcer in response to this change from /ba/ to /da/. When the infant anticipates the activation of the reinforcer on three consecutive trials (i.e., detected and responded to the change in the speech stream by turning his/her head toward the reinforcer before the reinforcer is activated by the experimenter), the testing stage is entered.

During the testing stage, the change in the speech category was controlled by a computer (Compac 286 Desk Pro) which randomly selected trial type (change vs. no-change). An experimenter (E1), seated outside the chamber, observed the infant through a one-way observation window and signaled the computer when the infant was in a state of readiness (i.e., not fussing, watching the assistant). The computer selected a trial type and awaited a button press response from E1. The experimenter was unable to hear the stimuli and was therefore blind as to whether a change or no-change trial had occurred. The experimenter then signaled the computer via a button press if the infant turned his/her head during the trial.

On change trials, that is, when the stimuli changed, for example, from /ba/ to /da/, a head turn resulted in the computer activating the reinforcer as well as social reinforcement from the experimental assistant. These responses are recorded as "hits" by the computer. If, on a change trial, the infant failed to turn his/her head, the reinforcer was not activated and a "miss" was recorded. On no-change, or control trials, where no change in the speech stream occurred, a head turn was recorded as a "false alarm" and the absence of a head turn as a "correct rejection".

Infants were tested first on the English contrasts /ba/ versus /da/ to determine whether they could (or would) perform in this procedure. Infants unable (or unwilling) to perform in the procedure were excluded from the study. Successful performance on this contrast was followed by testing on the non-native, Hindi /da/-
/Da/, speech contrast. Testing on the non-native speech sounds was preceded by a short re-presentation of the English contrast to ensure that the subject would still perform in the procedure. A series of three consecutive correct responses to the native contrasts was taken as evidence of continued competence and conditioning/testing phases with the non-native stimuli was then carried out.

Two measures of success on the speech contrasts were taken: the ability to reach a preset criterion of consecutive responses, and the overall percentage of correct responses to each contrast. By the criterion method, the infant was judged capable of discriminating the contrast presented if they were able to string together a series of 7 correct responses (hits plus correct rejections) out of 8 consecutive trials. The session ended when the infant reached the pre-established criterion, or 25 testing trials had occurred, whichever came first. All infants were required to reached the preset criterion on the English contrast as a condition of remaining in the study. The use of preset criterion is common with the Head Turn procedure although some debate surrounds calculations of the probability of attaining 7 correct responses in 8 consecutive trials in a 25 trial sample. Probability estimates range from .001 to .05. Most published reports use the criterion as a screening tool to remove subjects unwilling to perform in the procedure and report the percentage of correct responses as the measure of success on the task. For all subjects a percentage of correct responses for each contrast was calculated by dividing the total number of correct responses (hits + correct rejections) by the total number of trials (hits + misses + correct rejections + false alarms).

At the conclusion of each testing session a computer printout of the infants' responses to each trial in the session was made. This included whether or not the criterion had been met, the percentages of hits, misses, correct rejections, and false alarms, and average reaction times for each type of response.

Visual Categorization Measures
The categorization measure used was a visual habituation/dishabituation procedure designed to assess the categorization skills of prelinguistic infants. During the habituation or familiarization phase, the infant was presented with a sequence of line drawn stimuli (2 presentations of each of 4 habituation stimuli, see Figure 1, page 82). The infant was seated on the parents' lap facing a television monitor (see Figure 4, page 85). Each stimulus was presented on the monitor for 18s during which the infants' visual fixation was recorded by an experimenter peering through a one-way observation window. In the test phase the infant was presented with the three test stimuli (see Figure 1, page 82). The experimenter was blind to the stimulus being presented and stimulus presentation order was randomized across subjects.

Trial presentation was controlled by computer (Hewlett-Packard, Vectra ES/12). A small fixation light was activated at the beginning of each trial. The experimenter signaled the computer when the infant had fixated on the light and a stimulus was presented on the monitor. The expiration of the 18s trial period caused the monitor to darken and the fixation light to begin flashing. Eleven trials were conducted: eight familiarization trials, followed by the three test trials. A computer printout of the total looking time and number of looks per trial was then made.
RESULTS

The data analysis was carried out in two stages. Both are identical with the exception that the infants who exhibited the AB error are excluded from the first stage of the analysis. Since these infants behave alternately like 'passers' and 'failers' and tend to 'muddy the waters' somewhat, the decision to exclude them from the first stage of the analysis is a strategic, rather than scientific, one. The first stage is intended to provide a clearer picture of the data before turning to the added complications of the error group. In both stages, the speech and categorization tasks are analyzed separately. This is followed by a test of the overall hypothesis that a strong developmental synchrony exists among the tasks. The data analysis was motivated by three basic questions:

1. Will a significant main effect emerge when AB task performance (pass/fail) is used as an independent variable in the analysis of the speech and categorization data? Previous investigations using the speech and categorization tasks have used age as an independent variable (Werker & Lalonde, 1988; Younger & Cohen, 1983). The purpose of this set of analyses is to determine whether the data pattern obtained using AB status resembles these previous reports.

2. Can performance on the speech and categorization tasks be accurately characterized as either 'pass' or 'fail'?

3. When subjects are assigned a 'pass/fail' status on each task, do their overall pass/fail task profiles express a logical underlying relation among the three tasks?

Stage 1 - Analyses of the AB Pass & Fail Groups.

Question 1: AB performance as an independent variable.

Speech Perception Task The measure of success on the speech task was defined as the percentage of correct responses to both change and no-change trials displayed to each of the speech contrasts. The percentage correct for each subject was calculated by dividing the number of hits and correct rejections by the total number of trials presented for each contrast. To ensure that no differences could be
attributed to the use of both natural and synthetic contrasts, a preliminary analysis was conducted comparing the scores of infants in sample 1 and sample 2. The split-plot ANOVA (2 samples X 2 AB groups X 2 speech contrasts) revealed no main effect for sample: $F(1, 24) = .382, p > .50$. Main effects were obtained for AB group: $F(1, 24) = 44.799, p > .0001$, and contrast: $F(1, 24) = 38.920, p > .0001$. A sample X contrast interaction also appeared: $F(1, 24) = 5.640, p < .05$. Post hoc comparisons revealed this was due to the lower scores of infants in sample 1 on the synthetic English contrast (78.6% versus 71.2% correct). No difference was obtained between the samples on the Hindi contrasts (57.1% versus 61.6%). The sample groups were combined for all subsequent analyses.

The scores were then compared across the two AB groups in a split-plot design analysis of variance. The between groups factor was AB task status (Pass, Fail), and the repeated within-group factor was the speech contrast (English, Hindi). The proportion of correct responses by group is shown in Table 4 below:

<table>
<thead>
<tr>
<th>AB Task Status</th>
<th>Speech Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>English</td>
</tr>
<tr>
<td>Fail</td>
<td>77.4</td>
</tr>
<tr>
<td>Pass</td>
<td>72.4</td>
</tr>
</tbody>
</table>

Table 4: Percent correct on the English and Hindi contrasts by AB group (Pass & Fail).

The overall analysis of variance (ANOVA) indicated that there were main effects for both the between-group factor (AB group), $F(1, 26) = 44.955, p < .0001$, and the within-group factor (Contrast), $F(1, 26) = 33.88, p < .0001$, as well as a significant AB group X Contrast interaction, $F(1, 26) = 14.948, p < .0007$. Subsequent Newman-Keuls comparisons showed that these effects were due to the Pass groups' low scores on the Hindi contrast ($F = 46.918, p < .001$).

In addition, a series of t-tests was conducted in which the proportion of correct responses per group to each contrast was compared to a chance value of 50%. Using the Bonferroni correction for a family of four t-tests ($\sum .05 = .0125$), for the
Pass group, performance was significantly above chance on the English contrast only, $t (13) = 9.174, p < .0005$. For the Fail group, performance was significantly above chance on both the English, $t (13) = 13.054, p < .0005$, and Hindi, $t (13) = 7.148 p < .0005$, contrasts.

A correlational analyses revealed an unexpected negative correlation between subjects' age and scores on the English ($r = -.321$) contrast. A multiple regression analysis of age on the English and Hindi scores produced a significant effect for age ($R^2 = .218, F = 3.481, p < .05$). This raised the possibility that the relation between AB task status and the speech perception measures merely rode in on a more powerful overall effect for age. To test this possibility, an analysis of covariance was conducted with age partialed out: the effect of AB status on the Hindi scores remained significant ($F = 35.497, p < .001$).

In response to the first question, the pattern of results for the AB Pass and Fail groups matches that reported previously by Werker and Tees (1984a) and Werker and Lalonde (1988) for infants over 10 months, and under 8 months of age respectively. As a group, infants in the present study who passed the AB task, like infants over 10 months, were unable to discriminate the Hindi contrast. Infants who failed the AB task, like under 8 month-olds, were able to discriminate the Hindi contrast.

**Categorization Task** The fixation times of each AB group to each of the test stimuli are shown in Table 5. The fixation times were entered into a 2 x 3, AB group (pass/fail) x stimulus type (correlated/uncorrelated/novel), split-plot design analysis of variance. The results yielded a significant effect for stimulus type, $F (2, 52) = 6.352, p < .005$, and a significant AB group x stimulus type interaction, $F (2, 52) = 3.557, p < .05$.

<table>
<thead>
<tr>
<th>Test Stimulus</th>
<th>COR</th>
<th>UNC</th>
<th>NOV</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB Task</td>
<td>Status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail</td>
<td>8.7</td>
<td>9.2</td>
<td>12.7</td>
</tr>
<tr>
<td>Pass</td>
<td>7.6</td>
<td>11.0</td>
<td>9.8</td>
</tr>
</tbody>
</table>

Table 5: Fixations times on the categorization test stimuli by AB group (Pass & Fail).
To further investigate these effects, separate one-way ANOVA's were performed for each AB group. For the Fail group, a significant effect for stimulus type was obtained, $F(2, 26) = 6.237, p < .01$. Subsequent Newman-Keuls post hoc comparisons revealed that the effect was due to the higher looking times displayed by this group to the Novel stimulus. For the Pass group, a significant effect for stimulus type was also obtained $F(2, 26) = 3.715, p < .05$. Post hoc Newman-Keuls comparisons revealed that this effect was due to higher looking times to the uncorrelated over the correlated stimulus. For the Pass group, looking time to the novel stimulus was not significantly different from either the correlated or uncorrelated. Although this latter finding is at odds with the results of Younger and Cohen (1983), the novel stimulus constitutes a control condition in the procedure, the correlated and uncorrelated being the more crucial stimuli. While this result is interesting and could reflect a difference in the novelty of the novel stimulus for each group, it is of little concern to the present purpose of understanding the groups' looking times on the correlated and uncorrelated test items.

The pattern of results for the AB Pass and Fail groups matches that reported by Younger and Cohen (1983) for 10- and 7-month-olds. The looking times of the AB Pass infants, like the 10-month-old group in the Younger and Cohen (1983) study, were significantly higher toward the uncorrelated than the correlated stimulus. The AB Fail group, like Younger and Cohen's 7-month-old subjects showed similar looking times to both the correlated and uncorrelated stimuli.

**Question 2:** Can performance on the tasks be characterized as 'pass/fail'?

In order to test the overall hypothesis of synchrony among the tasks, it was necessary to assign individual subjects a pass/fail status on the speech and categorization tasks. Cluster Analyses were performed on the data in an effort to produce meaningful cut-off scores on the speech and categorization data by which subjects could be classified pass or fail.
**Speech Data**  The speech task data used were the percentage of correct responses on the Hindi contrast (HIN). For infants able to discriminate the contrast this value should be relatively high, for those unable to discriminate the contrast, the value should be closer to chance (50%).

Two- and 3-cluster solutions were extracted for both sets of scores to guard against the possibility that a two-cluster solution would be merely convenient and cluster together infants who rightfully belonged in separate groups.

The 3 cluster solution for the HIN scores consisted of one group of clear 'failers' scoring between 33 and 50% correct, one group of clear 'passers' scoring 70 to 88%, and a 'mixed' group scoring 53 to 68% \((F = 112.189, p < .001)\). The 2 cluster solution revealed a more 'sensible' pattern with one group scoring 33 to 59% and a second group scoring 62 to 88% \((F = 95.117, p < .001)\). This pattern reflected a clear pass/fail dichotomy. A cutting score between 'pass' and 'fail' on the speech task was set at 60.65% correct. Subjects were then assigned a pass or fail status on this task relative to the cutting score. The 2- and 3-cluster solutions for the HIN scores are presented in Table 6 below:

<table>
<thead>
<tr>
<th>3 Cluster Solution</th>
<th>2 Cluster Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. n=11, mean=42.2, range=33.3-50.0</td>
<td>1. n=15, mean=46.2, range=33.3-58.8</td>
</tr>
<tr>
<td>2. n= 7, mean=60.1, range=53.6-68.7</td>
<td>2. n=13, mean=74.7, range=62.5-88.0</td>
</tr>
<tr>
<td>3. n=10, mean=77.5, range=70.0-88.0</td>
<td></td>
</tr>
</tbody>
</table>

**Table 6**: Three- and 2-cluster solutions for the speech data (AB Pass & Fail).

The 2-cluster solution for the Hindi scores was compared to the number of infants able to meet the preset performance criterion of 7 correct responses in 8 consecutive trials (see Design section). The cluster analysis grouped all of the 14 subjects who had met the criterion into cluster 2, adding one subject (58.8% correct) who did not meet the criterion.

**Categorization Data**  For the categorization data, a difference score (DIFF) was obtained for each subject by subtracting the looking time to the correlated stimulus
from the looking time to the uncorrelated stimulus. For infants able to detect and use the correlational structure contained in the test stimuli, the looking time difference score should be relatively high. For those unable to detect the correlational structure, the value should be near zero. The difference score was chosen, over looking time to the uncorrelated stimulus, to remove the confounding effect of differences in overall looking between the Pass and Fail groups, and to preserve, in a single value, the relation between looking times to the correlated and uncorrelated stimuli for individual subjects.

The first group of the 3-cluster solution for the categorization data contained a single member whose difference score was -11.11 seconds. The second group consisted of 13 infants scoring between -5.7 and 1.6 seconds, while the third group of 14 infants scored between 2.4 and 11.63 seconds ($F = 36.538, p < .001$). The 2-cluster solution merely collapsed clusters 1 and 2 from the 3-cluster solution, with one group scoring between -11.1 and 1.6 seconds, and another scoring between 2.4 and 11.6 seconds ($F = 39.442, p < .001$). Since the 3-cluster solution made little theoretical sense, the 2 cluster was used to produce a cutting score between 'pass' and 'fail' for the categorization task at 2.05 seconds. The 3- and 2-cluster solutions for the categorization data are presented in Table 7 below:

<table>
<thead>
<tr>
<th>3 Cluster Solution</th>
<th>2 Cluster Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 n=1, (single observation -11.11)</td>
<td>1 n=14, mean= -1.7, range= -11.1- +1.6</td>
</tr>
<tr>
<td>2 n=13, mean= -1.0, range= -5.7 - +1.6</td>
<td>2 n=14, mean= 5.8, range= 2.4 - 11.6</td>
</tr>
<tr>
<td>3 n=14, mean= 5.8, range= 2.4 - 11.6</td>
<td>2 n=14, mean= 5.8, range= 2.4 - 11.6</td>
</tr>
</tbody>
</table>

Table 7: Three- and 2-cluster solutions for the categorization data (AB Pass & Fail)

The cluster analyses were conducted with the view toward assigning a pass or fail status to individual subjects on the speech and categorization tasks. In both instances, the analysis produced statistically significant and theoretically...
meaningful cutting scores. From these analyses, it appears that performance on the speech and categorization tasks can be characterized as pass or fail.

**Question 3:** Is there a logical relation among the tasks?

In order to test the overall hypothesis, a profile of task performance was derived for each subject by applying the cutting scores from the cluster analyses. The observed frequency of each pattern is presented in Table 8 below.

<table>
<thead>
<tr>
<th>Categorization Task</th>
<th>Pass</th>
<th>Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speech Task Pass</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Speech Task Fail</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task</th>
<th>Pass</th>
<th>Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Task Pass</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 8: Frequencies of task performance profiles by AB group (Pass & Fail).

In this way each subject could be said to have 'passed' or 'failed' each of the tasks. To illustrate, the profile of an infant who passed the AB task, failed the categorization task, and failed the cross-language speech perception task, would be Pass/Fail/Fail, and fall in the lower right hand corner of Table 8. It should be noted that a 'passing' grade on the speech task is assigned to infants who 'failed' the Hindi contrast - infants pass this task when they perform like 'native listeners'.

Prediction Analysis of Cross-Classifications (Hildebrand, Lange, & Rosenthal, 1977) was used to test the hypothesis that infants unable to coordinate separate sources of information will fail all three tasks, while those equipped with this ability will pass all three tasks. The predicted relation among the tasks was that an infant able to pass any one of the tasks should pass all three, while an infant unable to pass any one task should fail all three. In Prediction Analysis, the cells in a table of cross-classifications are assigned either 'hit' or 'error' status according to the model being tested. The analysis determines the extent to which the number of obtained 'errors' exceeds what could be expected by chance. Specifically, the analysis determines
whether the value of the test statistic \( \text{DEL} \) significantly exceeds zero (\( \text{DEL} = \left[ \frac{\Sigma e - \Sigma o}{\Sigma e} \right] \)), where \( \Sigma e \) = the number of expected errors, and \( \Sigma o \) = the number of obtained errors).

The matrix of hit and error cells designed to test the present model is shown in Table 9.

<table>
<thead>
<tr>
<th>Categorization Task</th>
<th>Pass</th>
<th>Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speech Task</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speech Task</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass</td>
<td>error</td>
<td>error</td>
</tr>
<tr>
<td>Fail</td>
<td>error</td>
<td>error</td>
</tr>
<tr>
<td>AB Task</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass</td>
<td>hit</td>
<td>error</td>
</tr>
<tr>
<td>Fail</td>
<td>error</td>
<td>error</td>
</tr>
</tbody>
</table>

Table 9: Hit cell matrix used in Prediction Analysis of Model I.

In Model I the 'hit' cells are those in which the infants either pass or fail all of the tasks, all other cells are considered measurement error. The prediction that infants will either pass or fail all of the tasks was supported in the analysis: \( \text{DEL} = .476, z = 3.70, p (z) < .001, \text{precision} = .696 \). A series of hierarchical models, designed to test less stringent relations among the tasks, were planned but rendered obsolete by this result.

To return to the three questions that motivated these analyses, a single conclusion seems warranted. First, on the basis of the data provided by the AB Pass and Fail groups, it appears that the likelihood of passing the speech and categorization tasks may depend as much on the infants' object search skill as on age. Both Werker and Tees (1984a), and Werker and Lalonde (1988) have shown that, in contrast to 11-13 month olds, infants of 6-8 months, have little difficulty discriminating the Hindi contrast. Simple extrapolation would make it difficult to predict the performance of infants between 8 and 10 month of age. Similarly, with regard to the categorization data, it would be difficult to predict the performance of infants in this age range on the basis of Younger and Cohen's (1983) report of the differences between 7 and 10 month-olds. Yet in the present study, an accurate prediction for infants in this intermediate age range could be made on both tasks on
the basis of their having passed or failed the AB task. In both cases the accuracy of
the prediction had little to do with the subject's chronological age. In the analyses
described below, the applicability of this conclusion to the AB Error group is
examined.

Stage 2 - Analyses including the AB Error group.

The analyses reported below identical to those described in the preceding
section with the exception that the group of infants who committed the AB error are
included. The same series of three questions where asked in these analyses.

Question 1: AB performance as an independent variable.

Speech Perception Task The percentage of correct responses to the Hindi and
English speech contrasts were compared across the three AB groups in a split-plot
design. The between groups factor was AB status (Pass/Fail/Error), and the repeated
within-group factor was the speech contrast (English/Hindi). The percentage of
correct responses by group is shown in Table 10 below:

<table>
<thead>
<tr>
<th>Speech Contrast</th>
<th>English</th>
<th>Hindi</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB Task Status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail</td>
<td>77.4</td>
<td>72.2</td>
</tr>
<tr>
<td>Error</td>
<td>73.5</td>
<td>62.9</td>
</tr>
<tr>
<td>Pass</td>
<td>72.4</td>
<td>46.5</td>
</tr>
</tbody>
</table>

Table 10: Percentage correct on the English and Hindi contrasts by AB group.

The overall analysis of variance (ANOVA) indicated that there were main
effects for both AB status, \( F(2, 37) = 22.844, p < .001 \), and Contrast, \( F(1, 37) = 41.07, p < .001 \), as well as a significant AB X Contrast interaction, \( F(2, 37) = 8.154, p < .005 \). Subsequent one-way ANOVAs comparing the AB groups within each contrast
revealed no effect for AB status on the English contrast scores: \( F(2, 72) = 1.146, p > .30 \). On the Hindi contrast a significant effect for AB status was obtained: \( F(2, 72) = 27.671, p < .001 \). Planned comparisons revealed that the Error group scored
significantly lower on the Hindi contrast than the Fail group, \( F(1, 37) = 5.704, p < .025 \), and significantly higher than the Pass group, \( F(1, 37) = 18.15, p < .0001 \).
In addition, two $t$-tests were conducted in which the proportion of correct responses by the Error group was compared to a chance value of 50% for each contrast. Using the Bonferroni inequality ($\Sigma_{.05} = .025$), the Error group significantly exceeded the chance value on both the English, $t(11) = 11.385, p < .0005$, and the Hindi contrast; $t(11) = 4.842, p < .0005$.

A simple regression analysis again revealed the unexpected negative correlation between subject age and scores on the English ($r = -.359$) contrast. A multiple regression analysis of age on English and Hindi scores produced a significant effect ($R^2 = .208, F = 4.864, p < .05$). An analysis of covariance was conducted in which age was partialed out. Again, the effect of AB on the Hindi scores remained ($p < .001$) while the effect of age failed to reach significance ($p > .20$).

On the basis of the speech data then, it would appear that the performance of the AB Error infants is unlike both of the other groups. Though these infants, as a group have more success on the Hindi contrast than did infants who passed the AB task, their scores remain significantly below those in the AB Fail group.

*Categorization Task* The fixation times for each AB group to each of the test stimuli are shown in Table 11. The fixation times were entered into a 3 x 3 (AB group x stimulus type) ANOVA. With the Error group added, the analysis revealed a significant effect for stimulus type, $F(2, 74) = 11.172, p < .0001$. No main effect was obtained for AB, and no AB group X Stimulus type interaction emerged.

<table>
<thead>
<tr>
<th>Test Stimulus</th>
<th>COR</th>
<th>UNC</th>
<th>NOV</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB Task</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail</td>
<td>8.3</td>
<td>8.9</td>
<td>12.6</td>
</tr>
<tr>
<td>Error</td>
<td>7.7</td>
<td>10.8</td>
<td>11.3</td>
</tr>
<tr>
<td>Pass</td>
<td>7.6</td>
<td>11.0</td>
<td>9.8</td>
</tr>
</tbody>
</table>

Table 11: Fixations times on the categorization test stimuli by AB group.

To further investigate the effect for stimulus type, separate ANOVA's were performed for each AB group. Results for the Pass and Fail group were reported above. For the Error group, a significant effect for stimulus type emerged, $F(2, 22) =$
5.443, \( p < .02 \). A planned comparison revealed that the effect was due to higher looking time to the uncorrelated stimulus over the correlated: \( F (1, 11) = 8.174, p < .02 \).

From the categorization data, the AB Error group appears to follow the pattern of the AB Pass, rather than the Fail group. The Error group showed higher looking times to the uncorrelated and the novel stimuli, generalizing only to the correlated stimulus. Like the AB Pass group, the looking times were significantly higher for the uncorrelated than the correlated stimulus. The pattern of looking times for this group matches what Younger and Cohen (1983) report for subjects in their 10 month-old group.

**Question 2:** Can performance on the tasks be characterized as 'pass/fail'?

**Speech Data** Cluster analyses were conducted as described in the previous section. The 3 cluster solution for the HIN scores consisted of one group of clear 'failers' scoring between 33 and 48% correct, one group of clear 'passers' scoring 67 to 88%, and a 'mixed' group scoring 50 to 64% (\( F = 141.447, p < .001 \)). Again, the 2 cluster solution was more sensible with one group scoring 33-62% and a second group scoring 64-88% (\( F = 102.509, p < .001 \)). The cutting score was set at 62.77%. The 2- and 3-cluster solutions for the HIN scores are presented in Table 12 below:

<table>
<thead>
<tr>
<th>3 Cluster Solution</th>
<th>2 Cluster Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. n=11, mean=41.9, range=33.3-48.3</td>
<td>1. n=22, mean=49.3, range=33.3-61.5</td>
</tr>
<tr>
<td>2. n=13, mean=57.9, range=50.0-64.2</td>
<td>2. n=18, mean=74.1, range=64.0-88.0</td>
</tr>
<tr>
<td>3. n=16, mean=75.2, range=67.0-88.0</td>
<td></td>
</tr>
</tbody>
</table>

Table 12: Three- and 2-cluster solutions for the Hindi speech task data by AB group.

The 2-cluster solution for the Hindi scores was compared to the number of infants able to meet the preset performance criterion of 7 correct responses in 8 consecutive trials. The cluster analysis grouped all of the 17 subjects who had met the criterion into cluster 2, adding one subject (64.2\% correct) who did not.

**Categorization Data** The first group of the 3-cluster solution for the DIFF data again contained the single infant whose difference score was -11.11 seconds. Cluster Results
2 consisted of 17 infants scoring between -5.7 and 1.6 seconds, and the third held 22 infants scoring between 2.3 and 11.63 ($F = 50.667, p < .001$). The 2-cluster solution merely collapsed clusters 1 and 2 from the 3-cluster solution, with one group scoring between -11.1 and 1.6, and another scoring between 2.3 and 11.6 ($F = 60.998, p < .001$).

As before, the 3-cluster solution made little theoretical sense, so the 2 cluster was used to produce a cutting score of 1.995 seconds. The 3- and 2-cluster solutions are presented in Table 13 below:

<table>
<thead>
<tr>
<th>3 Cluster Solution</th>
<th>2 Cluster Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 n=1, (single observation -11.1)</td>
<td>1 n=18, mean= -1.6, range= -11.1 - +1.6</td>
</tr>
<tr>
<td>2 n=17, mean= -1.0, range= -5.7 - +1.6</td>
<td>2 n=22, mean= 5.6, range= 2.3 - 11.6</td>
</tr>
<tr>
<td>3 n=22, mean= 5.6 range= 2.3 - 11.6</td>
<td></td>
</tr>
</tbody>
</table>

Table 13: Three- and 2-cluster solutions for the categorization task data by AB group.

As before, the cluster analyses were conducted with the view toward assigning a pass or fail status to individual subjects on the speech and categorization tasks. With the AB Error group added, the results change very little. In both instances, the analysis produced statistically significant and theoretically meaningful cutting scores. Again, the characterization of subjects’ performance on the speech and categorization tasks as pass or fail appears reasonable.

**Question 3:** Is there a logical relation among the tasks?

A profile of task performance was again calculated for each subject by applying the cutting scores from the cluster analyses. The observed frequency of each pattern is presented for all groups in Table 14 below.
### Table 14: Frequencies of task performance profiles by AB group.

Prediction Analysis was used to test the hypothesis that infants unable to coordinate separate sources of information will fail all three tasks, while those equipped with this ability will pass all three tasks (Model II). As noted previously, infants who commit the AB error are said to possess the ability to coordinate secondary schemata by virtue of their success on A trials. By this standard, the Error should pass both the speech and categorization tasks. The prediction was tested using the matrix of hit and error cells shown in Table 15. The prediction was supported by the analysis: DEL = .381, $z = 3.139$, $p(z) < .001$, precision = .644.

### Table 15: Hit cell matrix used in Prediction Analysis of Model II.

Since model II could have accounted for the observed data pattern by riding on the stronger prediction that infants will either pass or fail all of the tasks (i.e., that Error infants need not pass both other tasks), a third model was conducted. In this model those infants who committed the AB error and passed both the speech and categorization tasks (cell 2, 1) were considered measurement errors. The prediction
that infants will either pass or fail all of the tasks was supported in the analysis: DEL = .270, z = 2.51, p (z) < .002, precision = .764.

To return to the three questions that motivated these analyses, the AB Error infants were predicted to show the same performance pattern as the AB Pass group. The prediction was only partially borne out in the analyses. While the Error group looked very much like "passers" on the categorization task, with 8 of the 12 subjects passing the task when the cutting score is used, their performance on the Hindi contrast was significantly above chance and the performance of the Pass group (only 6 of the 12 passed the task). Though the scores on the Hindi contrast were lower for the AB Error group than the Fail group, the difference is not a significant one. Finally, the prediction analyses confirm that the significant fit of the observed data pattern to the prediction of equivalence between the Error and Pass groups is a result of the more exclusionary prediction that infants will either pass or fail all of the tasks. On balance, we may conclude that the Error group is less homogeneous than either of the other two groups and may therefore represent a transitional stage.
DISCUSSION

One of the aims of the present research was to reproduce the pattern of results obtained by both Werker and Tees (1984a) and Werker and Lalonde (1988) using object search performance rather than age as the independent variable. The conclusion to be drawn in this case was that reorganization in speech perception skills evident in Werker's research (Werker & Tees, 1983; 1984a; Werker & Lalonde, 1988) could be seen as a function of changes in object search skill, rather than age. Toward this end, the speech task results are compared to the pattern reported by Werker and her colleagues for infants under 8- and over 10 months of age.

The percentage of correct responses given by the AB Pass and Fail groups to the English contrast (77.4 and 72.4) were significantly above what would be expected if the infants had been responding randomly. In addition, all subjects were able to reach the preset criterion of 7 correct out of 8 consecutive responses. By either measure, all subjects were able to discriminate the English voiced, bilabial versus alveolar, /ba/-/da/, place of articulation contrast. Given that infants of this age (8-9 months) have been repeatedly shown to discriminate these speech sounds, and that subjects unable to make this discrimination were eliminated from the study, this level of performance is not surprising. The performance of subjects on the Hindi /da/-/Da/ contrast was designed to discriminate between what Werker (1989) has termed "native and non-native listeners". For the object search Fail group, the percentage of correct responses to the Hindi contrast (72.2%) was significantly above chance. In addition, all of these subjects met the 7/8 criterion for this contrast. Again, by either measure, the subjects in the Fail group were able to discriminate this contrast. Subjects in the object search Pass group, however, had considerable difficulty with the Hindi contrast. The percentage of correct responses was not significantly different from what one would expect by chance, and only 2 of the 14
subjects reached the 7/8 criterion. Thus, as a group, the object search Fail subjects could discriminate the Hindi contrast, while the Pass group could not.

As a group, infants in the present study who failed the object search task, like the infants under 8 months of age in both Werker and Tees (1984a) and Werker and Lalonde (1988), were able to discriminate the Hindi contrast. Infants who passed the search task, like the the infants over 11 months, were unable to discriminate the Hindi contrast. In summary, the Fail group could be considered "non-native listeners", and the Pass group "native listeners".

The performance of the infants who committed the AB error was unlike that of either the Pass or the Fail group. The percentage correct for both the English and Hindi speech contrasts was significantly above what one would expect if the infants had been responding randomly. On the Hindi contrast the performance of the Error group was significantly higher than the performance of the Pass group, but significantly lower than that of the Fail group. It appears that some of the infants in the Error could discriminate the Hindi contrast while others could not. Four of the 12 infants in this group reached the 7 correct out of 8 consecutive trials criterion on the Hindi contrast, and 6 of the 12 had percent correct scores that fell within 'pass' range for the task as defined by the cluster analysis (64 - 88%). This pattern of results suggests that, as a group, infants who commit the AB error may be as likely to pass the speech task as to fail.

A second aim of the research was to replicate the results of Younger and Cohen (1983) using object search performance rather than age as the predictor variable. Again, the purpose was to demonstrate that the changes in categorization skill reported by Younger and Cohen could be interpreted as a function of object search skill rather than age. To test this possibility, the categorization data were compared to the pattern reported by Younger and Cohen (1983) for 7- and 10-month-olds.
A comparison of the looking times accorded each of the test stimuli revealed significant differences between the object search Pass and Fail groups. Both groups showed similar (i.e., low) looking times to the correlated stimulus, the Pass group displayed higher looking time to the uncorrelated stimulus, while the Fail group looked longer at the novel stimulus. As noted in the results section, the difference between the groups in looking time to the novel stimulus is curious but not crucial to the present purpose. While both groups were expected to show high looking times to this stimulus, the measure of interest is the relative looking time accorded the correlated and uncorrelated stimuli: if these are similar one is led to conclude that the infants have not made use of the correlation among stimulus attributes in category formation, if the looking time to the uncorrelated is higher, we may conclude that the infants have made use of the correlational information. Thus the Fail group were predicted to show similar looking rates to both the correlated and uncorrelated stimuli, while the Pass group was predicted to show higher looking time to the uncorrelated.

The pattern of results obtained in the present study for object search (pass/fail) matches that reported by Younger and Cohen (1983) for age (7-month-olds/10-month-olds). In the present study, the group of infants who failed the object search task were, like the 7-month-olds in the Younger and Cohen study, unable to use the correlational information contained in the stimulus set. The AB Pass group, like Younger and Cohen's 10-month-olds, were able to form categories using the correlations among the stimulus attributes.

The performance of the infants who committed the AB error on the categorization task was, on the whole, more akin to the AB Pass group than to the Fail group. As a group, the infants who committed the error appeared to match the pattern reported by Younger and Cohen (1983) for 10-month-olds: looking time was low for the correlated stimulus and significantly higher for the uncorrelated and
novel stimuli. Unlike the AB Pass group, there was no drop in looking time to the novel stimulus. When the cluster analysis cut-off scores are applied, however, a slightly different picture emerges: 8 of the 12 infants passed the task and 4 failed.

The hypothesis that all three tasks depend on the ability to coordinate separate sources of information stems from a characterization of these tasks as problems which can only be solved by such coordination. It follows from this characterization that infants who possess the prerequisite coordination skill should perform differently on the tasks than would those who lack the ability. Thus, a pattern of developmental synchrony among the tasks was predicted. The analysis of this overall hypothesis was operationalized by predicting that those infants who either passed the AB task, or committed the AB error, would pass the speech and categorization tasks, while those who failed the AB task would fail the other two tasks. Subjects who did not evidence these patterns of performance would constitute errors in measurement. The Prediction Analysis tested the extent to which the measurement error deviated from what would be expected by chance given a true null hypothesis. The results of the analysis support the view that the changes in task performance occur in synchrony. The interpretation given this result is that all three tasks depend on the ability to coordinate separate sources of information.

A caveat must accompany this conclusion, however. The varied performance of the AB Error group on the speech and categorization tasks deserves further mention. Their performance was, on the whole, more like the AB pass group than the AB fail group, though by no means identical to the Pass group. Six of the 12 infants in Error group passed both the speech and categorization tasks, 4 failed both, and 2 passed one and failed the other. This pattern of results weakens the conclusion that infants who commit the error should be considered "passer's" in spite of their perseverative searching. Indeed, when the infants in this group are classed as measurement error in a prediction analysis, we may safely conclude that infants
must fully solve the AB riddle before they can be expected to pass the speech and categorization tasks. It would seem that, despite their coordination skill, only half of the infants in this group are "passer's".

By all accounts, the AB error is an ephemeral creature - it appears under some circumstances but not others, and persists for some indeterminant amount of time depending on the particular procedure used (type of concealment, number of hiding places, and hiding method). It is difficult to say with certainty, therefore, from a single procedure that a particular infant should be classed as "error". Despite the reliability of the AB ratings and the clear evidence of perseverative search errors in the current sample of AB error infants, the judgement depends on the assumption that the infant meant to look at A, that they really believe it is a viable plan for retrieving the object. It is possible then, that the AB error group is not a 'pure' sample. The fact that the probability of eliciting the AB error can be manipulated relatively easily through minor changes in the procedure, likely means that the proportion of Error infants who will pass the speech and categorization tasks is not fixed at 50 percent.

It is likely that the Error infants are different from the other groups, perhaps being less stable in their ability to use this new skill, or inconsistent in its application. The important question left unanswered by this research concerns the speed at which the skill stabilizes and, ultimately, whether or not this discrepancy is theoretically trivial. The answer to that question awaits a longitudinal study. Without stronger support for the notion that infants who exhibit the error should pass the speech and categorization tasks, the admittedly tentative conclusion drawn from this sample is that there is a trend toward better performance on the other tasks with increasing object search success.

The research described here was designed to assess the extent to which three different cognitive/perceptual abilities become integrated during the second half of
the first year of life. The study represents an attempt to link together three previously separate findings by demonstrating that the changes observed in task performance all result from a change in the infants' ability to coordinate information. The results suggest that while the chosen tasks were not developed to measure the ability to mentally coordinate separate sources of information, the demands of the three tasks are such that the infant possessing this ability stands a much higher chance of success on all three than one who lacks the skill. Nevertheless, two fundamental issues remain unresolved by the analysis, leaving the results open to alternate interpretations.

First, there is the possibility that, however strong the effects may appear, the results could still be produced by a happenstance of development. There is little to be said in an effort to ward off this interpretation. It is possible, by this reading, that the number of infants who did not conform to the predicted pattern (18 of 40) were not errors in measurement, but evidence of a less stringent, or different kind of relation among the tasks. The performance of the AB error group in particular lends credence to this view. Alternatively, the pattern of results could replicate over many, and more substantial, samples and still not rule out the plausibility of a developmental coincidence. In a cross-sectional design, one can never rule out the possibility that the results would be substantially different in longitudinal sampling. Even were similar results obtained in a longitudinal study, the possibility of coincidence forever remains.

Second, the tasks may not be related, as I have argued, by the requirement of coordination, but by a hidden 'third force' which accounts for both the coordination of separate sources of information, as well as the observed improvements in task performance. In fact, one such force was discussed in the review of the object search literature. Diamond's research (1985; 1988) into the role of brain maturation in the development of object search skills offers a promising first step down this
reductionist path. It seems reasonable to assume that a skill of this sort could depend as easily on the development of certain forebrain structures as on Piaget's 'special searches'. If correct, however, this brain based explanation would merely locate the genesis of the coordination skill rather than replace it. From a practical stand-point, this second issue constitutes a fundamentally insurmountable obstacle to firm conclusions, for one can never reject a 'third force' explanation. Even if the data pattern obtained here is the result of a hidden variable, all is not lost. The purpose of the research was to explore the possibility that a common bond exists among these three seemingly different skills. If that connection can, in the end, be shown to result from some other developmental change, the aim of the study will still have been realized.
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Figure 1: Experimental stimuli used by Younger & Cohen (1983).

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Figure 2: Experimental set up the object search task.
Figure 3: Experimental set up for the cross-language speech task.
Figure 4: Experimental set up for the visual categorization task.