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# 12

# Getting Development off the Ground

## Modularity and the infant's perception of causality

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What is the role of perception in the development of thought? If perception has its own distinctive organisation, what are the consequences for development? These issues are considered in relation to the understanding of objecthood and physical causality in infancy and the preschool period. It is argued that the "modular" organisation of perception has a specially useful role in getting development started in these areas. Modular perception is inherently limited to analysing "appearances" in fixed ways. This has important advantages for allowing the rapid build up of general knowledge, even though such knowledge must eventually go beyond appearances to underlying realities. It also allows the human child to benefit from the long evolution of the perceptual apparatus in lower species, giving rise to a more competent infant.

I want to discuss some issues concerning the role of perception in development. The discussion will center round the contribution perception can make to the development of "empirical" concepts. What I mean by this will, I hope, become clear in the course of discussion. For the moment, let me say that such concepts are involved in understanding objecthood and physical causality. Fundamental to this is the distinction between how the world appears to a perceiving organism and how its underlying realities might be grasped (perfectly or imperfectly) by a thinking organism.

One might hold the view that perception has no distinctive role in development, save that of registering elementary sensations. If so, one will see the development of perception and the development of thought and general knowledge as simply different ends of essentially the same thing. This has been the traditional outlook for both empiricist and constructivist positions. A quite different view is that perception has its own distinctive organisation and therefore its own distinctive role in development. On this view it becomes vitally important to investigate what the consequences of perceptual organisation are for development.

## THE ORGANISATION OF PERCEPTION.

One rapidly emerging view is that perceptual processes are to a significant extent impenetrable to cognition (Fodor, 1983; Kanizsa, 1985; Marr, 1982; Ramachandran, 1985; Rock, 1985; Ullman, 1985). This impenetrability may reflect an underlying "modular" organisation. To say that a process is modular is to assert that it is highly independent of other processes both in terms of the information it accesses and the computations it performs.

For example, Marr (1982) argued that the visual process of stereopsis is modular. The main problem in stereopsis is in reconciling two retinal images which are not quite the same. An edge in one image must be put in correspondence with the correct edge in the other image. The processes which do this, however, appear to operate quite early on in the analysis of the retinal array. In particular, they do not have access to, for example, information about the shape of common objects, their function, the likelihood of finding such an object in these surroundings, and so on. Perhaps such information might conceivably be relevant to solving some stereopsis problems. But, even if it is, the module for stereopsis has to do without it. Modules apply their own local solutions to their own limited problems. They perform their task automatically and mechanically with resources which are fixed beforehand. They cannot call for outside help if the going gets tough. The main advantage of such organisation, it seems, is in the speed of computation that can be achieved when complex problems are broken down into smaller parts and dealt with independently (Fodor, 1983).



Just as there are advantages for the organism in this kind of organisation, so there are inherent limitations. One of the main limitations is that perceptual processes can only deal with appearances and not with underlying realities. This is because "reality" does not always fit into the neat packages allowed for by automatic modular processing (though often it does). This limitation of modularity may explain the existence of perceptual illusions (Ramachandran, 1985; Long & Toppino, 1981). Ramachandran (1985) gives a particularly bizarre example. Under appropriate conditions, we see apparent motion of a light through our own hand, despite conflicting tactile information, commonsense, and even expert knowledge concerning the illusion. Modules for motion perception automatically apply their fixed analyses, returning the results of these procedures without regard for how absurd *or* contradictory they are. In other words, it is left to cognition to sort out what is "really" there.

Fodor (1983) argues that the processes which are responsible for the "fixation" of our beliefs about what is really there are of a quite different character. These central thought processes can access a vast and in principle unlimited range of information, consider all sorts of possibilities, weigh them up, one against the other, and arrive at conclusions which it can always revise later. But such central processes are unable to influence the activities of the "input modules". This has the advantage of ensuring speedily available information about what is present to the senses and avoids us "seeing" just what we think "ought to be there". But it can also give rise to illusions that simply will not go away!

## THREE EXAMPLES OF EMPIRICAL KNOWLEDGE.

The inherent advantages and limitations of modular architecture in perception will have important consequences for development. Some of these consequences can be seen in connection with "empirical" concepts. I shall look briefly at two such concepts: first, the question of what sorts of concrete objects there are in the world; and second, what identity particular objects have as we encounter and re-encounter them. Then at somewhat greater length, I shall discuss a third: the question of discovering what causal regularities there are in the world. These questions are faced in particularly vicious forms by scientists, but they are also faced at a more mundane level by quite small children.

Object Sorts.

One approach to the child's developing understanding of objects focuses upon the learning of rules and definitions. To take one example, having a concept of a dog is equated with understanding definitive criteria for deciding whether an object one. has encountered is a dog or not. Such *a* definition might be in the form of a list of criterial features of "dogginess". The issues surrounding the problems of the nature and formation of concepts are highly complex (see Carey, 1982 and Medin & Smith, 1984 for lucid reviews) and my purpose here is not to enter into that debate nor in particular into more recent versions of the classical approach such as prototypicality (Rosch, 1978) or fuzziness (Zadeh, 1965). I do want to draw attention, however, to the contrast between having a definition for a given type of object, and having something more akin to a theory.

Definitions can be formulated without the benefit of theories. And theories do not always make criteria clear by which to judge whether a phenomenon or object belongs to a given type or sort. In fact, no one knows what the necessary and sufficient conditions are for something to be a dog. If this what a definition is, then no one knows what the definition of dog is (cf. Kripke, 1972; Putnam, 1975).

The good news (especially for dog lovers) is that one does not need to know the necessary and sufficient conditions for being a dog in order to recognise instances of dogs,



mostly with success. Our concept of dog may rule out electro-mechanical dogs without us being able to tell at a glance or even after a lot of study which are dog "androids" (canoids?) and which real dogs. Having a concept of dog implies having some general or theoretical knowledge about the nature of dogs (however partial and inaccurate). This allows us to separate the problem of acquiring the concept from the problem of learning how to recognise instances of it. Indeed, our general knowledge about dogs does not have to play any part at all in our normal processes of recognising instances.

Osherson and Smith (1981) draw a somewhat similar distinction between a concept's core and its identification procedure and suggest that prototype theory (Rosch, 1978) characterises an important identification procedure. Murphy & Medin (1985) use the notion of "theoretical" knowledge in a similar way to that intended here to suggest an organised piece of knowledge about the world. If it is preferred, we can talk instead of encyclopaedic or general knowledge.

We can link all this with the earlier discussion in the following way. The problem of concrete objecthood splits into two major parts. The first concerns the operation of a device for recognising objects (mostly successfully) by applying a set of fixed perceptual tests to perceptual input. It operates as if it possesses a definition for a given object but actually is subject to all the advantages and disadvantages of an input module. It operates fast, is cognitively impenetrable and is inherently limited to appearances. The second part of the problem has to do with a centrally constructed set of ideas, in effect a rudimentary theory, that attempts (often imperfectly) to describe realities underlying appearance (whales are really mammals...). The "attempt" is what is important since describing underlying realities correctly is something that neither nature nor culture could guarantee. The attempt surfaces in the open ended evaluation of hypotheses and in the revisable nature of conclusions reached. Object recognition in contrast may proceed as Marr & Nishihara (1978) have argued in the automatic application of a fixed algorithm. But concepts, as we are thinking of them, belong to central processes of thought and have the job of attempting to relate to what is really the case.

Object Identity.

This sort of picture can be extended to another aspect of concrete objecthood, namely, the problem of object permanence, as Piaget (1955) called it. Again, current approaches have often focused upon the application of internal rules or definitions. For example, Bower (1982; Wishart & Bower, 1983) argues that the infant follows a lengthy developmental path before she can solve the problem of how to tell when an object retains its identity from one encounter to another. For example, a red ball goes out of sight behind a screen and emerges again on the opposite side. Bower and his colleagues have used this and other types of situation to study young infants judgements of the enduring identity of objects.

Bower argues that infants pick out persistent objects by consulting an internal definition of when an object remains the same despite changes (of position etc. ) or alternatively, that the infant applies rules for re-identifying a particular object across successive encounters with it. Spelke (1982) has studied a similar problem concerned with when a stimulus configuration is perceived as a single unified object and when as a set of distinct objects. Again the infant seems to apply a set of fairly complex rules to decide this.

It seems clear that the infant is not addressing the "empirical" version of these questions. Instead, the infant is applying a sophisticated yet fixed and automatic set of perceptual rules and definitions for deciding the identity and unity of objects. I suggest that she computes the apparent Identity of the objects she perceives through the automatic and fast action of an input module. But the question, "Is this object really the same one as before?" is a question the input module can neither pose nor answer. The psychologist does not expect the infant to want first to see what's really going on behind the screen before committing herself to a response. The infant, like her input systems, responds in a sophisticated way to appearances. Perhaps the three or even two year old has the competence to address empirical questions. "Could this really be my teddy? How could my teddy have got from my house to here? Did mummy bring it perhaps?" These are empirical questions for which there are no predetermined fixed rules for getting the correct answers.



Causality.

Understanding cause and effect raises a similar dichotomy between input analysis and empirical reasoning. Current approaches suggest that the child picks out causes and their effects from the stream of events by consulting a "tacit definition of cause-effect relations" (Bullock et. al., 1982) or by applying "rules of causal attribution" (Shultz, 1982).

Recent evidence shows that 3 and 4 year olds use a number of rules in their selection of a cause for a given event including covariance, temporal priority, temporal contiguity, spatial contiguity and so on. The child gives different weights to these different rules in different situations: in some, spatial contiguity will have more emphasis than temporal contiguity, while in other circumstances spatial contiguity will just be ignored (Bullock et al., 1982; Shultz, 1982). Three year olds can select a cause on the basis of a minimal covariance pattern (AX, B, ABX = A cause X). But even more interestingly these same children will change their minds when given mechanical information that contradicts the selection of the covariant event (Shultz, 1982). Thus, previous conclusions can be revised and in a way that contradicts appearances.

Even the young child seems to be trying to understand the event sequences as plausible mechanisms (Bullock et al., 1982; Bullock, 1985). The "rules" of causal attribution are not used literally as rules to rigidly and definitively specify a cause. They are perhaps "rules of thumb" or heuristics to suggest a plausible hypothesis. Such hypotheses even when initially confirmed remain revisable if further considerations crop up. Processes of this sort have the characteristics of the central processes that Fodor describes. Unlike input modules, they are sensitive to encyclopaedic or general knowledge and their conclusions remain revisable and tentative. But, of course, general knowledge is one thing small children are desperately short of.

The problem in talking *of* "rules of causal attribution" or of a "definition of cause-effect relations" is that it can not be taken literally. There is literally no such thing. If there was a definition or set of rules for causality then there would also be a mechanical procedure for carrying out empirical investigations. There would be a fixed and specifiable way for determining the causal structure of the world and therefore a mechanical or formal procedure for doing science. If there was such a thing, we could guarantee the "truth" of the answers we receive from it simply by making reference to the fact that we had faultlessly followed the procedure.

To think, then, of the child's development as requiring him to learn or employ causal rules or definitions could be misleading. On the other hand, flexibility, uncertainty and a willingness to change one's mind could all be symptoms of a genuine empirical approach to underlying reality.

However, some parts of human processing do appear to operate as if empirical questions can be settled definitively by applying fixed tests. These are the input systems. Input systems provide "take it or leave it" descriptions of appearances. Central processes inherit these descriptions and evaluate them in the light of further considerations. Although they operate in a quite different way, the input systems speak the same "language" as the central processes. Their descriptions categorise and identify objects and propose causes and effects. This is why input systems sound as if they are empirical.



## THE ONE-SIDED DIALOGUE.

### Two Dialogues.

Allow me to illustrate these ideas in terms of dialogues between input systems and central processes. Object Recognition: a tree.

Input Systems: "That's a tree"

Central Processes: "Hang on, this is a desert. Trees don't normally grow in deserts. Let's see about this!" (Goes up close to have a look at the "tree")

Input Systems: "That material is plastic"

Central Processes: "So I was right, it's not a tree! ' (Walks away, then looks back)

Input Systems: "That's a tree"

Central Processes: "No it's not, it just looks like a tree"

Input Systems: "That's a tree"., etc.

Re-identifying Particular Objects: My pen.

Input Systems: "That's my pen"

Central Processes: "It can't be. It's the Professor who has it. I didn't give it to her and she would never steal. "

Input Systems: "That's my pen"

Central Processes: "It can't be - it just looks like my pen"

Input Systems: "That's my pen"

### Causality: Michotte's illusion.

Michotte (1963) discovered that adults would report seeing a causal interaction between two entities despite the fact that the stimuli used were just pencil marks on paper or coloured lights projected on a wall. The adult observers knew full well how the displays were made and thus knew that there was no question of real objects really causing one another to move. But, as in the example of a light going through a hand, their knowledge and reasoning powers did nothing to prevent the illusion. Over and over again, the causal illusion was obtained, unaffected by the subject's knowledge. I leave it to the reader to construct the dialogue for this one.

I suggest that Michotte's causal illusion results from the operation of an input module. The module applies a fixed algorithm and has access to only very restricted information, probably operating fairly early in the analysis of motion. Nevertheless, it can give outputs in an "abstract" causal code. Before considering the possible developmental role of such a module, I want to summarise briefly results from a series of experiments on six month old infants that are beginning to indicate that this module might be in place and running that early.

All the experiments measured the infants' visual attention to cinematic stimuli using an habituation - dishabituation of looking technique (Leslie, 1982b, 1984a, 1984b, 1984c; Leslie & Keeble, forthcoming). This widely used technique allows one to measure the recovery of the infant's interest following a change in a stimulus that has become familiar to the infant. From the patterns of renewed interest discernible over a number of experiments involving different kinds of stimulus comparisons, it is possible to begin to make inferences about the ways in which the infant is internally representing and comparing the events presented (Leslie, 1982a, 1984b). Thus, one can make hypotheses about the kinds of structural descriptions the infant is assigning the various events.

A red brick glides across a table top and appears to impart its motion to a stationary green brick by colliding with it. In this direct launching the first brick appears to make the second one move. If a short interval of say half a second is interposed between impact and the reaction of the second brick, this impression of direct causality is lost. Infants around six months are sensitive to the difference between the continuity of motion in direct launching and the discontinuous motions in the delayed reaction sequence (Leslie, 1982b).



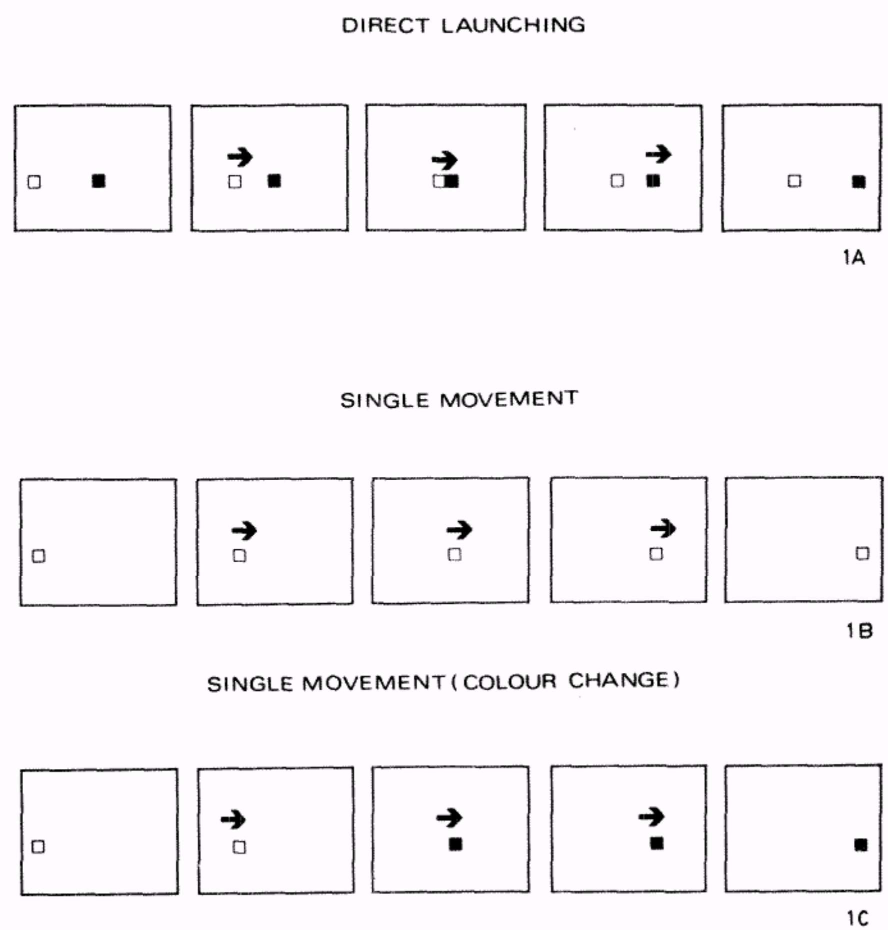


FIGURE 1: Illustrations of the event sequences used to test infants' ability to parse submovements in direct launching. The white square represents the red object in the films used and the black square the green object. Each sequence lasts approximately 3 seconds including the stationary periods at the beginning and end. For more details the reader should consult the appropriate reference given in the text.

But can they distinguish the submovements in the continuous direct launching or is it perceived simply as a single unanalysable "whoosh"?

Leslie (1984c) reasoned that if direct launching was for the infants an event with internal structure (i. e. composed of submovements), then reversing the event should alter that structure. The amount of recovery to this reversal could then be compared with the recovery produced by reversing an event with no internal structure (i. e. a single movement made by a single object). One group of infants was habituated to a direct launching event (see Figure la) shown over and over again in a single direction. Meanwhile another group of infants was habituated to a sequence in which a single red brick moved from one side of the screen to the other, again in a single direction (Figure Ib). Having reached a predetermined criterion of habituation, the film the infant had been viewing was reversed by the simple expedient of turning the projector into reverse. Now the objects moved in the opposite direction to before. For the single object group this is the only resulting change. But for the direct launching group the relative order of the submovements is also changed (red first to green first). If, then, this direct launching group distinguished and remembered the submovements, they should recover their interest more. The results indeed showed significantly greater recovery in the direct launching group.

A further experiment showed that direct launching was highly discriminable from another single movement event in which the object changed colour from red to green around the position where impact takes place in direct launching (Figure Ic). Direct launching is not simply perceived then as a "whoosh" with a red beginning and a green ending.

Incidentally, these findings also show that the infants do not have to rely simply upon their pattern of eye movements for encoding these events, since both direct launching and a single movement event are tracked smoothly by infants (Borton, 1979). We can conclude then that the six month old is capable of a true perceptual encoding for the submovements in these events (Leslie, 1984c).



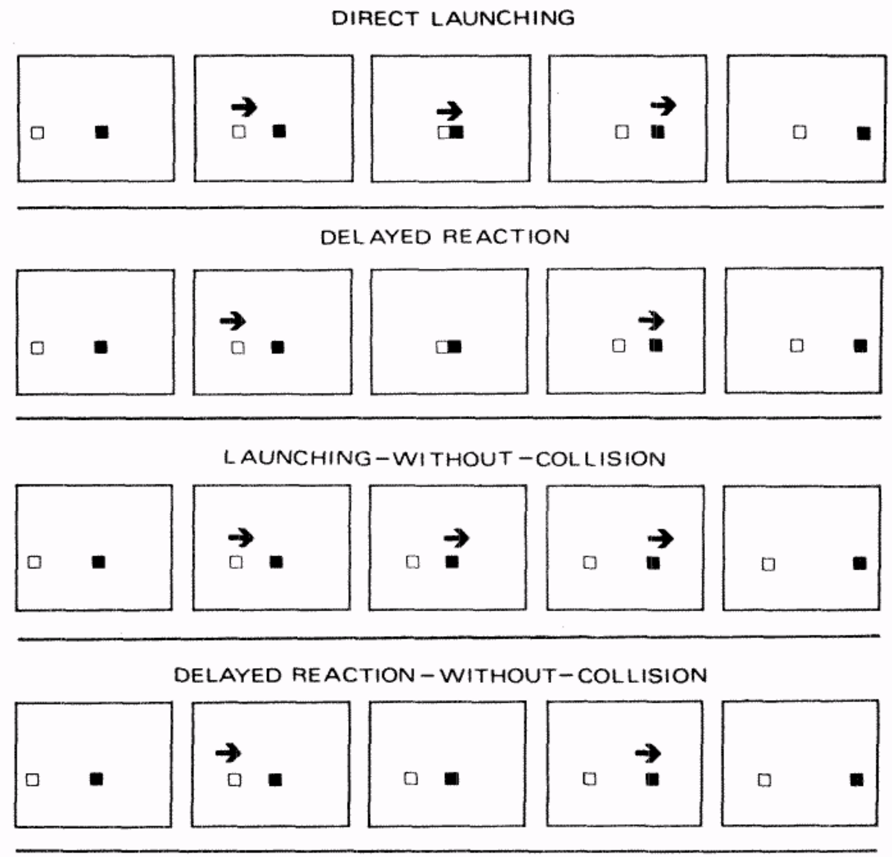


FIGURE 2: Illustration of the event sequences used to test infant's encoding of the relationship between the sub- movements. The nature of the stimuli is outlined in the legend to Figure 1.

Infants perceive internal structure in direct launching. But what kind of structure? Leslie (1982b) suggested two alternative hypotheses. The first was based upon the classical analysis of causality provided by the Scottish Empiricist Hume (1740). This was that infants would encode the spatial and the temporal relations between the submovements as two distinct and independent features (or orthogonal dimensions).

The second competing hypothesis was derived from Michotte. This was that the infant's recovery of interest would depend upon whether the two sequences contrasted in apparent causality or not. Direct launching is the only sequence that should appear causal out of those shown in Figure 2. A comparison of it with any of the others should produce more recovery than a "Hume-equivalent" comparison not involving it. For example, in going from causal Direct Launching to non-causal Delayed Reaction-without-collision both the spatial (contact/no contact) and temporal (delay/no delay) features change. In going from Delayed Reaction to Launching-without-collision both these features change too (the reader can check this in Figure 2). But with this latter pair neither sequence should appear causal. According to Michotte's but not Hume's hypothesis then, there should be more recovery with the causal change pair.

The results supported Michotte's hypothesis: the Direct Launching group showed greater recovery despite the fact that the contrast seen by the Delayed Reaction group was by Hume's hypothesis exactly equivalent (Leslie, 1984c: Experiment 2).

However, if it was the apparent causality of direct launching that was really producing this effect then direct launching should prove more contrastive in other comparisons as well. For example, in direct launching versus delayed reaction (delay change) there should, be more recovery than in launching-without-collision versus delayed reaction-without-collision (also delay change). And so too for the comparisons involving the equivalent changes in the spatial feature. But here the results failed to support Michotte.

Each sequence was discriminable one from the other, but there was no indication that direct launching had a "special"



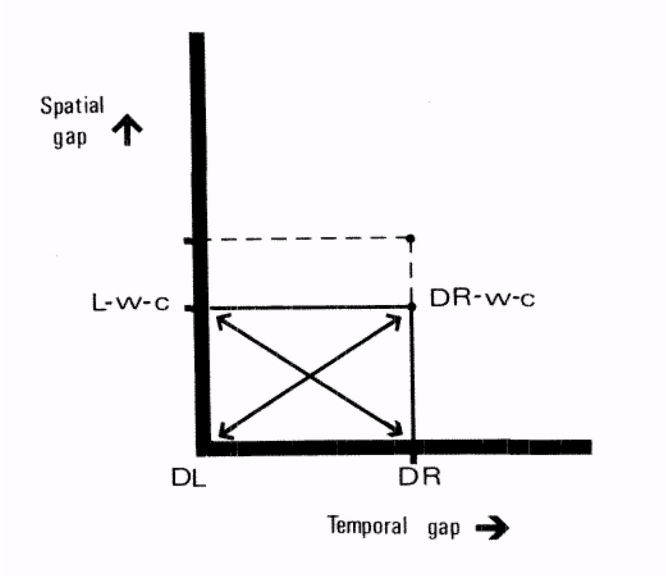


FIGURE 3: Theoretically possible 2-dimensional similarity space for the following stimuli: DL = direct launching; L-w-c = launching-without-collision; DR = delayed reaction; DR-w-c = delayed reaction-without-collision. A similarity space can be used to predict subjective similarity between members of a stimulus set. Predictions are made by measuring the distance between the points representing the stimuli. The closer two stimuli are to one another, the more subjectively similar they should be.

status (Leslie, 1984c: Experiment 3).

Suppose Hume's hypothesis was reformulated as two orthogonal dimensions instead of two binary features. One axis would represent the size of the spatial gap, while the other axis, orthogonal to this, would represent the size of the temporal gap or delay. Would this better explain the results? Perhaps the size of the spatial gap used did not equal the size of the temporal gap. Is this a problem for these results?

In fact, it is not. A glance at Figure 3 shows why. Direct launching with zero spatial and temporal gaps lies at the origin of the two axes. Launching-without-collision will be somewhere along the X-axis, and delayed reaction somewhere along the Y-axis. Delayed reaction-without-collision is diagonally opposite direct launching. If this graph has any psychological reality, we could use it to predict the amount of recovery a given pair of films will give rise to. The rule would be to measure the distance between the points representing the sequences. The greater the distance between them, the more subjectively dissimilar they are, and the more dishabituation of looking we expect. In the special case that the spatial gap exactly equals the temporal gap, the resulting space will be a square. In all other cases it will be a rectangle. Either way, the diagonals ought to be equal. This was not what was found. Analysis also showed that there was no interaction between dimensions (Leslie, 1984c). The results thus contradict a space with 2 dimensions.

In fact, the results can neatly be described by a similarity space consisting of a single dimension (see Figure 3). This single dimension can be interpreted as representing the degree of spatiotemporal continuity between the submovements, i. e. the sum of the values in the two dimensional space. We are currently testing predictions from this new hypothesis.

In a more recent study (Leslie S Keeble, forthcoming), we controlled for differential changes in spatiotemporal properties so that we could better isolate causal properties. To do this we returned to the technique of reversing events. One group (causal) was habituated to direct launching, while another group (non-causal) was habituated to delayed reaction. After reaching criterion, both groups were then tested on the same films respectively but shown with the projector running backwards (see Figure 4). The reasoning was as follows. Reversing either event will change it from moving rightwards to moving leftwards and from red moving first to green moving first. Both will reverse spatiotemporal direction. But if direct launching is seen as causal, reversal will also change its causal direction. From red cause, green effect it will go to green cause, red effect.

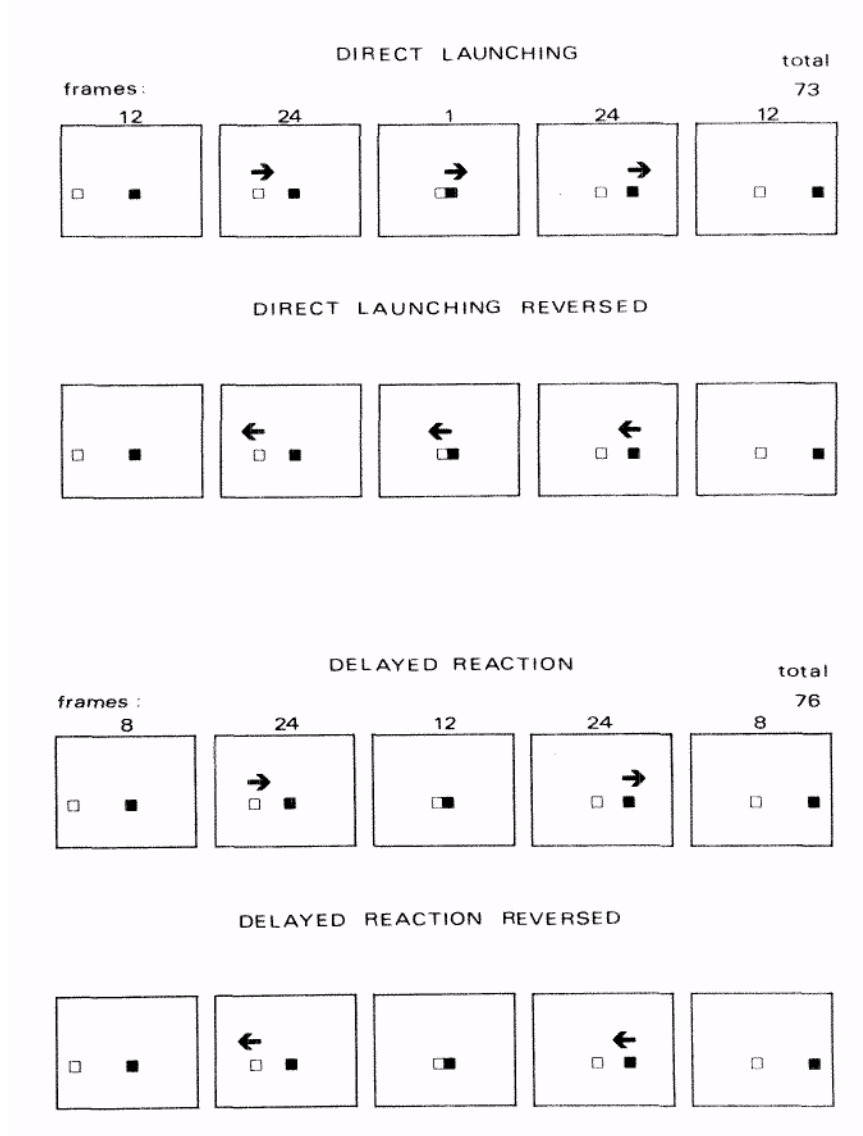


FIGURE 4: Illustration of the stimuli used to test infants' perception of causal direction with spatiotemporal direction controlled for.

So, if infants perceive causal direction only in direct launching and not in delayed reaction, they will be differentially sensitive to its reversal.

This is just what we found in two separate experiments (Leslie & Keeble, forthcoming). In both, infants recovered their looking more to the reversal of direct launching than to the reversal of delayed reaction. The six month old seems to perceive a specifically causal property of this event. We have already seen from the studies discussed above that direct launching is not simply "better" remembered than delayed reaction. Instead there seems to be a. causality factor that increases the importance either of spatiotemporal direction or of the entities' causal roles. This factor appears to be distinct from the gradient discussed earlier since a sequence in reverse will have the same degree of continuity/ discontinuity it has when played forward.

The point of making these detailed studies is to arrive at precise ideas about the kinds of structural descriptions for events the infant visual system can generate. So far these seem to include:

(1) parsing of submovements;

(2) encoding of degree of spatiotemporal continuity between the submovements;

(3) encoding of causal direction in direct launching.

This is beginning to look rather similar to Michotte's causal percept. I would now suggest that the same input module is involved in Michotte's causal illusion in adults and in these results with infants. It is possible, in other words, that the module develops very little or not at all from 6 months to adulthood.

## A WORKING HYPOTHESIS

The working hypothesis that my current studies are bent on testing is illustrated in Figure 5. The basic idea is that the origins of our understanding of causality lie, at least in part, in a fairly low level visual mechanism. This mechanism



may be modular in nature and take its input from lower level processes of motion perception. For example, Restle (1979) outlines a model of how two dimensional motions may be coded in the visual system, extending the work of Johansson (1950, 1973). Representations of motion amplitudes, phases, orientations and so on might be the input to the mechanism we are hypothesising. This mechanism will then have the task of producing higher level descriptions of the spatiotemporal properties of the event configuration and, in the right cases, a description of (apparent) causal structure. Such higher level descriptions then constitute output, to be processed further by the visual system or passed to central processes.

One feature of the model in Figure 5 is that the module computes multiple representations for the same event, each more "abstract" than the one before. A higher level description is computed from a lower one. Thus, given two motions forming a launching event, the spatial and temporal relations between the sub-motions are computed and represented independently. I have to say immediately that there is still no evidence for this level in infants. The reason it appears in the model is that first, I think it a reasonable guess as to how the next level (for which there is evidence) is computed i. e. as a sum of the spatial and temporal gaps identified at the first level and second, I have the hunch that given simultaneous presentation of Launching-without-collision and Delayed Reaction infants would have no trouble discriminating them. We are starting studies now to look at this possibility.

We have already discussed the evidence for the second level. Further studies are testing this predictively but it is too early at time of writing to say how these will turn out. At least it is easy enough to see what the point of such a level would be, offering a succinct description of launching and its variants. The third level is postulated on the basis of the findings of differential sensitivity to reversal of direct launching. Description at this level would only be computed for those events having some high degree of continuity. Perhaps causal roles are described at this level.

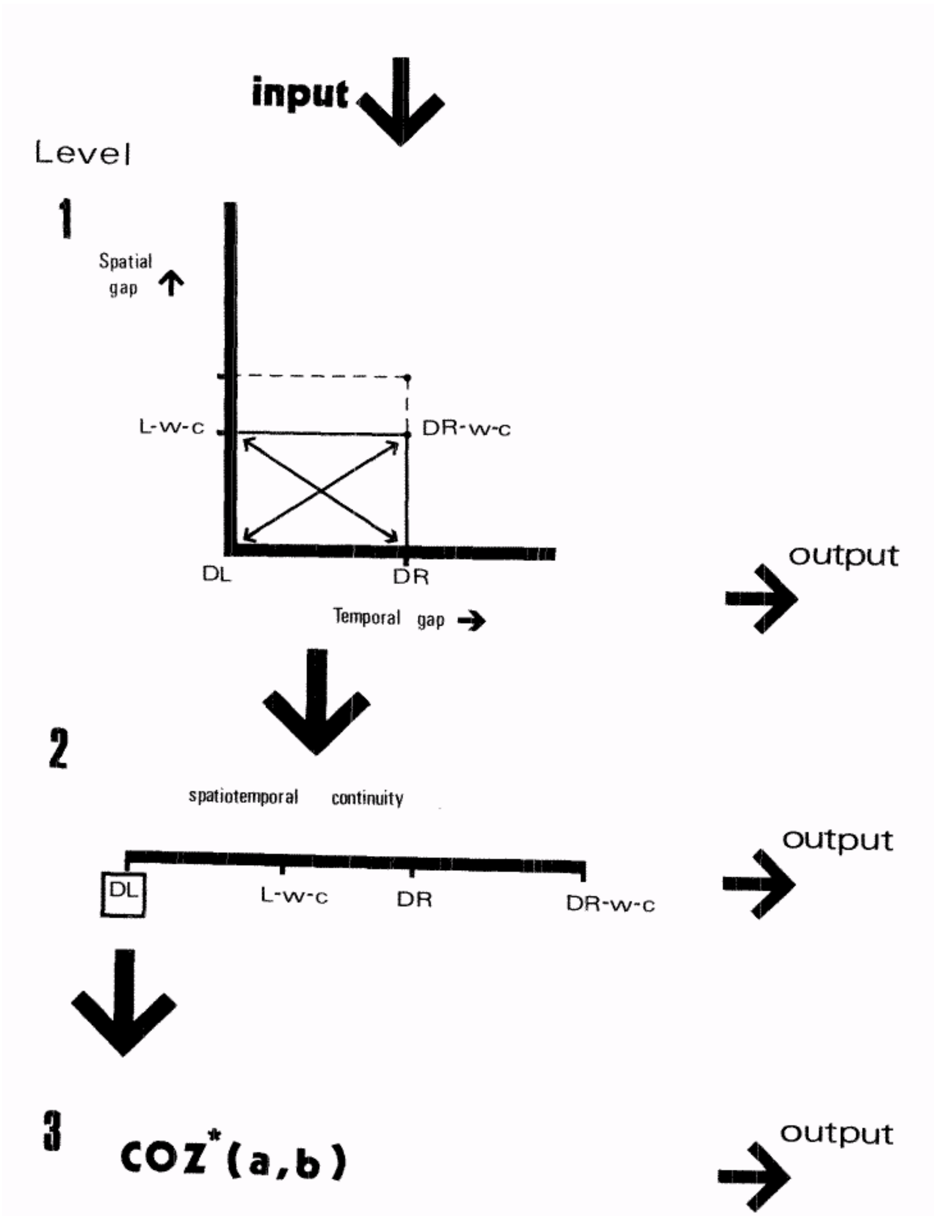


FIGURE 5: A working hypothesis: three levels of representation for direct launching computed by an input module functioning in infancy. * Note- not the English word "CAUSE"!



Again current studies are investigating this.

I find it useful to think in terms of such a mechanism in order to be as definite and precise about its properties as possible. I have come to realise that there are many plausible ways of describing launching type events. In experimental investigation we try to discover which descriptive systems the infant's visual system employs. There are other questions too. For example, what is the information in these events that visual analysis picks up? What are the lower level descriptions of motions that are used by the module we have postulated? And of course there are questions regarding the consequences for development the operation of this module may have. It is to this question that we turn next.

## MODULARITY: GETTING DEVELOPMENT STARTED.

We saw that one of the advantages of breaking perceptual processes down into modules is the speed of computation which is possible. Applying limited resources to a given task means that solutions are found fast, even if, from a wider perspective, the "solution" may sometimes be defective or even bizarre. Rigidly limiting the resources also means that the module is impenetrable to cognition and general knowledge. This impenetrability has one other advantage which nature may have exploited in designing an organism like us whose development involves a large information gain. The lack of influence by general knowledge and reasoning suffered by a perceptual module enables it to operate quite happily in the absence of general knowledge and reasoning ability. And this, of course, is essential for a mechanism that has to operate very early in development, before there is general knowledge or reasoning ability.

Indeed, a mechanism which can operate independently of general knowledge to provide interlocking descriptions of the environment would be very handy for producing development. This may be the crucial point of modularity. Clearly, there would have to be other learning devices that could take advantage of the descriptions provided by such mechanisms. Ideally they should go beyond the description of appearances and place such descriptions in wider contexts of knowledge and resources. But for solving the problem of getting a little general knowledge in the first place and of thus getting development, off the ground, modular perceptual devices are ideal.

As we have seen, there is a good sense in which, though they may be computationally highly sophisticated, perceptual modules perform "tricks", mimicking empirical descriptions of the world without really understanding what is going on. This characteristic of modules may be of central importance in allowing them to be biologically predesigned and built in. Their presence in infancy may give the appearance of specific innate knowledge (of particular causes, for instance). In fact, their function is to allow the process of acquiring knowledge to get started.

Thus, the module we postulated above for the perception of launching can provide "knowledge" about causal interactions without really knowing what a cause is. For the module a "cause" is just what the module says it is. But this may be just enough to get causal development off the ground.

There are a number of ways in which this mechanism could promote development. For example, although the submovements in all the sequences I used covaried equally and perfectly the infant was able to distinguish direct launching, for instance, from delayed reaction. The perceptual mechanism could therefore help in sorting causally connected events from those which merely covary or are just coincidental. It could also play a role in picking up kinetic properties of events (Kaiser & Proffitt, 1984; Todd S Warren, 1982). Visible causal chains could be followed and distinguished. All these things are important for understanding the mechanics of events and for providing thought processes with initially plausible hypotheses about them. The module could tell central processes "A COZED B". Central processes could then begin the abstraction of causal regularities by asking questions such as, do A's always cause B's? under what further circumstances? what are the properties of A's such that they cause B's? and so on. In other words, the output of this module may provide the starting point for the development of some of the preschooler's causal "theories", in the sense intended earlier.



## PERCEPTUAL MODULE VERSUS CENTRAL "THEORY".

The view that perception has a special and distinct role in development brings into sharp focus the following issue. Given that we can identify and describe a particular early competence, what aspects of it are due to the operation of input modules and what to the elaboration of general knowledge? How does the nature of perceptual descriptions influence the construction of central "theories"?

I have been arguing that a part of the child's causal competence is due to an input module. I have argued this on the basis that there is evidence suggesting that young infants are subject to a similar causal illusion as adults. On the one hand, the existence in adults of a perceptual illusion is prima facie evidence of impenetrability (and thus perhaps a module) and on the other hand it seems unlikely that a six month old would have such a percept by virtue of general knowledge and reasoning.

Findings that general knowledge and/or individual differences may play some role in the adult percept (Beasley, 1968; Gemelli & Cappellini, 1958) may simply indicate that-verbal reporting of introspections in adults is not the best way to test the properties (or existence) of this module. Such reports are certainly open to "contamination" in various ways by general knowledge and attitude. Some of the rather "flowery" descriptions obtained by Gemelli S Cappellini (1958) underline this and Beasley's (1968) technique of getting subjects to write down their descriptions may not help either.

On balance, then, it is reasonable to suggest the existence of a common mechanism which explains both the infant and at least the basic adult phenomena.

These arguments and evidence are hardly conclusive but they are, I submit, at least worth taking seriously, especially if lessons learnt from them can be applied to understanding other infant competences (e. g. perception of numerosity (Starkey, Gelman & Spelke, 1983), of musical structure (Trehub, Bull & Thorpe, 1984), perhaps of faces (Maurer, 1981), and so on).

What I now want to do is briefly consider the issue of perceptual mechanism versus central "theory", bringing in some other causal events to contrast with launching.

Gruber, Fink s Damm (1957) studied (adult) perception of an event in which *a* "bridge" collapses. The bridge consisted of a vertical bar supported by two upright posts. When one of the posts was removed the bar would collapse depending upon whether or not the experimenter switched off an electromagnet that was actually responsible for the bar staying up. Gruber et al. manipulated the time interval between removal of the post and collapse of the bar, asking subjects to describe their impressions. As the time interval between removal and collapse was increased, subjects reported a causal link between the two less and less often. This seemed to be a direct analogue for the effect of increasing delays between impact and reaction in Michotte's launching effect.

But is it? Gruber et al. also found that a subject's temporal threshold for a causal judgement was increased by watching a series of trials with very long delays, but decreased by watching a series with no delay. This was interpreted as an effect of experience on an "immediate" perception. Powesland (1959) replicated this result. But when he made a similar study of launching there was no effect of simply watching a series with long or short delays. The temporal threshold for a causal impression remained unchanged (Powesland, 1959). Here then is an interesting difference between the perception of causality in the bridge collapse situation and in launching.

Keil (1979) used a very similar set up to Gruber et al. (1957) with a bar apparently supported by two posts but actually held up by an electromagnet. However, Keil was



interested in the understanding of support and balance that 18 month olds have. Using a surprise measure, he found that the infants were clearly surprised when the bar did not collapse after removal of both supports (they were not surprised when it did). Keil interpreted this as showing that the infants had already come to expect the collapse of an unsupported object. However, the infants were not surprised at the non-collapse of the bar after the removal of a single support, even when the unbalanced nature of the bar was accentuated. Keil argued that while the infants had come to anticipate the outcome of a no support situation, a single support would suffice and the importance of balance to the outcome was not appreciated. Even 30 month olds still did not seem to appreciate the nature of balance. Keil argued that the infant had acquired a rule of inference such that no support implies collapse. Collapse, on the other hand, does not imply previous lack of support (none of the children were surprised when the bar did collapse in the balance situation).

If Keil is right, then the appreciation of support and balance involves the learning of inference rules. The perception of this causal situation then involves an important element that goes beyond the operation of input systems. This would help to explain the results of Gruber et al. (1957) and Powesland (1959) discussed above. The bridge situation and launching may differ in that one involves an (over-learned) central inference, while the other is a direct perception.

Of course, it might well be that the learning of this bit of general knowledge, this inference rule, is promoted by an input module of the right sort, perhaps even the module for dealing with launching. We need a detailed understanding of the relevant input mechanisms and the sorts of descriptions they produce for thought processes. This will provide *a* good starting point for the study of the central learning processes themselves. In fact, I can't think of a better one.

Finally, I raise briefly some other findings on six month olds' perception of a hand picking an object up (Leslie, 1982, 1984a). I do this to draw attention to the issue of development within modules versus central learning.

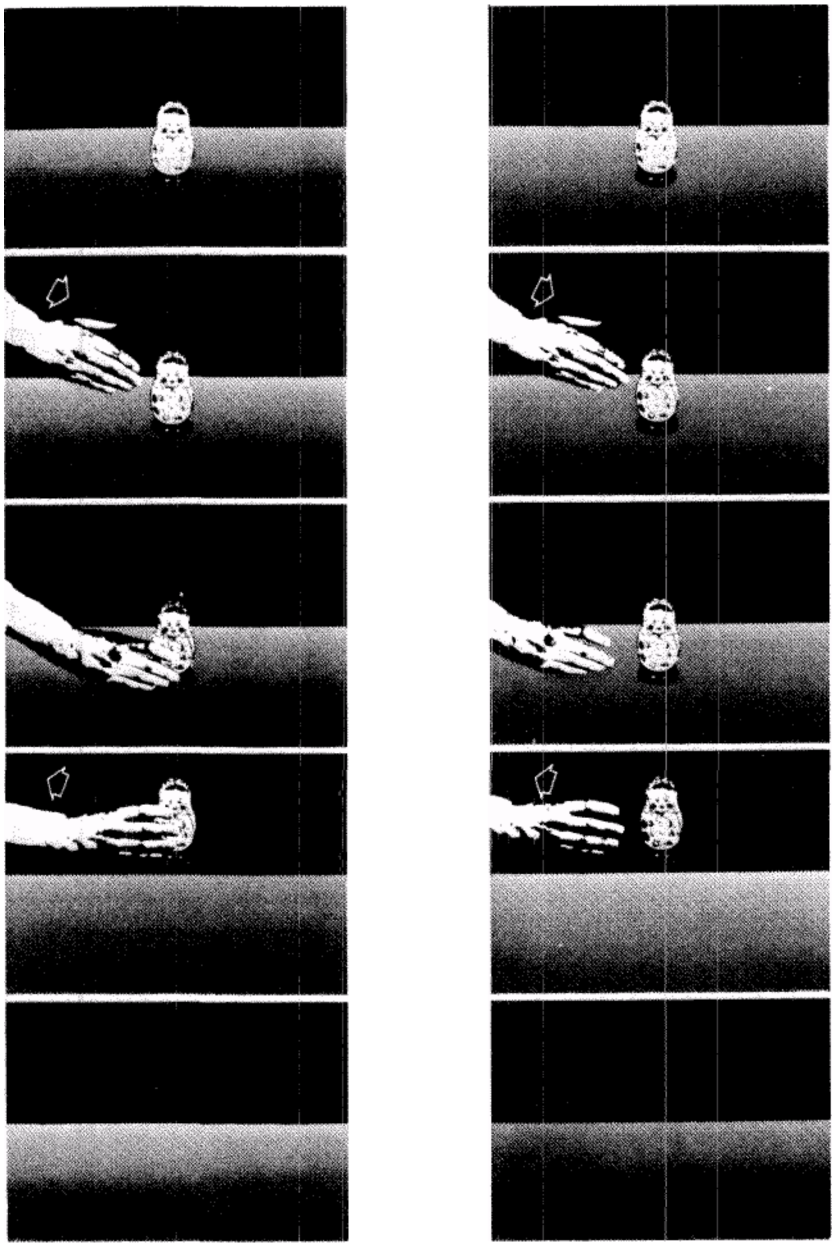

FIGURE 6; Illustration of two sequences used to test infant perception of pick up.



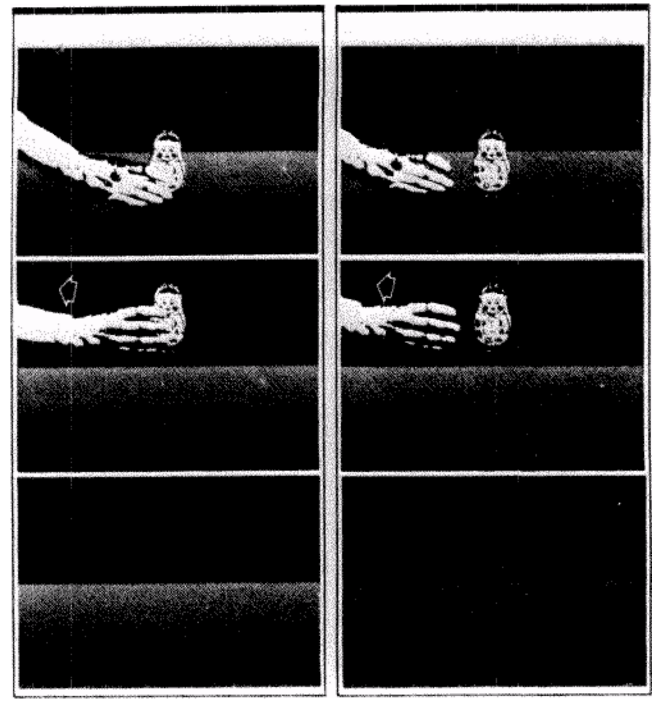

FIGURE 7a: Illustration of sequences used to test specificity of infant response to contact change in pick up (hand picking up the object).

Briefly the findings of these experiments were as follows. Infants readily discriminate a normal pick up from one in which the hand does not actually make contact with the object (see Figure 6). Such a change produces more recovery than, for example, a right-left inversion of normal pick up. More interestingly, this discrimination is only made when the hand actually picks up the object (as opposed to assuming a static relationship) and only when it is a hand picking up and not another inanimate object substituting for it and making similar movements (see Figure 7).

Michotte claimed that the nature of the entities involved

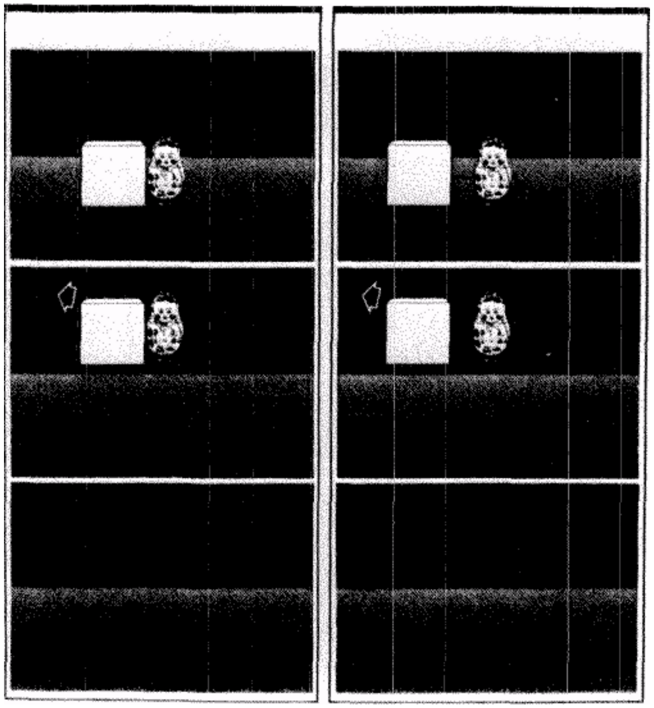

FIGURE 7b: Illustration of sequences used to test specificity of infant response to contact change in pick up (inanimate object - cube - substituting for hand picking up object).

in launching was irrelevant for the causal percept. If so (but see Beasley, 1968), this could be interpreted as evidence that the module involved operates independently of object recognition. This seems plausible if it is part of the motion analysis system, given the evidence for motion analysis creating its own "objects" (see e. g. Johansson, 1950; Restle, 1979). In the case of the infant's perception of pick up, however, the nature of the objects (whether it is a hand or not) plays an important role.

This pick-up percept would have to have access to object recognition information and so have to be organised at a much



later stage of visual processing than launching. It is suggestive that cells have recently been discovered in the visual association cortex of the chimpanzee that respond specifically to mechanical hand-object interactions but not to similar actions only mimed in the presence of the object (Chitty, Perrett, Mistlin & Potter, in press). In the chimpanzee, at any rate, such manual mechanics seems to be processed at the highest stages of vision.

The perception of manual mechanisms and object recognition may also be the product of late visual processing in the human.

Certainly, the child learns to recognise an enormous number of objects within the first few years. Probably the rate of information gain outstrips even that of word learning which averages 8 new words a day between 2 and 5 years (Carey, 1978). So, while some modules may change very little after they become functional, others may acquire a great deal of specialised knowledge.

## A FINAL REMARK.

I have been arguing that perception with its distinctive organisation has a distinctive role in development. If perception is prior in ontogeny, it must make its influence felt in the development of thought. It also seems likely that input processes are prior in phylogeny. Perhaps the evolution of human thought likewise has capitalised on the nature of input descriptions.

## NOTE

1. A recent study by Baillargeon, Spelke and Wasserman (1985) provides a fascinating case study for these issues. Their results show that five-month-olds believe in the continued existence of an occluded object in a particular location which should then resist the motion

of another visible object through that location. When an "impossible" event was shown them in which the visible object passed through this location, they were surprised or puzzled. I would speculate that the five-months-old's input systems already specify both the continued existence of objects that become occluded and the non-existence of things in locations through which an object travels. The appreciation of the contradiction, however, between successive input descriptions in the Baillargeon et al. situation is surely the work of the five-month-old's central processes. This study, then, has interesting implications for both input and central systems in infancy.

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