Cognition, 25 (1987) 265–288

Do six-month-old infants perceive causality?*

ALAN M. LESLIE
STEPHANIE KEEBLE

MRC Cognitive Development Unit, London

Abstract

The idea of cause and effect is often assumed to originate in prolonged learning. However, the present findings suggest that 27-week-old infants may already perceive a cause–effect relationship. Reversal of an apparently causal event (direct launching) produced more recovery of attention following habituation than the reversal of a similar but apparently non-causal event (delayed reaction). In both cases the changes *in the spatiotemporal properties of the stimuli were identical. Hence the infant's percept of direct launching may involve more than an encoding of its spatiotemporal properties. Since the same kind of stimulus gives rise to a causal illusion in adults, it may be that the additional factor at work is the perception of a causal relationship. This finding may be significant in terms of the modularity of the infant visual system and the later development of causal understanding.*

The idea of cause and effect lies at the heart of both commonsense and scientific thought. The question of its origins in psychological development has long been a topic of speculation (e.g., Gibson, 1984; Gibson & Spelke, 1983; Hume, 1740; Kant, 1781; Michotte, 1963; Piaget, 1955). Recent experimental studies of children show that even 3-year-olds employ fairly sophisticated causal ideas in understanding mechanical interactions (Bullock, 1985; Bullock, Gelman, & Baillargeon, 1982; Kun, 1978; Shultz, 1982). The origins of causality must, therefore, lie further back in development, perhaps in infancy.

*We thank Uta Frith, John Morton, Graeme Halford and Jean Mandler for helpful comments on earlier drafts. Earlier versions of this paper have also formed portions of talks given to the Departments of Psychology at the Universities of St. Andrews, York and Manchester, to the 5th Biennial International Conference on Infant Studies, Los Angeles, April 1986, and to the Salk Institute, University of California, San Diego. Reprint requests should be addressed to Alan Leslie, MRC Cognitive Development Unit, 17 Gordon Street, London WC1H 0AH, U.K.

0010-0277/87/$7.70

Hume (1740) argued that only the spatial and temporal arrangement of events, and not their causal connections, could be sensed. Since causal relations are not known by force of logic, our belief in a causal world could only be the result of "imagination" on our part: a natural response of our minds to prolonged experience of events which occur constantly together and which are closely connected in time and space. If Hume had ever considered infancy, he would no doubt have thought that infants, lacking any substantial experience of the world, would only be able to sense the spatial and temporal arrangement of events, and have little or no knowledge of causality.

Piaget (1955) speculated that infants might be sensitive to the feelings of effort that accompany action. He thought that this, together with detecting "statistical" associations between events or stimuli, might jointly be the basis for later causal understanding. Evidence has since accumulated on one of these points: infants can indeed detect contingencies between their own actions and events in the world (see Watson, 1984 for a review).

There is also recent evidence that infants can perceive and remember the internal spatiotemporal structure of at least two objective events that appear causal to adults (Leslie, 1982, 1984a, 1984b, 1984c). For example, the spatial relation of contact between a hand and a doll while the hand picks up the doll, appears to be important to 6-month-olds in a way that contact between another similarly moving inanimate object and doll is not (Leslie, 1984a). Infants of this age also appear to be able to remember the degree of spatiotemporal continuity between the movements in collision events (Leslie, 1984b).

The young infant's sensitivity to spatiotemporal correlates of causality, like contingency and continuity, is certainly suggestive. But there has been no direct evidence so far from these or any other studies that infants are able to perceive a specifically *causal* relation. Among the traditional approaches to causal perception, only Michotte (1963) has suggested that infants might have a direct impression of cause-effect as a sort of perceptual gestalt (cf. Rock, 1983, p. 134–138). This arises for adults from certain kinds of collision events, as, for instance, when one billiard ball launches another by striking it. But as Michotte showed, a causal percept can also be obtained with quite abstract stimuli such as marks on paper or coloured lights, so long as the movement pattern is right. Michotte argued that such stimuli gave rise to a *perceptual illusion* since the effect appeared to be obtained immediately, repeatedly and despite the observer's knowledge of how the display was actually produced. Since then, further work, while questioning a number of the details, has tended to support this central finding of Michotte's (Beasley, 1968; Gemelli & Cappellini, 1958; Powesland, 1959).

Infantile perceptions: Michotte versus Hume

Experimental test of these ideas with infants must proceed in a number of steps, each contributing to the overall picture. We have used the habituation-dishabituation of looking technique for this purpose with sets of cinematic stimuli depicting a red object colliding with a green object in a variety of ways.

Parsing subcomponents

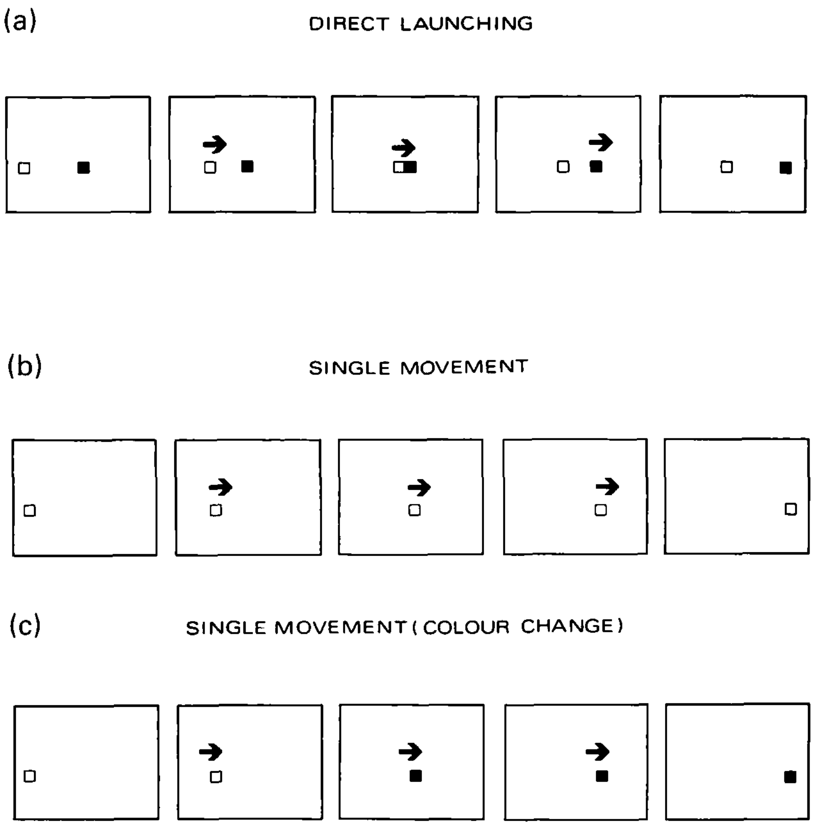
In the first of these studies, Leslie (1982) showed that infants can distinguish the continuous motion of a direct launching from similar but discontinuous events. Given this, the next question to ask is, Can they distinguish the *submovements* in the continuous direct launching or is this perceived simply as a single unanalysable "whoosh" from one side of the screen to the other? This was tested in the following way. We reasoned that if direct launching is seen as an event with a particular internal structure (i.e., composed of submovements), then reversing the event, by playing the film backwards, should rearrange that structure. If, however, an event has *no* submovements, then reversing it would only affect those properties, such as spatial direction, which do not depend upon structured subcomponents.

The general idea here can perhaps be grasped by considering a linguistic example, like the word "houseboat". This word has lexical subcomponents which can be reversed to produce "boathouse". But where there are no lexical subcomponents (as in "vehicle"), reversal can affect only lower level (e.g., phonemic) structure.

The idea then was to use reversal to probe for the infant's perception of internal structure in direct launching. To do this, Leslie compared the effect of reversing direct launching with the effect of reversing a single movement made by a single object (see Figure 1a & b). Since a single movement has no subcomponents, reversal will change only its spatial direction. Using an habituation-dishabituation of looking technique, one can predict the following from the subcomponent hypothesis; a group of infants habituated to direct launching and tested on its reversal will recover their looking *more* than a group habituated to a single movement and tested on its reversal.

Leslie (1984b, Experiment 1A) used the above design. Both groups of infants were equated by presenting the same spatial direction change, but the direct launching group was hypothesised to see, in addition to this, a reversal of an internal relationship like temporal order. Of course, it was possible that both groups would recover their looking to ceiling level, since both changes might be discriminable. However, given that discrimination may be a *neces-*

Figure 1. *Illustration of sequences used in Leslie (1984b; Experiment 1 A & B). The open square represents the red brick, the shaded square the green brick. Each brick moved consecutively for 1 s (24 frames) in direct launching and for 2.17 s in the single movement films. Differences in sequence duration were compensated for by adjusting the stationary periods at the beginning and end of the sequence. Films were formed into loops for continuous projection. For more details about how these stimuli are constructed see Leslie (1984b) and below. Reversal of the top two sequences was produced by turning the projector into reverse.*



sary but certainly not a sufficient condition for dishabituation,[1] it was reasonable to hope that ceiling effects would not obscure any differential response there might be to reversal. And indeed, the results showed little recovery in the single movement group and a significantly higher level of recovery in the direct launching group.

Despite this result, it was still possible that direct launching was perceived as a single movement with differently coloured halves. That is, it might have been encoded as a single moving entity that changes colour from red to green half way across. To look at this possibility a film was made in which exactly this happened (see Fig. 1c). If infants encode direct launching as a single movement with colour change, they should not readily discriminate these sequences. The results of a new experiment, however, showed they did (Leslie, 1984b, Experiment 1B). Taken together, then, these two studies suggested that 6-month-olds could indeed detect internal structure and thus parse the submovements in direct launching.

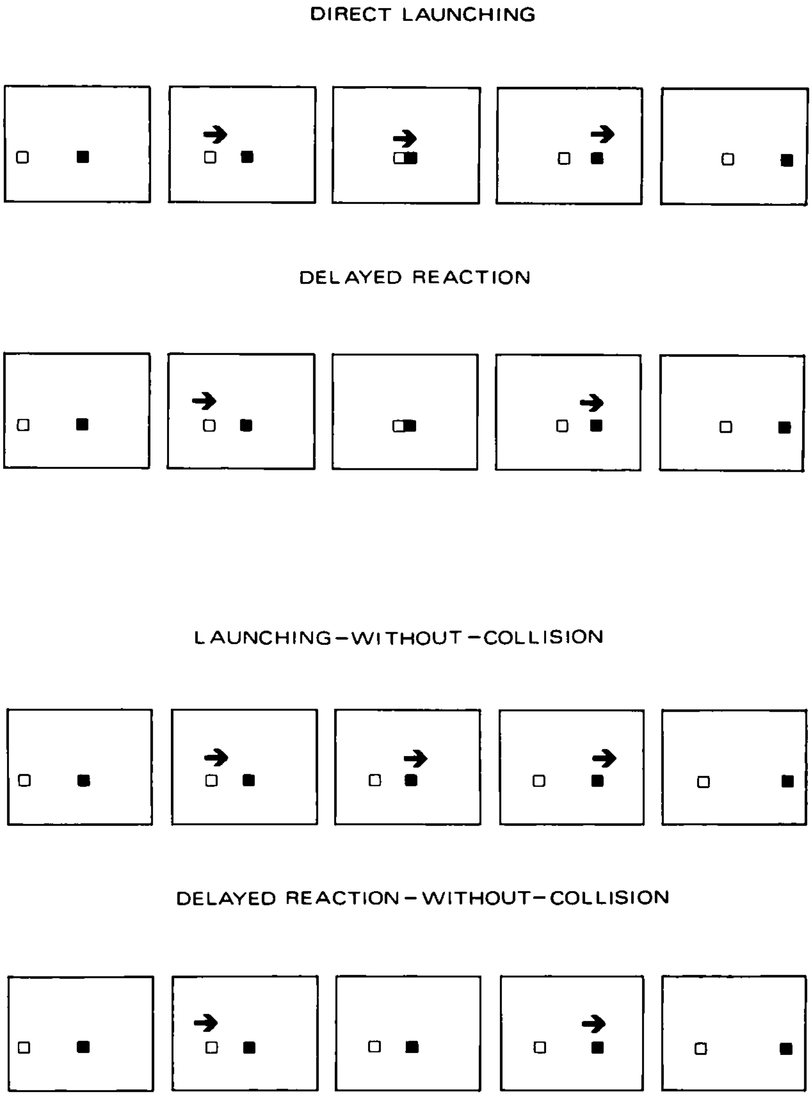
Perceiving connections

One could now ask about *what kind* of internal structure, beyond submovements, infants perceive in direct launching. In particular, how do they perceive the relationship *between* the submovements? As we have seen, there are two traditional but opposing hypotheses about the nature of this relationship as naively perceived. On the one hand, Hume would argue that infants will perceive two independent aspects of the event—the spatial contact and the temporal succession of the movements. Against this Michotte (in company with Gibsonians) asserts that a causal relation will be registered directly. The next step then was to contrast these hypotheses experimentally.

To do this four sequences were made. The following descriptions can be checked against Figure 2 which illustrates these sequences. In addition to direct launching, there was *delayed reaction* with a half second delay between impact and the reaction of the second object, *launching-without-collision* where the first object stops 6 cm short of the second which then immediately

[1]This is clearly shown where infants fail to dishabituate to stimulus contrasts which we know independently they can discriminate, as in generalised habituation to a class of stimuli (e.g., Bomba, 1984; Bomba & Siqueland, 1983; Cohen & Strauss, 1979; Reznick & Kagan, 1983). Actually, it seems that discrimination, in the usual sense at least, is not even a necessary condition for dishabituation. In a recent study by Baillargeon, Spelke and Wasserman (1985) infants dishabituated when they saw a screen revolve backwards despite the fact that this was the same event they had previously habituated to. The reason for their dishabituation was that just before this another object had been placed *behind* the screen; the authors suggest that the infants thought this now invisible object should have interfered with the screen's movement and were surprised at the "impossible" event. It seems very likely then that dishabituation reflects the central evaluation of a given contrast for its *significance* or *interest*, and not an automatic process of perceptual discrimination.

Figure 2. *Illustration of sequences used in Leslie (1984b; Experiments 2 & 3). The delay between impact and reaction in the relevant films was half a second (12 frames). The spatial gap was equivalent to 6 frames of movement. Again differences in sequence duration were compensated for during the stationary periods at the beginning and end of each sequence. Michotte predicts that only Direct Launching will be perceived as "causal".*



moves off without being struck, and *delayed reaction-without-collision* where the temporal delay and the spatial gap of the other two respectively are combined. Michotte predicts that these last three variants will tend to appear non-causal to the adult observer (and we have confirmed this prediction for our stimuli, at least informally, by soliciting the opinions of visitors to our laboratory).

Notice that, according to the Hume hypothesis, direct launching is to delayed reaction-without-collision what delayed reaction is to launching-without-collision. That is, both pairs should present exactly the same contrast: contact versus no contact together with delay versus no delay. Infants might then encode the internal relationships in these events as pairs of binary features corresponding to [±contact] and [±delay]. This idea is made clear in Table 1. Alternatively, "Hume's hypothesis" can be recast as a similarity space with orthogonal dimensions representing the size of gap and the length of the delay as illustrated in Figure 3.

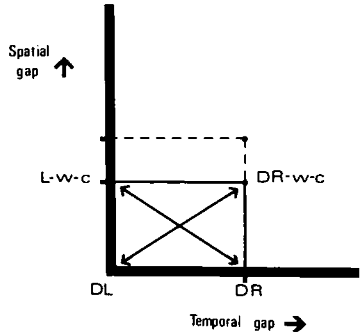
Either way—features or dimensions—there should be no difference in the amount of recovery shown by one group of infants habituated to direct launching and tested on delayed reaction-without-collision and another group habituated to delayed reaction and tested on launching-without-collision. Figure 3 also makes clear that this should hold even though the subjective size of the spatial gap does not equal the subjective size of the temporal delay. When they are equal, we have the special case in which the stimulus set forms a square within the similarity space. But in all cases the diagonals representing the relevant comparisons should be equal.

These predictions from the "Hume hypothesis" contradict those from the "Michotte hypothesis". The latter predicts that the comparison with direct launching should be seen as more novel and therefore produce more dishabituation, since it is the only causal sequence.

Table 1. *Launching and its variants described according to independent spatial and temporal features—"Hume's hypothesis". According to this hypothesis, the first pair contrasts in the same way as the second pair.*

Sequence	Encoding	Contrast
Direct Launching	[+ contact, − delay]	
vs.		Both features
Delayed Reaction-without-collision	[− contact, + delay]	
Launching-without-collision	[− contact, − delay]	
vs.		Both features
Delayed Reaction	[+ contact, + delay]	

Figure 3. *Subjective similarity space for the sequences illustrated in Figure 2 implied by "Hume's hypothesis" of infant causal perception. The* y*-axis represents the size of the spatial gap between the movements of the objects, while the* x*-axis represents the delay between the end of one movement and the beginning of the other. This places Direct Launching (DL) at the origin, Delayed Reaction-without-collision (DR-w-c) opposite, and Launching-without collision (L-w-c) and Delayed Reaction (DR) along the* y*- and* x*-axes respectively. The broken lines show the special case of the spatial gap equalling the temporal gap, while the solid lines illustrate a case where the spatial gap is smaller. It is easy to see in either kind of case that the diagonals would be equal. The results of Leslie (1984b) discussed in the text suggest that 6-month-old infants' coding is not adequately described by this kind of space.*



Leslie (1984b; Experiment 2) tested these predictions. Again the theoretical possibility of ceiling effects did not materialise and the results instead showed significantly more recovery in the direct launching group, favouring Michotte and contradicting both versions of "Hume's hypothesis".

But if it really was *apparent causation* that was responsible for this effect, then direct launching should always be "special" since it is the only causal film. Thus, direct launching versus delayed reaction should produce more recovery than delayed reaction-without-collision versus launching-without-collision despite the fact that both involve a delay change. And so too for the comparisons involving changes in contact (direct launching versus launching-without-collision and delayed reaction-without-collision versus delayed reaction). This made four experimental groups which are shown in Table 2. These four groups test "single feature" changes against the causal hypothesis. They were run along with two control groups who saw an unchanged sequence again on the test trial. The controls establish a baseline against which recovery in the other groups can be compared. This allowed us to see if the spatial and temporal changes were discriminated and, more particularly, if direct launching contrasts were "special". The results showed that each of the four films was discriminable from the others. But, *contrary to the causal hypothesis*, there was no indication that direct launching appeared more contrastive (Leslie, 1984b, Experiment 3).

How can the results of these two experiments be reconciled? In one experiment, direct launching appears more contrastive than it should on "Hume's hypothesis", while in the other it does not. We have measurements of infants' recovery for each of the six comparisons between the four sequences. Examination of these scores suggested a simple explanation (Leslie, 1984b, 1986). The four sequences may be encoded on a *single* dimension, with direct launching at one extreme, delayed reaction-without-collision at the other, and the remaining two sequences somewhere in the middle. Such a gradient can be interpreted as representing the degree of *spatiotemporal continuity* between the submovements. This model implies that while the infants were able to remember that the previous sequence had been discontinuous (to some degree), they could not remember whether the gap had been spatial, temporal or some mixture of the two.

It was not possible then to conclude that the infants had perceived a causal relation. But the theoretical possibility remains that that study was insensitive to a causal percept because infants compare the stimuli within this set in terms of what they have in common, i.e., their lying at various points along a continuity/discontinuity gradient. Thus it might be that infants can neverthe-

Table 2. *Predicted contrast between direct launching and its variants according to Hume's and Michotte's hypotheses (tested in Leslie, 1984b).*

Sequence	Hume's hypothesis	Michotte's hypothesis
Direct Launching vs. Delayed Reaction	Delay contrast	Causal contrast
Direct Launching vs. Launching-without-collision	Contact contrast	Causal contrast
Delayed Reaction-without-collision vs. Launching-without-collision	Delay contrast	No causal contrast
Delayed Reaction-without-collision vs. Delayed Reaction	Contact contrast	No causal contrast

less perceive direct launching as causal, but will not use this dimension for comparison with events which are not causal. Alternatively, the gradient may represent degree of causal connection.

Testing a causal connection

To get at infants' perception of specifically *causal* properties of launching, it now seemed necessary both to minimise and control for spatiotemporal differences between the sequences presented. The only way we could think of to do this, was to return to the technique of reversing the event.

The reasoning behind the present study then was as follows. In some causal events, reversal of spatiotemporal direction entails reversal of causal direction as well.[2] For example, billiard ball A directly launches billiard ball B by colliding with it in a rightwards direction—A causes B to move. In the reverse of this event, billiard ball B comes back and directly launches ball A in a leftward direction—B causes A to move. Thus, causal direction, *as well as* spatiotemporal direction, reverses.

But in the non-causal variant of this, produced by interposing a short delay between impact and reaction, which we call "delayed reaction", causal direction is, by hypothesis, absent. That is, if delayed reaction is not perceived as causal, then reversal will affect *only* its spatiotemporal direction (left/right orientation and order of movement). At the causal level, however, it will lack internal structure.

Therefore, we reasoned that if infants perceive causal direction only in direct launching and not in delayed reaction, they ought to be differentially sensitive to the reversal of these two sequences. That is, they ought to respond to causal *and* spatiotemporal reversal in the case of direct launching, but only to spatiotemporal reversal in the case of delayed reaction. Alternatively, spatiotemporal direction reversal might not be effective in either case or only in the causal case. Either way, (assuming that as before ceiling effects will not arise), the reversal of direct launching should produce more dishabituation, if it is perceived as causal.

Experiment 1

Differential infant sensitivity to the reversal of causal and non-causal events was the hypothesis tested here, using a habituation-dishabituation of looking

[2]By "spatiotemporal direction" we mean both the spatial orientation of the movements and their relative temporal order (e.g., A moved first); by "causal direction" we mean the orientation of the causal relationship (e.g., A caused B).

technique. Such a technique measures decline in looking to a repeatedly presented stimulus and subsequent recovery when the stimulus is changed. It was predicted that infants who were habituated to a direct launching sequence would recover their looking more when it was reversed than another group habituated to a delayed reaction sequence and tested on that reversed. This should occur despite the fact that the change in spatiotemporal relations (i.e., reversal) is identical for both groups. Consider: for *both* groups, the spatial direction of movement changes, the temporal order of objects moving changes, and if a sequence has a certain degree of continuity in one direction it will have that same degree in the other direction as well.

This control of spatiotemporal factors allows a strong test of the hypothesis and distinguishes this experiment from previous ones. As we have seen, a similar design was used in the first experiment reported in Leslie (1984b) but the comparison there was between the reversal of direct launching and the reversal of a single object moving. The results of that experiment could therefore only show whether infants perceived some internal structure in direct launching, but not what structure. Using the reversal of delayed reaction as the comparison provides a test of the much stronger hypothesis that the internal structure perceived includes a specifically causal relation.

Method

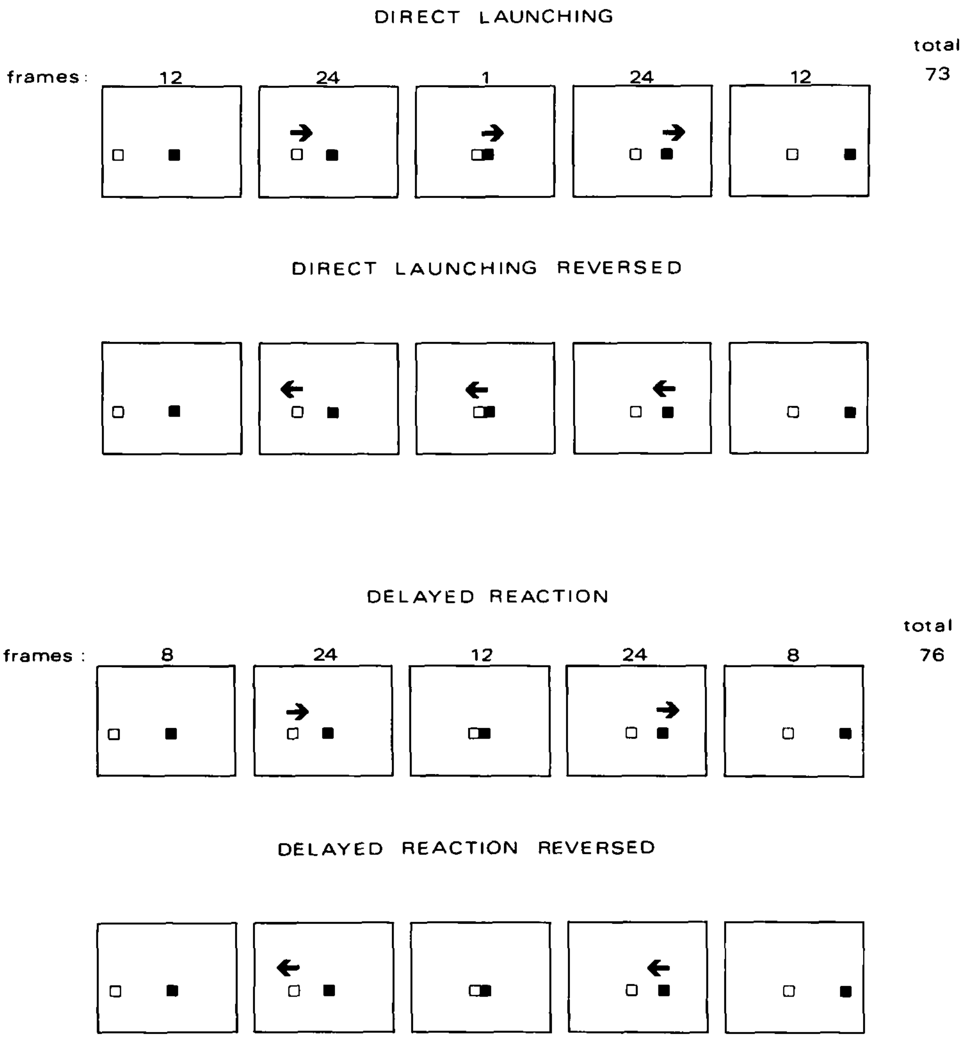
Subjects

Thirty-four healthy full-term infants between 24 and 32 weeks at testing (mean age = 27.1 weeks, s.d. = 2.3) were used. To reach $N = 34$, a total of 49 infants were seen, of which 15 were rejected: 8 for fussing, 1 for falling asleep, 1 for refusing to look, and 5 through experimenter errors. All subjects, accompanied by a caregiver, were transported to and from the laboratory by taxi cab and were drawn randomly from a pool of volunteers.

Stimuli

The stimuli are illustrated in Figure 4. These were prepared on 16 mm colour ciné film (Ektachrome VNF) by animation technique for projection at 24 frames per second. Total projected picture size was 30 cm × 44 cm showing two toy building bricks, one red, the other green, each 3.1 cm × 3.8 cm. In both sequences each brick moved for 18.1 cm smoothly over 24 frames such that one brick collided with the other. Reaction was then either immediate (Direct Launching) or delayed for 0.5 s (Delayed Reaction). The duration of the stationary periods at the beginning and end of the two sequences was

Figure 4. *An illustration of the sequences used in the present studies. The stimuli were 16 mm colour ciné films prepared by animation technique and formed into loops for continuous projection at 24 frames per second. The objects used were two toy bricks. The left hand brick was bright red, the right bright green. Differences in movement duration were compensated by adjusting the stationary periods at the beginning and end of each sequence. Film of individual sequences was formed into loops for continuous projection. Reversal was produced by switching the projector to run backwards. See text for more details.*



varied slightly to compensate for the extra frames in the delay period in Delayed Reaction (see Fig. 4). The ratio of overall movement time to static time was thus equated for the two stimuli. Each sequence was formed into a loop for continuous projection with 8 frames of unexposed film spliced into the join. To produce reversal the projector was switched into reverse, cycling the film in the opposite direction.

Apparatus

The experiment was conducted in a darkened room specially adapted for infant habituation studies. Infants sat on their mother's lap, approximately 1 m away from a Marata screen onto which the films were back projected. The screen was built flush with a grey partition which divided the room and screened off equipment and experimenter from the infant. A pair of flashing lights mounted just above the screen could be turned off and on to attract the infant. Films were shown by means of a Bell & Howell TQ III Specialist 16 mm ciné projector adapted with an electronic shutter over the lens to start and stop projection. An electronic timer was used to time the infant's looks. Infants were observed and recorded via an infrared-sensitive video system. The camera looked through a lens-sized hole in the partition 2.5 cm above the top of the projection screen. Video illumination was provided by two diffused semi-discrete 150 W infrared light sources in the subject half of the room. Distracting surfaces were shrouded by ceiling to floor grey drapes.

Design and procedure

Infants were randomly assigned to one of two groups, with 17 infants in each group. The first group were habituated to the film depicting Direct Launching. The second group were habituated to a film depicting Delayed Reaction. Having reached the habituation criterion (see below) both groups were then tested on their respective film with the projector running in the opposite direction to habituation. The initial direction of the sequence (presented for habituation) was counterbalanced within groups.

An infant control procedure was used (Cohen & Gelber, 1975). A trial began with a pair of lights flashing above the projection screen. When the infant appeared to look at these the shutter on the projector was opened to repeatedly project the film loop. As soon as the infant appeared to look at the screen, an electronic timer was started. When the infant looked away for more than one second, the timer was stopped and the shutter closed. This constituted one trial.

After the first 3 trials the mean length of looking was calculated. The habituation phase then proceeded until the infant looked for at least 0.5 s less than this mean on each of 3 consecutive trials. This constituted the criterion for habituation. All subjects thus had at least 6 trials; a maximum of 18 trials was planned but all infants habituated before then. This is a fairly weak criterion, yet it has produced both reliable declines in looking and similar last trial looking times around 6 seconds consistently across 10 previous experiments with cinematic stimuli. Indeed, such a criterion may be more appropriate to tests with cinematic stimuli which often only differ for short periods within their cycle. The infant might simply miss these periods if she was too bored. After reaching criterion there was an interval (as in previous studies) of approximately 40 seconds during which the projector was switched into reverse. A test trial with the reversed stimulus was then given in the same way. Just before this trial, the mother was asked to close her eyes so that she could not see the test stimulus, thus controlling differential maternal influence on recovery.

All sessions were rescored from videotape by another experienced observer blind as to the film being shown. These are the scores reported here. Inter-observer reliability was calculated on all scores from a randomly selected 20 subjects and was high (mean r = 0.98, s.d. = 0.01).

Results

Table 3 shows the mean length of looking on the First and Last Habituation Trials and mean length of looking over all habituation trials for each group. As in previous studies, first trial looking was extremely variable. Analysis of

Table 3. *Mean looking times in seconds (s.d. in brackets) Experiment 1.*

Groups	Habituation			Recovery
	First Trial	Last Trial	Mean Look per trial	Test Trial − Last Trial
Direct launching				
n = 17	38.1	6.9	15.0	+ 9.5
	(51.8)	(4.0)	(12.9)	(13.1)
Delayed reaction				
n = 17	17.2	7.6	11.4	+ 2.9
	(10.2)	(3.6)	(3.9)	(5.6)

N = 34, mean age = 27.1 weeks.

variance on First versus Last Habituation Trials × Groups shows that the decline in looking within groups was significant [$F(1, 32) = 11.04, p = .002$]. Between group differences were not significant. Groups did not differ significantly on mean look per trial [$t(32) = 1.11, p = .28$, two tailed].

Since none of the data was normally distributed or showed homogeneous variances, all results were confirmed by non-parametric analyses. Groups did not differ significantly on either First Habituation Trial (Mann-Whitney, $z = 0.78, p > .5$, two tailed), Last Habituation Trial (Mann-Whitney, $z = 1.02, p = .3$, two tailed) or on mean look per trial (Mann-Whitney, $z = 0.0, p > .5$). The number of infants showing a decline in looking versus staying the same or increasing was significant in both Direct Launching (Binomial Test, $z = -3.88, p < .001$, one tailed) and Delayed Reaction groups (Binomial Test, $z = -3.4, p < .001$, one tailed).

The Recovery scores for each group (calculated as Test Trial − Last Habituation Trial) are also shown in Table 3. Planned comparison of these scores shows that, as predicted, the Direct Launching group increased its looking to the reversed sequence significantly more than the Delayed Reaction group [$t(32) = 1.93, p = .031$; $U = 95.5, p < .05$, one tailed].

Discussion

The results of this experiment give the first clear indication that young infants might perceive causal as opposed to spatiotemporal properties of an event. There may, however, be a worry over the disparity between the two groups in their first trial scores. Despite the fact that the difference was not significant, the longer looking Direct Launching infants on the first trial may have looked slightly longer on the test trial too, inflating the differential dishabituation effect. At the same time, given that the Delayed Reaction group showed a small but positive recovery it would be interesting to know whether they had actually dishabituated to spatiotemporal reversal or if they had simply recovered spontaneously (from fatigue, for example). Furthermore, given the possible significance of the obtained result, it is important to know how reliably it can be obtained. For all these reasons, a second experiment was run replicating the first but with the addition of a control group whose habituation film was simply shown again on the test trial without reversing the projector.

Experiment 2

A replication of Experiment 1 was run with a control group. This allows an assessment of the reliability of the effect found in Experiment 1, while the inclusion of a control group will allow a clear interpretation of the pattern of the recovery. For example, did recovery to direct launching reflect a reaction to novelty as predicted or could it possibly reflect a preference for familiarity (Rose et al., 1982; Wagner & Murphy, 1986)? in which case the control should recover strongly as well. On the other hand, if the control group is at or below zero, then we can also test for the significance of recovery to the reversal of Delayed Reaction.

Method

Subjects

There were 36 healthy full term infants between 24 and 32 weeks (mean age = 26.9 weeks, s.d. = 2.2) who had not taken part in similar studies before. To reach N = 36, 50 infants were seen of which 14 were rejected, 8 for fussing, 2 for falling asleep, 1 for failing to reach criterion by the 18th trial, and 3 through experimenter error. Again infants were transported by taxi, accompanied by caregivers, and were drawn randomly from a pool of volunteers.

Stimuli and apparatus

These were the same as in Experiment 1.

Design and procedure

Infants were randomly assigned to one of three groups, 12 in each group. In the Direct Launching Reverse and Delayed Reaction Reverse groups the initial direction of the sequence for habituation was counterbalanced within groups. In the Control group, half the infants saw direct launching and half delayed reaction, the same film being used on the Test Trial without reversal. Scoring and rescoring were carried out in the same way as before. Mean inter-observer reliability was calculated on all scores from a randomly selected 18 infants (r = 0.95, s.d. = 0.07). The procedure was the same as in Experiment 1.

Results

Table 4 shows the means for First and Last Habituation Trials and mean look per trial during habituation by groups. ANOVA on First versus Last Trial × Groups shows there was a significant decline in looking over habituation phase within groups [$F(1, 33) = 36.1$, $p < .001$], but no significant between groups differences. First Habituation Trial scores were quite similar with slightly higher looking to Delayed Reaction this time. There were also no significant differences between groups on mean look per trial in habituation [$F(2, 33) = 0.52$, $p > .5$].

Again because the data was not normally distributed nor showed homogeneity of variance, all results were confirmed non-parametrically.

We confirmed that there were no significant differences between groups on First Habituation Trial (Kruskall-Wallace, $H = 0.6$, $p > .5$), on Last Habituation Trial ($H = 0.61$, $p > .5$), or on mean look per trial ($H = 0.85$, $p > .5$). All 12 subjects in each group showed a decline in looking from first to last trial (Binomial Test, $p < .001$).

Recovery scores for each group are also shown in Table 4. One-way ANOVA showed a significant effect of treatment on recovery [$F(2, 33) = 8.62$, $p = .0013$] with a significant linear trend ($t = 3.95$, $p = .0006$). Planned comparison replicated the result of Experiment 1 with the Direct Launching group showing significantly higher recovery to reversal than the Delayed Reaction group [$t(22) = 2.6$, $p = .008$, one tailed]. Non-parametric trend/con-

Table 4. *Mean looking times in seconds (s.d. in brackets) Experiment 2.*

Groups	Habituation			Recovery
	First Trial	Last Trial	Mean Look per trial	Test Trial – Last Trial
Direct launching				
$n = 12$	32.8	6.7	17.5	+ 14.8
	(14.1)	(4.4)	(7.6)	(13.5)
Delayed reaction				
$n = 12$	39.4	7.2	15.0	+ 2.7
	(38.7)	(3.6)	(7.7)	(9.1)
Control				
$n = 12$	34.7	7.2	14.9	– 0.7
	(27.5)	(2.7)	(5.6)	(3.6)

$N = 36$, mean age = 26.9 weeks.

trast analysis with coefficients Direct Launching > Delayed Reaction > Control was highly significant (Kruskall-Wallace, $H = 17.63$, z for trend = 3.98, $p = .0001$).

We cannot carry out a planned comparison testing recovery in the Delayed Reaction group versus the control since this is not orthogonal to the main comparison above. However, control group recovery was very close to zero (in fact showing a slight decline reflected equally in the Direct Launching (−0.8 s) and the Delayed Reaction (−0.5 s) controls). This allows us to ask, Was recovery in the Delayed Reaction Reverse groups, combined across Experiments 1 and 2, significantly greater than zero or did they perform like the controls? The results show that their positive recovery was significantly different from zero: $t(28) = 2.14$, $p = .02$, one tailed. Again this is confirmed by non-parametric test: 20 infants increased while 9 stayed the same or decreased; among the controls, 4 increased while 8 stayed the same or decreased ($\chi^2 = 3.09$, Fischer-Yates exact probability = .0397, one tailed). There is evidence, then, that the infants were able to remember the spatiotemporal direction of delayed reaction.

General discussion

This study provides evidence suggesting that young infants can perceive a specifically causal relation. Given that spatiotemporal changes were controlled, it would appear that causal, as opposed to spatiotemporal, properties were involved in the infant's differential reaction to reversal. The interval of nearly a minute between habituation and test shows that the infants were able to memorise something about this causal property.

This experiment does not directly address the question of how the event was represented in memory. Previous studies give no reason, however, to believe that direct launching is simply more "easily" remembered than delayed reaction (Leslie, 1984b). In those studies, infants who were habituated to direct launching and tested on delayed reaction did not dishabituate more than those infants who received the sequences in the counterbalanced order, as one would expect if memory on the test trial was better for direct launching than for delayed reaction. There was also no indication that direct launching produced faster rates of habituation. Furthermore, in the present experiment, there was hardly any difference whatsoever in the recovery scores shown by the controls for direct launching and delayed reaction. If infants were having trouble remembering delayed reaction or if the interval had partially "erased" memory, there should have been positive recovery in the controls or at the very least an imbalance between the control subgroups. Since there was no hint of either, it is unlikely that "better" memory accounts for the present result.

Nor does it seem likely that the infants simply preferred to look at a stimulus that is constantly dynamic as opposed to one with delays. Several things speak against this. For example, first trial looking to delayed reaction was actually higher than to direct launching in the second experiment, and while mean look per trial was somewhat higher in both experiments the difference did not approach significance. In previous studies with these stimuli looking time during habituation has shown insignificant differences in the opposite direction. Furthermore, there are the results, reported in Leslie (1984b, Experiment 1A) and discussed earlier, showing that reversal of direct launching produces more recovery than reversal of a constantly dynamic single movement. But most telling of all, the direct launching controls in the present Experiment 2 did not recover looking more than the delayed reaction controls: in other words, only direct launching *reversed* seems to be "preferred". We conclude from this that a structural explanation is required.

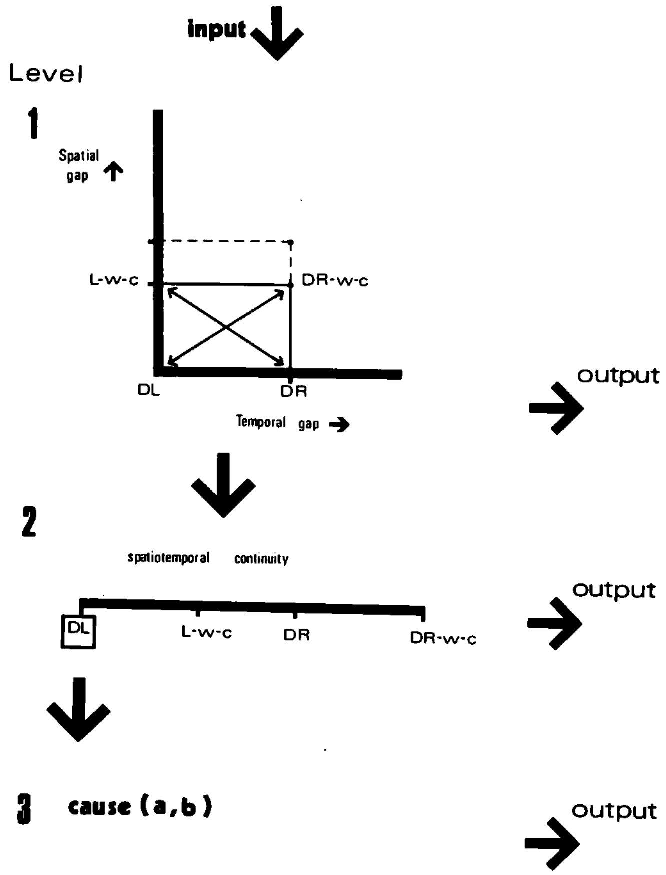
A working hypothesis

Six-month-old infants recover their interest more to a reversal of direct launching than to a reversal of either delayed reaction or a single continuous movement. This makes it seem likely that there is a causal percept factor at work. This factor increases the salience either of spatiotemporal direction or of the roles played by the objects in the event. We are not, at this stage, able to say what the crucial information for the causal factor in the event was, though the continuity relation is suggestive here. Further work is required to clarify these questions.

But on the prior and more basic question, Can infant visual processing parse an event as causal? we now have some positive evidence. We can therefore hypothesise a visual mechanism, already operating at 27 weeks, which is responsible for organising a causal percept. Such a mechanism would presumably take input from lower level processes of motion perception. For example, Restle (1979) has outlined a coding model for the perception of two dimensional motions. Representations of motion amplitudes, phases, wavelengths and so on, perhaps along the lines Restle proposes, could form the input to the slightly higher level mechanism whose existence we are postulating. The task of this mechanism will then be to produce higher level descriptions of the spatiotemporal properties of the event and, in the appropriate cases, to produce a description of its causal structure. Such outputs might subsequently be processed further by the visual system or passed to central cognitive processes.

Figure 5 illustrates a working hypothesis about the nature of this mechanism. The main feature of this model is that it computes multiple representations for the same event. Each level is more abstract than the one before and the higher level description is computed from the lower one. At the first level, the spatial and temporal relations between the submovements are computed and represented orthogonally. The reason for postulating this level is that it seems a reasonable first guess as to how the next level (for

Figure 5. *A working hypothesis concerning the structure of a possible input module concerned with analysis of launching type events and operating as part of visual motion processing in 6-month-old infants. Input is assumed to come from lower level processing of motion and output to be in the form of multiple encodings of the same event.*



which there is some evidence) might be computed. The existence of this first level might be tested, for example, by presenting infants, following familiarisation, with a *simultaneous* preference task using a launching-without-collision versus a delayed reaction that are equated for subjective continuity. Finding a preference under these conditions would argue for access to level one descriptions.

The second level provides a succinct spatiotemporal description of launching and its variants. This could be computed by summing the values of the parameters at level one. The second level also allows the selection of highly continuous events for redescription at the last level. Perhaps causal roles are described at this third level.

Infant perceptual mechanisms like this may provide a singularly important avenue for studying very early "primary" representational capacity (Leslie, in press).

Perceptual organisation and development

We argue for the following perspective on the development of causality. Instead of causality being entirely a result of the gradual development of thought (Piaget, 1955; Uẑgiris, 1984) or of prolonged experience (Hume, 1740), an important and perhaps crucial contribution is made by the operation of a fairly low level perceptual mechanism.

But is it credible that causal understanding should have its beginnings in a low level visual mechanism? We suggest it is. The same mechanism may be responsible in adults for the causal *illusion* of launching (Michotte, 1963). In this, observers view marks on a paper disc which is made to rotate behind a viewing slit. Adults will repeatedly report seeing a causal interaction between the marks despite knowing full well how the trick is generated. One can probably also make Michotte's point in connection with cartoon films where the observer can readily "see" causal interactions between "objects" despite knowing that only drawings are involved.

Like other perceptual illusions, such effects appear to be impervious to general knowledge and reasoning. The cognitive "impenetrability" of visual mechanisms has been explained by some as reflecting the modular organisation of visual processes (e.g., Fodor, 1984; Marr, 1982; Ramachandran, 1985; Ullman, 1985). A modular process, though it may be computationally very complex, nevertheless occurs in a fixed, automatic and mechanical way without being influenced by information or reasoning abilities that lie outside the module.

It may be, then, that the illusion of causality discovered by Michotte exists as a side effect of the modularity of the underlying mechanism. The modularity of the device would enable it to operate independently of general knowledge and reasoning. If so, this would be ideal for a mechanism whose job might be to *produce* development and which may thus have to operate early in infancy when there is a virtual absence of general knowledge and only limited reasoning ability. Indeed, this might be the *developmental* significance of modular organisation.

Perceptual input systems are required to feed central learning systems with descriptions of the environment. Such information will provide the initial data set for whatever central learning device there may be for a given domain. The input descriptions therefore must be immediately relevant to the inductive problems of that domain. If there was a "launching module", then it could provide information about the spatiotemporal and causal structure of appropriate events. And it could do this without having to know what a cause "really" is (Leslie, 1986). In short, perceptual modularity may be designed to get development started in the absence of prior relevant knowledge.

The mechanism described here may well contribute to the sophisticated mechanical understanding found in preschoolers by preselecting plausible hypotheses for cognitive processes. For example, it could play a role in analysing visible mechanisms, distinguishing causally connected events from those which are coincidental. It could contribute to the picking up of kinetic properties of events (Kaiser & Proffitt, 1984; Todd & Warren, 1982) and provide a perceptual basis for identifying causal chains. Finally, it may be the first processing device to introduce a cause-effect format for internally representing events.

If perception has its own distinctive organisation, then it probably also has its own distinctive role in development. This makes it vitally important to have a detailed account of the initial descriptions of a domain which are produced by perception and inherited by thought.

References

Baillargeon, R., Spelke, E.S., & Wasserman, S. (1985). Object permanence in five-month-old infants. *Cognition, 20*, 191–208.

Beasley, N.A. (1968). The extent of individual differences in the perception of causality. *Canadian Journal of Psychology, 22*, 399–407.

Bomba, P.C. (1984). The development of orientation categories between 2 and 4 months of age. *Journal of Experimental Child Psychology, 37*, 609–636.

Bomba, P.C., & Siqueland, E.R. (1983). The nature and structure of infant form categories. *Journal of Experimental Child Psychology, 35*, 294–328.

Bullock, M. (1985). Causal reasoning and developmental change over the preschool years. *Human Development, 28*, 169–191.

Bullock, M., Gelman, R., & Baillargeon, R. (1982). The development of causal reasoning. In W. Friedman (Ed.), *The developmental psychology of time*, 209–254. New York: Academic Press.

Cohen, L.B. & Gelber, E.R. (1975). Infant visual memory. In L.B. Cohen & P. Salapatek (Eds.), *Infant perception: From sensation to cognition*, 347–403. New York: Academic Press.

Cohen, L.B. & Strauss, M.S. (1979). Concept acquisition in the human infant. *Child Development, 50*, 419–424.

Fodor, J.A. (1983). *The modularity of mind.* Cambridge, Mass.: MIT Press.

Gemelli, A., & Cappellini, A. (1958). The influence of the subject's attitude in perception. *Acta Psychologica, 14*, 12–23.

Gibson, E.J. (1984). Reflections on awareness of causality: What develops? In L.P. Lipsit & C. Rovee-Collier (Eds.), *Advances in infancy research*, 136–144. Norwoord, NJ: Ablex.

Gibson, E.J., & Spelke, E. (1983). Event perception. In J.H. Flavell & E.M. Markman (Eds.), Vol. 3, *Handbook of child psychology*, P.H. Mussen (Ed.). New York: John Wiley & Son.

Hume, D. (1740/1978). *A treatise of human nature.* London: Clarendon.

Kaiser, M.K., & Proffitt, D.R. (1984). The development of sensitivity to causally relevant dynamic information. *Child Development, 55*, 1614–1624.

Kant, I. (1781/1929). *Critique of pure reason.* London: Macmillan.

Kun, A. (1978). Evidence for preschoolers' understanding of causal direction in extended causal sequences. *Child Development, 49*, 218–222.

Leslie, A.M. (1982). The perception of causality in infants. *Perception, 11*, 173–186.

Leslie, A.M. (1984a). Infant perception of a manual pick-up event. *British Journal of Developmental Psychology, 2*, 19–32.

Leslie, A.M. (1984b). Spatiotemporal continuity and the perception of causality in infants. *Perception, 13*, 287–305.

Leslie, A.M. (1984c). The infant's encoding of simple causal events. Paper presented at 4th Biennial International Conference on Infant Studies, New York, NY, April, 1984.

Leslie, A.M. (1986). Getting development off the ground: Modularity and the infant's perception of causality. In P. van Geert, (Ed.), *Theory building in development*, 405–437. Amsterdam: Elsevier North-Holland.

Leslie, A.M. (in press). Pretense and representation: The origins of "theory of mind". *Psychological Review*.

Marr, D. (1982). *Vision.* San Francisco: Freeman.

Michotte, A. (1963). *The perception of causality.* Andover: Methuen.

Piaget, J. (1955). *The child's construction of reality.* London: Routledge and Kegan Paul.

Powesland, P.F. (1959). The effect of practice upon the perception of causality. *Canadian Journal of Psychology, 13*, 155–168.

Ramachandran, V.S. (1985). The neurobiology of perception. *Perception, 14*, 97–103.

Restle, F. (1979). Coding theory of the perception of motion configurations. *Psychological Review, 86*, 1–24.

Reznick, J.S., & Kagan, J. (1983). Category detection in infancy. In L.P. Lipsitt & C.K. Rovee-Collier (Eds.), *Advances in infancy research*, Vol. 2, 79–111. Norwood, NJ: Ablex.

Rock, I. (1983). *The logic of perception.* Cambridge, Mass.: MIT Press.

Rose, S.A., Gottfried, A.W., Melloy-Carminar, P., & Bridger, W.H. (1982). Familiarity and novelty preferences in infant recognition memory: Implications for information processing. *Developmental Psychology, 18*, 704–713.

Shultz, T. (1982). Rules of causal attribution. *Monographs of the Society for Research in Child Development, 47*, No. 1.

Todd, J.T., & Warren, W.H. (1982). Visual perception of relative mass in dynamic events. *Perception, 11*, 325–335.

Ullman, S. (1985). Visual routines. *Cognition, 18*, 97–159.

Užgiris, I.C. (1984). Development in causal understanding. In L.P. Lipsit & C. Rovee-Collier (Eds.), *Advances in infancy research*, Vol. 3, 130–135. Norwood, NJ: Ablex.

Wagner, S.H., & Murphy, W.D. (1986). Schema decay: from R-F-R-N to N-R-F-R. Paper presented to 5th Biennial International Conference on Infant Studies, Los Angeles, CA, April 1986.
Watson, J.S. (1984). Bases of causal inference in infancy: Time, space, and sensory relations. In L.P. Lipsit & C. Rovee-Collier (Eds.), *Advances in Infancy Research*, Vol. 3, 152–160. Norwood, NJ: Ablex.

Résumé

On admet souvent que les idées de cause et d'effet résultent d'un apprentissage prolongé. Les résultats présentés dans cet article suggèrent qu'un bébé de 27 semaines est déjà capable de percevoir des relations de cause à effet. Le renversement d'un événément d'apparence causale (lancement direct) a produit une plus grande récupération d'attention après habituation que le renversement d'un événément semblable mais d'apparence non-causale (réaction retardée). Dans les deux cas, les *changements* des propriétés spatio-temporelles des stimuli étaient identiques. La perception par le bébé du lancement direct n'implique donc pas qu'un simple codage de ses propriétés spatio-temporelles. Puisque ce même stimulus donne lieu à une illusion de causalité chez les adultes, il se peut que le facteur additionnel en jeu soit la perception d'une relation causale.