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## Spatiotemporal continuity and the perception of causality in infants

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**Abstract.** Infant perception of a Michottean launching event in which one object causes another to move through collision is examined in a series of habituation-test experiments. A number of hypotheses concerning how infants aged around 30 weeks might perceive and encode launching and its noncausal variants are identified and tested. The results of the first experiment indicate that infants can perceive direct launching as an event with *internal structure*, that is, as composed of two temporally ordered movements. The nature of the encoding by the infants is *perceptual* and not specifically motor-based. The second experiment makes it seem unlikely that the infants encode independent spatial and temporal features (for example, contact and successivity), while the third experiment suggests a *spatiotemporal continuity gradient*. Some implications for the origins of causality are discussed.

### 1 Introduction

The sort of event typified by a billiard ball launching another through collision has seemed to many to be an exceptionally clear example of the operation of cause and effect. Psychologists especially have been interested in how launching is perceived and how it comes to be seen as causal (Olum 1956; Michotte 1963; Ball 1973; Lesser 1977; Borton 1979; Leslie 1982a, 1982b). Michotte argued that adult observers were subject to a *causal illusion* and would report causal interactions with respect to launching stimuli constructed from marks on paper. Since this illusion did not appear to diminish either with repeated exposure or knowledge of what was actually happening, Michotte proposed that the perception of causality must, in some cases, be *direct and immediate*, without the assistance of prior experience or language. For these same reasons, Michotte believed that the causal percept would emerge very early in life—probably in infancy.

Michotte's views stand in contrast to other traditional positions on the origins of causality. Hume (1740/1978) argued that a belief in causality arises through prolonged experience of events that are regularly conjoined. Piaget (1955) proposed that causality originally develops through the *active* experience of producing effects *oneself*. He claimed that the infant's first efforts at this take scant account of spatial relations, but with the coordination of sensory-motor schemes the infant's activities gradually become spatialised. It is not until the later stages of infancy, however, that awareness of the spatial properties of causal connection is progressively extended to events outside the sphere of the child's own activity. Contemporaneously infants begin to recognise sources of causal power independent of themselves.

Neither Piaget nor Hume, therefore, would predict a Michottean percept in early infancy. In Piagetian terms, one object launching another would necessarily be an 'objective' event, that is, one occurring independently of the infant's own activity. Furthermore, direct launching has a particular spatiotemporal relation between its two constitutive movements which distinguishes it from its noncausal variants such as 'delayed reaction' and 'launching without collision' (Leslie 1982b). Since this relation is itself 'objective', young infants should take no account of it. Conversely, if young

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infants did possess something like a Michottean percept it would imply substantial competence in understanding objective events and relations. At the same time, it would diminish the burden that active experience may otherwise have to bear in producing this development.

There have been remarkably few attempts to study this question directly with infants. Ball (1973) found that a group of children, with ages ranging from 9 to 112 weeks, dishabituated more to launching-without-collision than to direct launching, after habituation to sequences in which a screen obscured the impact zone. Borton (1979) found that launching-without-collision produced more greatly disrupted visual tracking in three-month-olds than either direct launching or the continuous movement of a single object.

Both these studies suggest a sensitivity to continuity of motion in infancy. They fail, however, to disambiguate the possibility that infants see direct launching as continuous because they perceive only *one* movement. A minimum requirement for a Michottean percept is that direct launching is perceived as being composed of *two* distinct movements. Furthermore, the possibility of perceiving a causal (or any other kind) of relation arises only if two submovements can be recognised.

Slightly stronger evidence that infants may perceive direct launching in something like this way comes from Leslie (1982b). Here two age levels of infants—around 4½ and 7½ months—were habituated to filmed events. One group in each age level saw direct launching while another saw a delayed reaction sequence where a half-second delay interposed between impact of the first object and the moving off of the second. Both groups were then subdivided and tested on one or either of two test films. The first test film showed the first object impact on the second without any result (no reaction). The second test film showed the second object move off without any antecedent movement of the first object (no prior movement). In both test films there was but a single movement.

Since both test films showed a single movement noncontinuous with any other, it was hypothesised that if infants saw the direct-launching sequence as (two) continuous movements and delayed reaction as (two) discontinuous movements, then the test films ought to appear less familiar to the direct-launching group and more familiar to the delayed-reaction group.

On the other hand, if direct launching, because of its continuity of motion, was seen as a single movement, then both (single movement) test films should appear more similar to it than to delayed reaction with its two distinct movement phases created by the temporal delay. The results in fact showed greater dishabituation of looking in both age levels in the case of the direct-launching group suggesting that the test films appeared less familiar following this than following the delayed-reaction film. This in turn could be taken as supporting the view that the infants had seen direct launching as two segregated but continuous movements.

It is still possible, however, that the basis for the infant's dishabituation was the different starting and stopping places of the movements shown in the test films compared with the direct-launching sequence. If this were so it could still be the case that infants perceive direct launching as consisting of a single movement. Indeed, it might even be the case that the infant's sensitivity to continuity of motion in *all* of these studies was based upon the form of eye movements used to track the stimuli. Thus the infant might register whether the stimulus requires smooth tracking or whether it requires interruption, and so on. Thus a fundamental question concerning infant perception of direct launching has still to be answered: can the infant parse two component movements out of the overall continuous movement envelope?

Until the infant can do this his perception of such events can hardly be causal in any sense. Indeed, failure to parse two submovements would indicate that the observational powers of the infant are severely limited, perhaps in the way that Piaget suggested. On the other hand, if the infant can parse for submovements, then the further question would arise: what sort of relationship between the components does the infant register?

As we have seen, previous studies have failed to point clearly in either direction on the first question. One way to formulate this is to ask if infants will detect any *internal structure* in a direct-launching sequence. If they do—if they see direct launching as composed of two successive movements—then it is reasonable to expect that they see the movements as temporally ordered. In an event in which there actually is a single entity moving, there can be no such temporal ordering. Reversing the time course of the single-entity event will merely reverse the *spatial direction* of movement. Reversing the time course of the direct launching will similarly reverse spatial direction but in addition it will also reverse the *temporal order* of the two movements. This simple fact is exploited in the first experiment to be reported here.

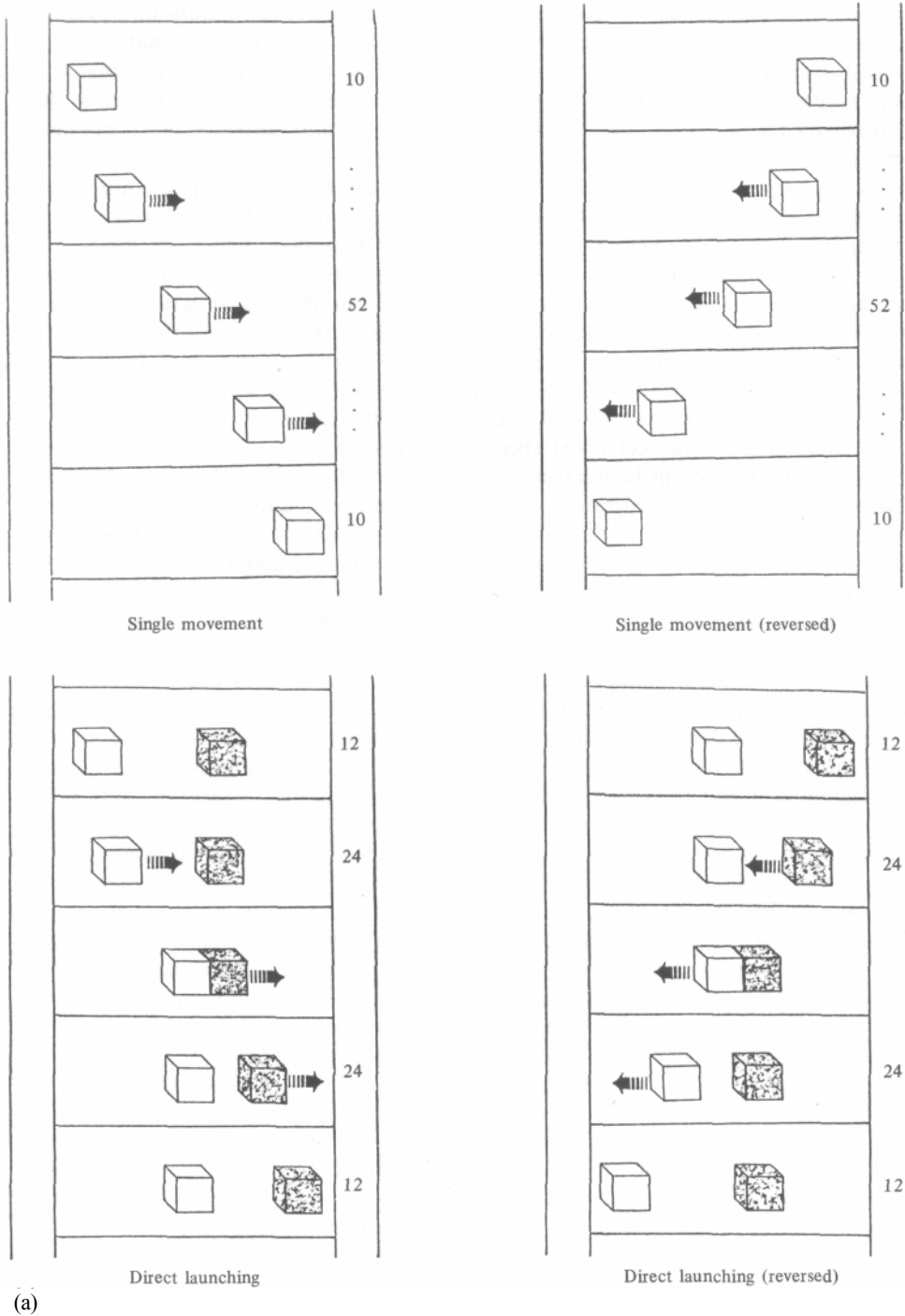
The experiment uses an habituation-dishabituation technique. Infants are habituated to a film of a red brick colliding with and launching a green brick. The bricks always move left to right. They are then tested on the same film which is simply run backwards through the projector. This time the green brick collides with and launches the red. The dishabituation this produces is compared with another group of infants who are habituated to a film of a red brick which moves continuously across the screen at the same rate as the direct-launching bricks. (The starting and stopping place of this movement is the same as the starting and stopping place of the overall movement in direct launching.) These infants are then tested for dishabituation on this film run backwards through the projector. Both groups see a reversal of spatial direction of the movement, but only the direct-launching group see a reversal in the temporal order of two movements. It was hypothesised, therefore, that this group would dishabituate more than the single-movement group.

It is still possible, however, that greater recovery to direct launching reversed could be due to the different colours of the objects used. That is, direct launching could be encoded as a single movement where the moving entity changes colour from red to green halfway across. If this were the case, the infants would not discriminate a single moving entity that changes colour from red to green halfway across from a direct-launching sequence. If, on the other hand, infants see direct launching as involving two entities, this discrimination ought to be made fairly easily.

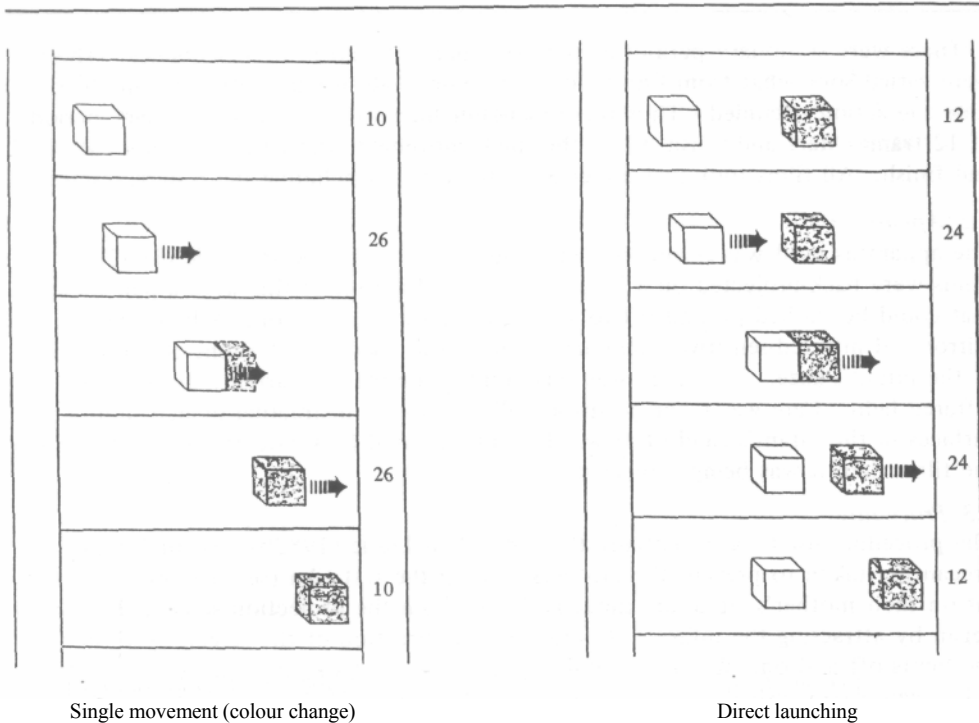
The following experiment, therefore, has a second part to it. Here, one group of infants is habituated to a film in which a red brick moves across the screen and changes colour to green halfway across. These infants are then tested on a normal direct-launching sequence. The recovery shown by this group is then compared to that of a control group who are habituated to direct launching and then tested on the same sequence. It was hypothesised that the experimental group would show higher recovery than the control: that is, that they would clearly discriminate a single movement-with-colour-change from a direct-launching sequence.

## 2 Experiment 1

There were two parts to this experiment. In part A, infant recovery of looking to *reversed* events following habituation was tested. In part B, infants' ability to discriminate a direct-launching sequence from an analogous film of single movement-with-colour-change was tested.



**Figure 1.** Illustration of films used in experiment 1. Number of frames in each phase are shown on right-hand side of each strip. Clear cube, red brick; shaded cube, green brick. Films projected at 24 frames per second, (a) The central frame in the direct-launching sequence depicts the 24th red movement frame, (b) The central frame in the single-movement (colour change) sequence depicts the change of colour occurring on the 37th frame.



(b) **Figure 1**  
(continued).

### 2.1 Stimuli

The films were shot with a Bolex 16 mm camera on high-speed Ektachrome 7250 Video News Film. An animation technique was employed based on a projection rate of 24 frames per second. The objects were two toy building bricks, one bright red, the other green. They moved along a strip of graph paper spread on a wooden table top. The film of each sequence was formed into a loop for continuous projection. A six-frame strip of unexposed (dark) film was spliced into the join.

Approximate projected dimensions were as follows: total picture displayed, 32 cm x 42 cm; bricks, 2.5 cm x 3.0 cm (front surface) with rear top edge 0.5 cm above front top edge owing to perspective. Bricks travelled at a rate of approximately 17 cm in 24 frames (one second). Unlike the study reported in Leslie (1982b), the green brick in the direct-launching sequence moved at the same rate and for the same distance as the red. In all films the red brick started at the right edge of the picture (infant's view). In the direct-launching film the green brick started at the centre. The red brick moved for 24 frames, at the end of which it had collided with the stationary green brick. In the next frame the green brick started to move at the same rate as red had been moving, while the red brick now remained stationary. The green brick also moved for 24 frames.

The single-movement (red only) film was made in the same way except that there was no green brick and the red brick moved all the way across to the other side of the screen. The red brick thus moved approximately 37 cm in 52 frames (the additional 4 frames coming from the time required to traverse the area occupied by the green brick in direct-launching) (see figure 1a).

The single-movement (colour change) film had the same specifications as the single-movement (red only) film except that the red brick changed to a green brick after 26 frames of movement (see figure 1b).

There were stationary periods at the beginning and end of each sequence. These were varied somewhat from film to film to compensate for the different lengths of time the action occupied. Thus the direct-launching sequence had stationary periods of 12 frames start and finish, while the single-movement films had 10 frames start and finish. All films took just under 3.5 s to recycle (including the 6 dark frames).

### 2.2 Apparatus

The apparatus used was essentially the same as that described in Leslie (1982b). Films were back-projected on a Polacoat screen. In front of this were a pair of lights that could be flashed on and off to attract the infant's attention. A half-silvered mirror and infrared-sensitive video arrangement was used to determine the direction of the infant's gaze. The room was very dimly illuminated, partially by invisible infrared light. Care was taken to shroud all potentially distracting objects and surfaces in the infant's field of view. The infant could look into the apparatus to see the film when it was being projected.

### 2.3 Procedure

The procedure used was essentially the same as in Leslie (1982b), except for the precaution taken to prevent the mothers viewing the test film (see below). Infants sat on their mother's lap approximately 1.2 m from the projection screen. Each trial began by attracting the infant's attention in the direction of the screen by flashing the lights off and on. When the infant appeared to be looking in this direction the lights were extinguished and projection of the film began. As soon as the infant appeared to look in the direction of the film a timer was started. As soon as the infant appeared to look away timing and projection were stopped. The length of look was recorded to the nearest 0.5 s. This constituted one trial. The next trial was begun within a few seconds by again flashing the lights.

After three trials the mean looking time was calculated. The experiment then proceeded in the same way until the infant produced three consecutive trials in which the length of looking on each trial was less than the initial mean. Having satisfied this criterion the habituation phase was terminated. Each infant thus had a minimum of six trials. A maximum of eighteen trials was allowed. If the infant had not satisfied the habituation criterion by the eighteenth trial (s)he was rejected.

At the end of the habituation phase an interval of approximately 45 s ensued during which the projector was switched into reverse (part A) or the films changed (part B). For the control group in part B a physically different film was shown in the test trial though both depicted direct launching. This helps to control for accidental differences between films (scratches, for example). After the interval, a test trial was administered using the same procedure. Just before this mothers were requested to close their eyes. After presentation of the test stimulus mothers were told they could open them again.

All sessions were video recorded and in-session scoring checked later. In addition to this a random selection of one third of sessions was checked by an independent judge blind as to which film was being used. Agreement for timing on trials was high: for 92% of trials there was complete agreement. For the remainder the timing was within the rounding error.

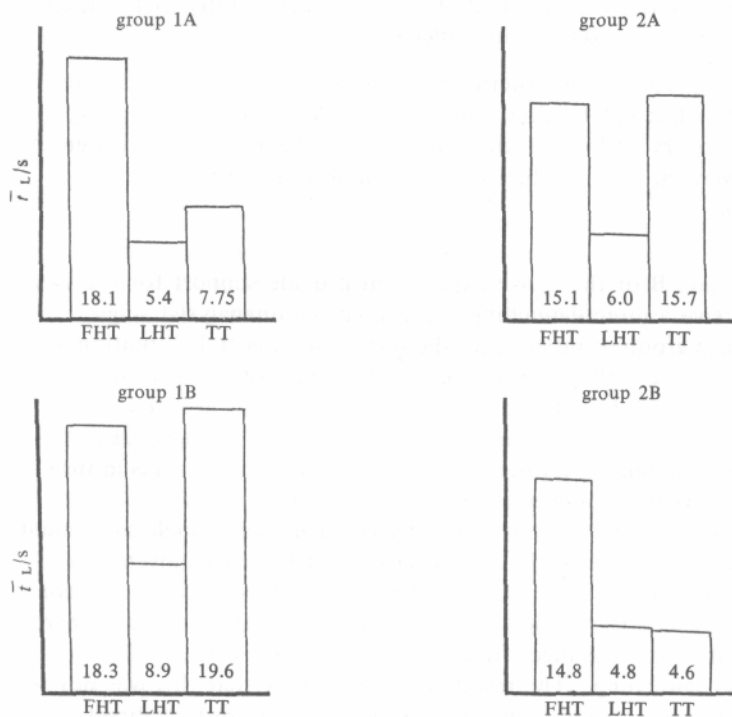
### 2.4 Subjects

In part A, there were sixteen subjects, eight per group with an even balance of males and females. Ages ranged from 24 to 32 weeks [mean age 28.75 weeks, standard deviation (SD) 2.7 weeks]. To reach  $N = 16$ , twenty-one infants were seen. Of the five rejections, three were rejected for persistent fussing, one for being inattentive from the start, and one failed to reach criterion within eighteen trials.

In part B, there were sixteen fresh subjects, eight per group with an even balance of males and females. Ages ranged from 24 to 32 weeks (mean age 28.25 weeks, SD 2.7 weeks). To reach  $N = 16$ , twenty infants were seen. Of the four rejections, three were rejected for persistent fussing and one for being inattentive from the start.

### 2.5 Results

Figure 2 shows the mean looking times on the first and last habituation trials and test trial by groups for parts A and B.



**Figure 2.** Experiment 1: mean looking time,  $t_L$ , by groups on first habituation trial (FHT), last habituation trial (LHT) and test trial (TT). Group 1A viewed the film pair single movement (red only) and reverse, group 2A the pair direct launching and reverse; group 1B viewed the pair single movement (colour change) and direct launching; Group 2B acted as controls viewing direct launching in both habituation and test.

**2.5.1 Part A.** Habituation was assessed by an analysis of variance on first versus last habituation trials with factors groups (2) x trials (2). The results of this analysis show a significant main effect of trials ( $F_{1, 14} = 6.4114$ ,  $p = 0.024$ ). No other main effects or interactions approached significance. Looking times thus declined significantly from first to last habituation trials and this decline was uniform across groups.

Recovery of looking was compared between groups by means of an a priori independent  $t$  test on both test trial looking and recovery scores (calculated as the difference test trial time - last habituation trial time). As predicted, the direct-launching group (2A) looked significantly longer on the test trial than the single-movement (red only) group (1A) ( $t_{14} = 2.4$ ,  $p = 0.015$ , one-tailed) and had higher recovery scores ( $t_{14} = 2.15$ ,  $p = 0.025$ , one-tailed).

**2.5.2 Part B.** Habituation was again assessed by an analysis of variance on first versus last habituation trials. The results showed a significant main effect of trials

( $F_{1, 14} = 7.399, p = 0.017$ ). Groups was not significant either as a main effect or in interaction. Again, groups did not differ on first or last habituation trials but showed a uniform decline in looking time. The somewhat elevated last habituation trial looking time of the single-movement (colour change) group (1B) was caused by a single subject: the mean excluding this subject was 6.36 s.

Comparing recovery of looking in a planned comparison showed the single-movement (colour change) group (1B) to have looked longer at direct launching on the test trial than did the control (group 2B) ( $t_{14} = 2.36, p = 0.017$ , one-tailed). Likewise, recovery scores for the experimental group were significantly higher than for the controls ( $t_{14} = 1.868, p = 0.041$ , one-tailed).

**2.5.3 Summary.** In both parts of this experiment there was no significant difference between groups on first or last habituation trials. In part A, the direct-launching group showed greater recovery of looking than the single-movement (red only) group. In part B the single-movement (colour change) group showed greater recovery of looking than the control.

## 2.6 Discussion

Taken together, parts A and B of the above experiment provide support for the view that infants do not perceive a direct-launching sequence as an unanalysed single movement. In part A, each group of infants sees the same film in both habituation and test phases; the only difference is that on the test trial the film is run backwards. The results show that the infants dishabituated less to the reversal of a single-entity movement than to the reversal of a direct-launching sequence. This strongly suggests that for direct launching some temporal order information was encoded. This in turn implies that (at least) two ordered components were distinguished.

The infants might, however, have simply identified two parts of a single movement according to colour (red then green) without registering that the part movements were associated with or belonged to different entities. But if direct launching were encoded purely and simply as a single movement with two differently coloured parts, then the single-movement (colour change) film ought not to have been readily discriminable from direct launching. The results of part B show that this was not the case. The only remaining and somewhat implausible possibilities are that direct launching is encoded as a single-movement (colour change) sequence plus either a couple of stationary entities mid-screen (one green, then one red) or one mid-screen entity that changes colour. If this had been the case one might have expected the direct-launching film to have been considerably more complex than the single-movement (colour change) sequence and thus take longer to encode during habituation (Caron and Caron 1969; Cohen and Gelber 1975). In fact, though the difference was not significant, the single-movement (colour change) film attracted longer total looking during habituation (116.25 s) than direct launching (90.81 s).

In future work it would, of course, be possible to do a reversal test using a direct-launching sequence involving two identically coloured bricks thus avoiding these problems. It remains to be seen whether this would give the infants added difficulty in remembering which object did what, aside from the question at issue.

It now seems reasonable, however, to propose that infants of around 7 months encode direct launching as a sequence of two temporally ordered moving entities and not as a single unanalysed movement. One version of the single-movement hypothesis claims that in habituation to direct launching the infant encodes the form of eye movement required to track the moving entity. This is a position that might follow, for example, from the Piagetian theory of the sensori-motor nature of infant intelligence and, in particular, from the notion of 'subjective groups'. Thus an 'enactive encoding' (Bruner 1966) of direct launching might specify an uninterrupted



smooth tracking. From the results of the present experiments, however, it is not at all clear what difference there might be between the eye movements required to track either of the single-movement stimuli and the eye movements required to track direct launching. Indeed, in a study specifically on visual tracking of such sequences Borton (1979) was unable to find any such difference between a single movement and a direct launching. It seems extremely unlikely, then, that the dishabituation patterns found here have a specifically motor basis.

Another version of the single-movement hypothesis would reject the motor character of the encoding and assert instead a true perceptual process. However, this process fails to parse a double movement in direct launching. The present experiments confirm the perceptual nature of the encoding but support instead a process of parsing for component parts.

The question can now be raised as to what sort of relationship between the components the infant perceives. Leslie (1982a) proposed two different hypotheses concerning this relationship. The first was Michottean in character: that the infant encodes direct launching as causal, while variants such as 'delayed reaction' would be represented as noncausal. The second hypothesis was that the infant represents direct launching and its variants in terms of two independent features, one temporal and the other spatial. The temporal feature would be something like [ $\pm$ successive], depending upon whether the two movements took place successively or with an interval between them. The spatial feature would be something like [ $\pm$ contact], depending upon whether or not one object made contact with the other.

Either of these hypotheses can account for Leslie's (1982b) results. One a priori advantage which the two-feature hypothesis has over the causal hypothesis is that it specifies how the variants of direct launching would be encoded. For example, delayed reaction would be [ $-$ successive,  $+$  contact] whereas launching without collision would be [ $+$  successive,  $-$ contact]. It is not entirely clear on the causal hypothesis how these would be encoded except to say that both would be noncausal. It is difficult to extract clear guidance on this from Michotte's theory. However, one can imagine a 'gradient' version of this hypothesis that formulates [causal] as a continuum with degrees of causal connection rather than as a binary feature (cf Michotte 1963, p 95). Similarly the two-feature theory could be reformulated as orthogonal dimensions. For ease of exposition at this stage both hypotheses will be discussed in binary form.

It has been suggested that choosing between these hypotheses "may be a decision without empirical content" (de Gelder 1982, p 10). This is clearly not the case. Consider the contrast between direct launching and delayed reaction without collision. Under the two-feature hypothesis these would be represented as [ $+$  successive,  $+$ contact] and [ $-$ successive,  $-$ contact] respectively. There should therefore be precisely as much contrast between these two sequences as between delayed reaction and launching without collision (that is, between [ $-$ successive,  $+$ contact] and [ $+$  successive,  $-$ contact]). In both contrasts, both features change. Under the causal hypothesis, however, the first contrast involving direct launching entails the difference between a causal and a noncausal sequence. This hypothesis therefore predicts a greater contrast in this pair than in the other pair where both sequences are noncausal.

The next experiment to be reported seeks to test this prediction of the causal hypothesis. The same habituation-test technique is used. One group of infants is presented with a direct-launching/delayed-reaction-without-collision pair of films, while a second group sees a delayed-reaction/launching-without-collision pair. It is predicted that, having been habituated to one member of the pair and tested on the other, that group which has received the direct-launching pair will recover its looking time more on the test trial than the other group. The two-feature hypothesis predicts no difference.

### 3 Experiment 2

The experiment was intended to test the viability of the two-feature versus the causal hypotheses of infant perception of direct-launching events.

#### 3.1 Stimuli

Four new films were prepared in the same manner as in experiment 1. Projected dimensions and rate of movement of the bricks was also the same. In the direct-launching film there was a one-frame delay (approximately 40 ms) between impact and reaction. In the delayed-reaction film there was a 12-frame delay (approximately 500 ms) between impact and reaction. In the launching-without-collision film the red brick moved approximately 11 cm in 16-frames, stopping approximately 6 cm short of the green brick with a one-frame delay before reaction. In delayed-reaction-without-collision there was a 12-frame delay between the red brick stopping 6 cm short of the green brick and reaction of the green brick. These films are illustrated in figure 3.

Again there were stationary periods at the beginning and end of each sequence. These varied somewhat from film to film to compensate for the different periods of action: direct launching, 12 frames; delayed reaction, 8 frames; launching without collision, 15 frames; delayed reaction without collision, 10 frames. Again, 6 dark frames between start and finish were spliced into each film which was then formed into a loop for continuous projection.

#### 3.2 Design and procedure

Within each group the order of presentation of the films with respect to the habituation and test was counterbalanced. Table 1 summarises the design.

The procedure and apparatus were exactly the same as in experiment 1. In-session scoring was again checked later from video tape. In addition, a randomly selected one-third of all sessions was scored by an independent judge blind as to which film pair was being presented. Agreement on timing for individual trials was high (93% of trials); on the remaining trials disagreement was within the rounding error.

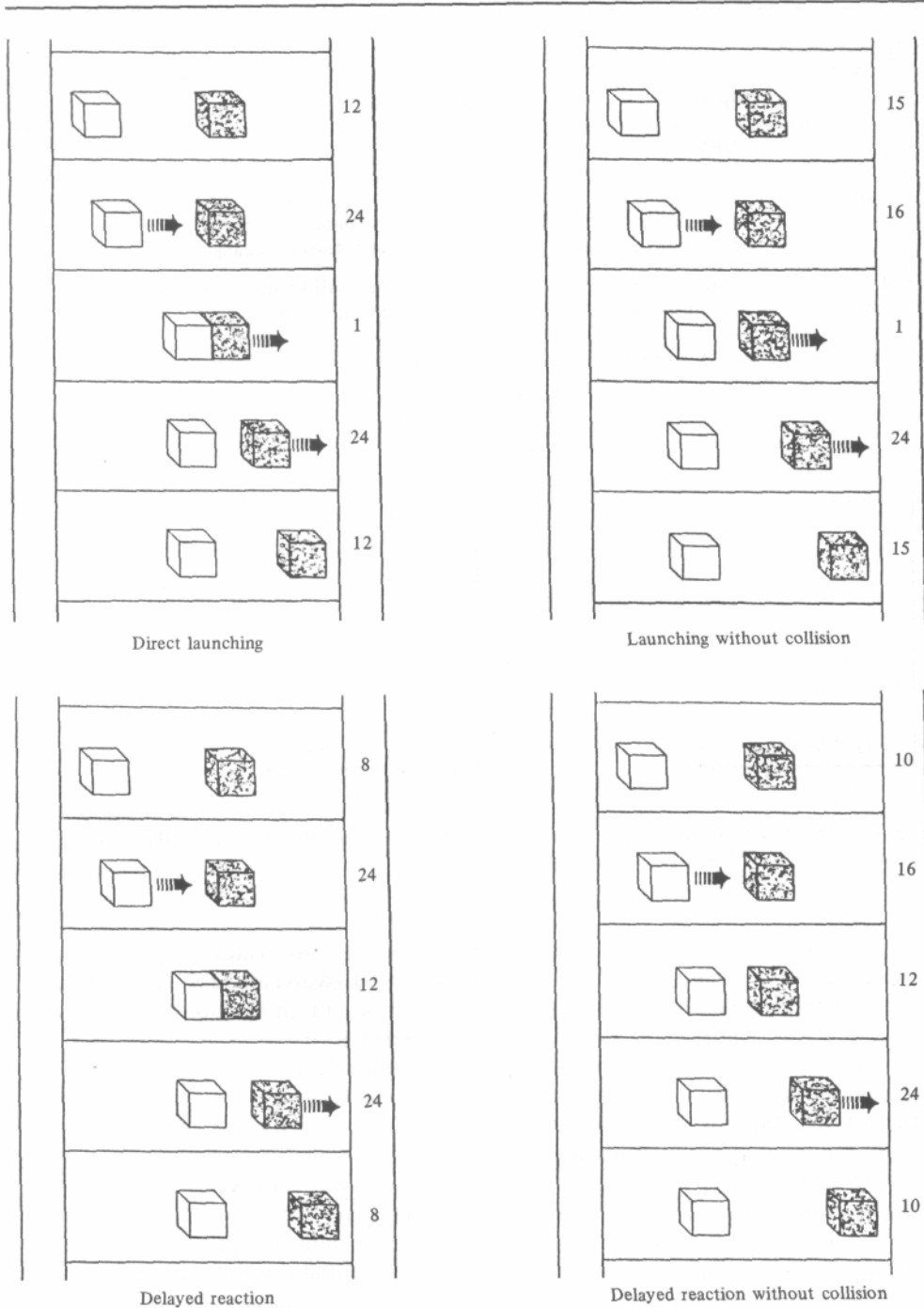
#### 3.3 Subjects

There were twenty-five infants, thirteen females and twelve males, between 26 and 34 weeks of age (mean age 30.7 weeks, SD 2.8 weeks). Group 1 consisted of fourteen subjects (eight females), and group 2 of eleven subjects (five females). To reach  $N = 25$ , thirty-three infants were seen. Of the eight rejections, four were rejected for persistent fussing, one failed to reach the habituation criterion within eighteen trials, one fell asleep, one was rejected through mechanical breakdown of the apparatus, and one was inattentive from the start.

#### 3.4 Results

Mean looking times on first habituation, last habituation, and test trials are shown in figure 4. Analysis of variance [groups (2) x trials (2)] was used to assess looking times on first versus last habituation trials across groups. The results show a significant decline from first to last trials [trials main effect: ( $F_{1, 23} = 16.67, p = 0.0005$ )]. There was no effect for groups and no interaction ( $F < 1.0$ ). Groups 1 and 2, therefore, did not differ on first-trial or last-trial looking times.

The experimental hypothesis was tested in a planned comparison using an independent  $t$  test on test-trial looking times and on recovery scores (see section 2.5.1). Test-trial scores for group 1 were found to be significantly higher than those for group 2 ( $t_{23} = 1.89, p = 0.036$ , one-tailed). Recovery scores for group 1 were also significantly higher than for group 2 ( $t_{23} = 2.66, p = 0.007$ , one-tailed).

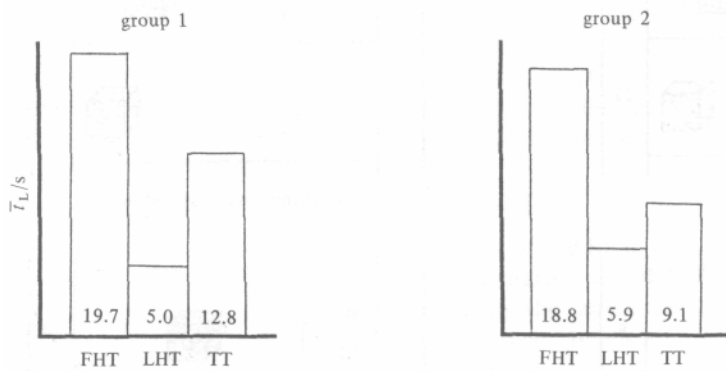


**Figure 3.** Illustration of films used in experiments 2 and 3. Number of frames in each phase are shown on right-hand side of each strip. Variations in stationary periods are to compensate partially for different lengths of action. The central frames here depict the periods of delay in the various films between end of red movement and beginning of green movement. Clear cube, red brick; shaded cube, green brick. Films projected at 24 frames per second.

**Table 1.** Experiment 2: design.

	Group 1	Group 2
Film pairs	DL/DRWC <sup>a</sup>	DR/LWC <sup>a</sup>
Two-feature hypothesis	[+ successive + contact ] <i>versus</i> [−successive −contact] (both features change)	[−successive +contact] <i>versus</i> [+ successive −contact] (both features change)
Causal hypothesis	[+ causal] <i>versus</i> [−causal] (causal contrast)	[−causal] <i>versus</i> [−causal] (no causal contrast)

<sup>a</sup>DL, direct launching; DR, delayed reaction; DRWC, delayed reaction without collision; LWC, launching without collision.



**Figure 4.** Experiment 2: mean looking time by groups on first habituation trial (FHT), last habituation trial (LHT) and test trial (TT). See table 1 for design.

### 3.5 Discussion

The results of this experiment clearly do not support the two-feature hypothesis. The pair of films involving a 'causal' contrast produced greater dishabituation than the pair of films which did not involve such a contrast. From the point of view of the two-feature hypothesis this difference should not have been found, since both pairs contrasted the same temporal and spatial relations between the movements. Thus, despite it being a plausible and useful way to describe the stimuli, the infants in the present study do not appear to have encoded successivity and contact as separate temporal and spatial features.

The same arguments apply to the two-feature hypothesis formulated in terms of orthogonal dimensions. Such a two-dimensional similarity space—with each of the four films located at different corners of a rectangle—would require equality of diagonals. This would be true even if the size of the spatial gap did not equal the size of the temporal gap: that is, even if the spatial value is not located as far up the *x* axis as the temporal value is along the *y* axis. Thus, the results suggest that infants around 7 months of age *do not* analyse direct launching and its variants into *independent* spatial and temporal relations between the submovements.

It has already been noted that the causal hypothesis derived from Michotte (1963) does not address the question of how the variants of direct launching might be encoded. One possibility is that they are all lumped into one category of noncausal. This might imply that infants will be less able to discriminate between the members of this class than between a given noncausal variant and the causal direct launching.

Another possibility is that discriminations can be made continuously within and across the noncausal class. Thus, instead of a binary [ $\pm$ causal] feature, there exists a graded dimension of causality ranging from the maximally causal direct launching to the minimally causal delayed reaction without collision. Delayed reaction and launching without collision would, in this model, be situated somewhere between these two extremes.

The next experiment examines the question of the discriminability of the noncausal variants. For example, one can habituate a group of infants to delayed reaction without collision. They can then be tested on delayed reaction. If the films are discriminable the infants ought to increase their looking time on the test trial. In a control group, which is tested on as well as habituated to delayed reaction without collision, looking time should stay around the same level.

This can be done for each of the film pair comparisons possible (in addition to the two already run in experiment 2). The 'graded dimension' version of the causal hypotheses would predict that in each of the four comparisons infants would show increased looking time on the test trial (while control groups should stay at around the same level or decrease). The 'binary feature' version, on the other hand, would predict that the two comparisons involving direct launching should exceed in recovery the two equivalent comparisons involving delayed reaction without collision. Thus, a group viewing the pair direct launching/delayed reaction should recover more than the group viewing delayed reaction without collision/launching without collision. This would be so in spite of the fact that in both cases only the temporal relation between the movements is changed. Similarly there should be more recovery in the direct-launching/launching-without-collision group than in the delayed-reaction-without-collision/delayed-reaction group (despite only the spatial relation changing). In other words, the binary feature version predicts greater recovery in film pairs where there is a causal/noncausal contrast than in pairs where both films are noncausal. The graded dimension version does not predict differences between the experimental groups.

#### 4 Experiment 3

The previous experiment appeared to rule out the two-feature hypothesis which asserted independent temporal and spatial features (or dimensions) in the encoding of direct launching and its variants by infants. The present experiment moves on to testing between two versions of the causal hypothesis: a binary causal feature assigning direct launching and its noncausal variants to different classes; or a unidimensional similarity space reflecting degree of causal connection. The design is illustrated in table 2. The order of presentation of films was counterbalanced within groups. Twin film versions were used in groups 5 and 6.

**Table 2.** Experiment 3: design.

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Film pair <sup>a</sup>	DL/DR	DL/LWC	DRWC/LWC	DRWC/DR	DL/DL <sup>b</sup>	DRWC/DRWC
Causal relation <sup>c</sup>	*	*	–	–	control	control

<sup>a</sup>DL, direct launching; DR, delayed reaction; LWC, launching without collision; DRWC, delayed reaction without collision;

<sup>b</sup>From experiment 1.

<sup>c</sup> \*, causal change; – , no causal change

#### 4.1 *Stimuli, procedure, and apparatus*

Fresh films were made in the same manner and to the same specifications as in experiment 2. The procedure and apparatus were identical to those of experiment 1. In-session scoring was checked from video tape. A randomly selected one-third of sessions was scored by an independent blind judge. Agreement with experimenter scoring was high (94% of trials).

#### 4.2 *Subjects*

Forty-seven fresh infants were used for this experiment, twenty-two females and twenty-five males. These were randomly assigned to five groups: twelve in group 1, ten in group 2, ten in group 3, nine in group 4, and six in group 6. Additionally, results from eight infants in experiment 1 part B were used for group 5.

In testing the new infants eighteen rejections occurred (with roughly equal numbers from each group). Of these, seven were rejected for persistent fussing, two through experimenter error, three failed to reach habituation criterion within eighteen trials, one fell asleep, two through mechanical breakdown, two were inattentive from the start, and one was inadvertently distracted by the mother.

Overall, ages ranged from 24 to 34 weeks (mean age 28.96 weeks, SD 2.63 weeks).

#### 4.3 *Results*

Mean looking times on first habituation, last habituation, and test trials are shown in figure 5. Analysis of variance on first versus last habituation trials showed a significant effect of trials ( $F_{1, 49} = 27.466, p < 0.0001$ ).  $F$  ratios for groups and groups  $\times$  trials were less than 1.0. Thus looking declined across groups in a uniform manner.

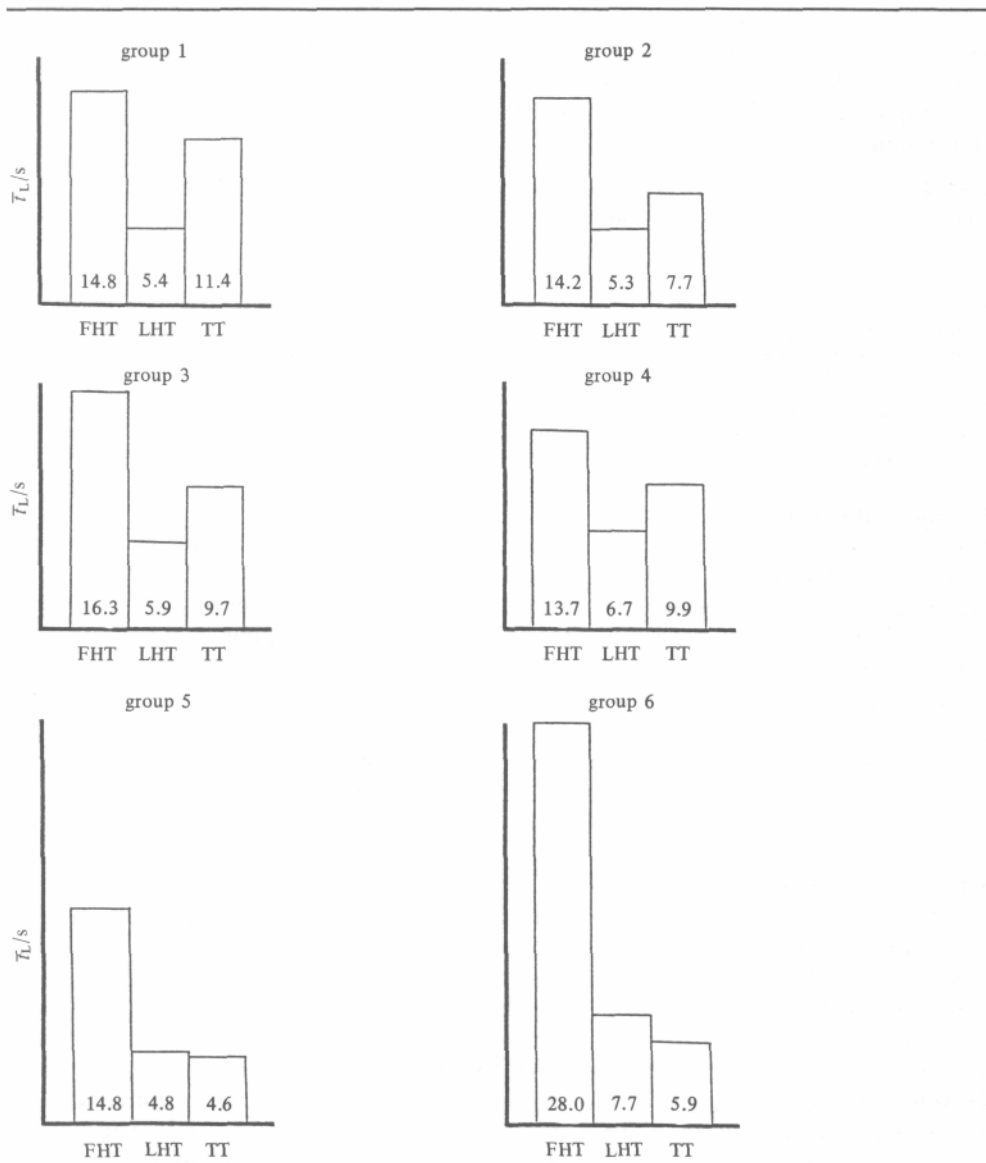
The first set of planned comparisons is shown in table 3. These show that the two control groups did not increase their looking time on the test trial over that for the last habituation trial. However, experimental groups 1, 2, and 3 did show a significant increase in looking time, while group 4 showed a definite trend for increased looking. (The launching-without-collision/delayed-reaction group of experiment 2 also shows significantly increased looking on this test:  $t_{10} = 2.46, p = 0.017$ , one-tailed.)

The second set of planned comparisons is shown in table 4. Here, it was found that group 1 was not significantly different from group 3 either in test-trial looking times or in recovery scores. Group 2 likewise did not differ significantly from group 4, and in this case the direction of difference was actually counter to prediction.

#### 4.4 *Discussion*

It was clearly not the case that direct-launching contrasts produced greater recovery than equivalent delayed-reaction-without-collision contrasts. These results therefore do not support the notion that dishabituation will be determined by encoding of direct launching as [+causal] and its variants as [—causal]. It did seem, however, that direct launching and its variants could all be discriminated one from the other. In each experimental group there was a rise in looking times on the test trial over the last habituation trial, although this was less pronounced in the delayed-reaction-without-collision/delayed-reaction group (4). In the control groups, however, looking times declined further on the test trial after the interval.

This pattern and the lack of difference between groups 1 and 2 versus groups 3 and 4 is in accord with the graded dimension version of the causal hypothesis. This proposes that the films lie along a continuum with direct launching at one extreme, delayed reaction without collision at the other extreme, and launching without collision and delayed reaction somewhere in between. The results for recovery of



**Figure 5.** Experiment 3: mean looking time by groups on first habituation trial (FHT), last habituation trial (LHT), and test trial (TT). See table 2 for design.

**Table 3.** Experiment 3: Planned comparison of looking times for last habituation versus test trial by groups; ns, not significant.

Group <sup>a</sup>	<i>t</i>	df	<i>P</i>
1 (DL/DR)	-3.565	11	0.002 (one-tail)
2 (DL/LWC)	-1.963	9	0.041 (one-tail)
3 (DRWC/LWC)	-2.118	9	0.032 (one-tail)
4 (DRWC/DR)	-1.686	8	0.065 (one-tail)
5 (DL/DL)	0.469	7	ns
6 (DRWC/DRWC)	1.09	5	ns

<sup>a</sup>See table 2.

looking time suggest that each of the films can be discriminated from each of the others (including launching without collision and delayed reaction from experiment 2). This implies that each of the films corresponds to a distinct point along this continuum.

**Table 4.** Experiment 3 : Comparison of test-trial looking times and recovery scores by a priori (independent) *t* test; ns, not significant.

	<u>Test trial</u>	<u>Recovery scores</u>
Group 1 versus group 3 <sup>a</sup>	$t_{20} = 0.638$ , ns	$t_{20} = 0.917$ , ns
Group 2 versus group 4 <sup>b</sup>	$t_{17} = -1.197$ , ns	$t_{17} = -0.374$ , ns

<sup>a</sup>Causal contrast versus no causal contrast; temporal relation change,  
<sup>b</sup>Causal contrast versus no causal contrast; spatial relation change.

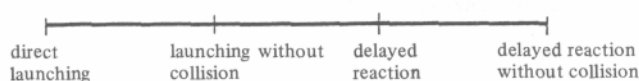
## 5 General discussion

Taken together, the results of experiments 2 and 3 can be accounted for by assuming: (a) that a unidimensional similarity space characterises one aspect of the infants' encoding of the sequences depicted in the films; (b) that the level of dishabituation for a given film pair will reflect the distance between the two films in this space.

From experiment 2 it appears that delayed-reaction and launching-without-collision should be somewhere in the middle of this space, with direct launching and delayed reaction without collision at opposite extremes. Moreover, the former pair of films appear to have been discriminable and therefore should not occupy the same point. From experiment 3 it appeared that delayed reaction was less reliably discriminated from delayed reaction without collision than from direct launching (see table 2). It is reasonable, therefore, to propose that this sequence lies closer to the delayed-reaction-without-collision pole, leaving launching without collision closer to the direct-launching pole. This ordering of the films fits the rank order of the recovery scores for each film pair fairly well (see figure 6).

Such a one-dimensional similarity space can be given a natural interpretation as a *spatiotemporal continuity gradient*. In other words, the infant represents (to within some limits) the degree of spatiotemporal continuity/discontinuity between the two movements that make up direct launching and its variants. In the case of the variants, according to this interpretation, the infants do not encode the specific source of discontinuity, that is, whether the discontinuity was spatial or temporal. Thus, at least when infants are tested after about a minute, the continuity relation coded is relatively abstract.

This model can be further tested against two-dimensional models. For example, the one-dimensional model states that for a certain size of spatial gap and a certain length of temporal delay, launching without collision and delayed reaction would be equally discontinuous and thus not discriminable. So if experiment 2 had used a slightly larger spatial gap, for instance, then direct launching and delayed reaction without collision would have been more discriminable, while launching without collision and delayed reaction would have been less discriminable. Two-dimensional models predict that any increase on a dimension should have a uniform effect on



**Figure 6.** Postulated similarity space.



discriminability throughout a stimulus set constructed in a similar manner to the one used here.

So far the evidence suggests that infants of around 7 months of age encode various degrees of spatiotemporal continuity or discontinuity between two moving entities. Perception of this rather *global* relation (as opposed to orthogonal spatial and temporal relations, for example), and segregation of the movements satisfy important requirements of the Michottean percept.

What remains to be shown is whether infants perceive in direct-launching sequences anything corresponding to 'productivity'. It is not immediately obvious how to translate this phenomenological notion. However, it could perhaps be related to the idea that the infant might represent distinct roles for the two objects. Thus, for example, one object is attributed an active causal role while the other is attributed the role of passive effect (cf Leslie 1984). Assuming that the more causal the sequence appears the more definitely these attributions would be made, it may be possible to investigate this by using the reversal of causal and noncausal sequences.

It was argued earlier (experiment 1) that differential eye tracking would not explain the registration of internal structure in direct launching. Borton (1979) had found that direct launching and continuous movement by a single entity both produced relatively smooth tracking in infants. The dishabituation patterns found in experiment 1 will not then be accounted for by *enactive*, or motor-based encoding. A more abstract form of representation is indicated, perhaps of the sort discussed by Bower (1974, 1979), Meltzoff (1981), Leslie (1982a, 1983), and Mandler (1983). It appears that it is within the capacity of this system to represent some objective relations between events. This approach can allow an important role for natural structures of observational intelligence in the infant. At the same time it is not at all clear that active motor experience is the sole and necessary vehicle for the development of causal perception (Leslie 1984).

### 5.1 Further research

One important goal of research in this area will be to show how the perceptual and representational structures developing in the first year of life relate to later causal reasoning in the child. Shultz (1982) has argued that among the rules of causal attribution available to the child a central and fundamental position is occupied by the notion of "generative transmission". This rule is often used preferentially over other rules such as covariance, spatial contiguity, temporal contiguity, and regularity of succession. For example, children of 2-4 years would identify an already operating fan as the cause of a candle blowing out if a gap in a windshield was oriented towards it just as a second fan was switched on. The fan which was capable of transmitting energy to the effect was selected as cause, in preference to a second fan which was not capable but whose onset of action was temporally contiguous with the effect. Various other phenomena involving tuning forks and flashlights also appeared to be understood in terms of "generative transmission from a powerful source" (at the expense of spatial contiguity or covariance, for instance) even at 3 years of age. As Shultz points out, the developmental histories of these different rules before this age is a matter of great interest.

It is tempting to speculate that a developmental basis for the notion of generative transmission could be partially provided by the spatiotemporal continuity percept. In the example cited above from Shultz (1982), transmission appears to involve a particular *spatiotemporal* relation between the powerful source (the fan) and the receiver (the candle). The importance of this relation is revealed by the fact that it was the unblocking of the transmission path by the realignment of the windshield that was used by the children to determine which of the fans was the cause of the

candle blowing out. Thus the transmission path ran in a straight line from source to target <sup>(1)</sup> and the effect occurred contemporaneously with the unblocking.

So generative transmission itself involves precise spatiotemporal constraints though these constraints are not always the spatial and temporal contiguity of direct causation, but can operate more like indirect connections between distant points on a causal chain. The children in Shultz's studies were apparently able to conceive of such an intermediate process of transmission as shown by their appreciation of blocking, their disregard of nontransmitting spatial contiguities, and so on. And they could do this despite the invisibility (and in the case of the experiments with tuning forks the complete imperceptibility) of the process.

It would be extremely surprising if young infants could access such an advanced conception in these circumstances. However, perhaps some events such as launching provide visible models of 'transmission'. In the simplest cases, there is a spatiotemporally continuous movement from one position to another where an effect may be produced; in more complex cases transmission involves *intervening* objects and events. And, of course, at any time spatiotemporal discontinuities may feature in the attenuation, deflection, or complete blocking of the transmission. Other events, like a hand picking up an object, have different structural properties (Leslie 1982b). Leslie (1984) found that infants appeared to treat a discontinuity in a pickup differently depending upon whether a hand was involved or another inanimate object substituting for the hand and performing analogous movements. Events such as these may also provide the infant with models for transmissions: in this case involving not just continuities, but also objects with special *powers* (hands, for example). Perhaps, then, the notion of generative transmission finds its first instantiations among simple, direct, and continuous causal sequences such as these, and later comes to be applied to events with more complex and less direct mechanisms such as those Shultz (1982) has studied.

Finally, one could note the role of spatiotemporal continuities and discontinuities in, for example, the studies of infant perception of object identity by Bower et al (1971) or studies of object unity by Spelke (1982). Does this have something in common with the infant's perception of causality? Is there a generalisation to be made in terms of spatiotemporal continuity relations? This raises the intriguing possibility that the infant's perception of objecthood and causality may share developmental roots. Clearly a great deal of further detailed research is required into these and the related questions raised in this paper.

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<sup>(1)</sup> In relation to this, it is interesting to note that Churcher and Scaife (1982) found that by 40 weeks (and sometimes sooner) infants could follow pointing and eye gaze with a high degree of spatial accuracy even in the absence of any target object. This, they argue, requires the infant to construct an imaginary straight line in space at an angle specified at the origin (ie head/eye/arm) to its intersection with a surface.

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