Abstract

Two experiments studied how 5- to 10-year-olds integrate perceptual causality with their knowledge of the underlying causal mechanism. Children learned about two devices by which a ball dropped into one end of a box made a bell ring at the other end, either immediately (contiguous mechanism), or after a delay (noncontiguous mechanism). When one ball was dropped first and a second ball was dropped after a delay, then the bell rang immediately, 5- and 7-year-olds chose the contiguous cause regardless of the mechanism inside. This was not due to lack of specific knowledge or problems with salient distractors. The results suggest a link between temporal contiguity and causality in children's understanding. Children also considered causal mechanism, in agreement with previous research, but they may not understand that mechanism is superordinate to perceptual cues for causality.
Seeing it Happen and Knowing How it Works:
How Children Understand the Relation between Perceptual Causality and Underlying Mechanism

A primary way to organise our experience of the physical world is by cause and effect. Often, we are satisfied to see that one event caused another, and a powerful cue to induce such impressions is perceptual contiguity. In other cases, however, we reason about how this link came about, considering mechanisms by which the cause produced the effect. For many, concern with mechanism is at the core of a mature conception of causality, and recent work suggests that even preschoolers show such concern. This study investigates a later change in causal understanding, asking how 5- to 10-year-olds understand the relation between underlying mechanism and the perceived structure of a simple mechanical problem.

The Mechanism Principle

For two events to stand in a causal relation we believe there must be a mechanism by which the cause produces the effect — this distinguishes causation from correlation and coincidence. Day and night correlate perfectly, yet we do not think one causes the other. Duncker (1945) had the convincing impression that opening a door made a light go on simultaneously at the other end of a hallway, yet he knew this to be an illusion. Without underlying mechanism by which one event produces the other, observable regularity may be spurious correlation and observable contiguity may be chance.

Because we believe in an underlying mechanism to link cause and effect, we form hypotheses about the nonobvious aspects of a causal problem. What its surface aspects mean depends on these hypotheses, and these in turn depend on prior knowledge. For Duncker over 50 years ago, a link between door opening and light was ruled out, but today one might consider motion sensors or remote controls. There is no special perceptual cue enabling mechanism-based inferences in a purely datadriven way. Instead, concern with mechanism involves an abstract, theory-driven form of causal thinking (also see Ahn, Kalish, Medin, & Gelman, 1995; Koslowski & Okagaki, 1986; Koslowski, Okagaki, Lorenz, & Umbach, 1989).

In an influential analysis, Bullock, Gelman and Baillargeon (1982) emphasized that belief in mechanism is not just an expectation based on experience, but a definitional principle or assumption not open to empirical disproof. If we cannot figure out how an event came about, we do not doubt that something somehow did cause it, but rather conclude that our reasoning was insufficient to uncover cause and mechanism.¹

This analysis of the role of mechanism in understanding causality agrees with Piaget’s (1974). The two views differ, however, on how such understanding develops. Piaget posited a late, operational acquisition, a view that has been criticized in many respects (e.g., Berzonsky, 1970, 1971; Bullock, 1984, 1985a, 1985b; Bullock et al., 1982; Carey, 1985; Gelman & Kremer, 1991; Koslowski, Spelton, & Snipper, 1981; Massey & Gelman, 1988; Nass, 1956; Sugarman, 1987; Tumer, 1985).

Most important in this context, even preschoolers are concerned with causal mediation when simple devices, clear manipulations and structured response measures are used. For example, in the classic "Fred-the-rabbit" studies (Bullock et al., 1982), a domino-like chain of blocks connected cause and effect. A rod knocked over the first block, the others toppled in turn and the last block pushed Fred into his bed. During test, a screen hid the blocks, but after pretest experience with the complete contraption, 4- and to some extent 3-year-olds could predict whether relevant and irrelevant modifications, e.g., changing length vs colour of the rod, would affect the result.

Such results show concern with mechanism not because children reason about an apparatus with multiple pieces, but because they appeal to unobservable links between cause and effect. Physical systems can be analysed at various levels of resolution, with no one level capturing the notion of causal mechanism in an absolute sense. One can always account for a causal link at one level by appeal to mechanism at a different, underlying level. Causality implies two levels of organisation: an
observable surface sequence of events, and an underlying mechanism that generated that structure.

Reasoning about causal mechanism, accordingly, is defined relative to perception. In the Fred-the-rabbit studies, with the blocks hidden, concern with how the rod can reach Fred indicates concern with mechanism. But with the apparatus in sight, one can observe the dominos, and some appeal to the physics underlying the individual links is needed to clearly indicate concern with mechanism. The level of resolution necessary to demonstrate concern for causal mechanism thus differs from one context to the next.

Different levels of resolution are a key difference between Piaget's and newer studies. Piaget typically studied children's explanations of complex, often natural systems. To show concern for mechanism in such cases usually requires reasoning at a level below everyday experience and appeal to physical concepts acquired in school. Bullock et al., in contrast, present simple mechanical systems, create gaps in children's experience by hiding parts, and assess whether their inferences bridge these gaps. In this approach, much younger children are concerned with unobservable mechanisms, as only concepts familiar from pretest or everyday life need be evoked.

Overall, it has become clear that Kindergardeners understand that mechanism is a necessary feature of causation (e.g., Bullock 1984, 1985b). By age 4 or 5 children assume there must be a mechanism and will search for it, even if they did not see it prior to test. Doubts remain about even younger children who do not show consistent concern with mechanism. So far it appears that for 3-year-olds mechanism is relevant only when information about it is obvious; they do not consider it when this is not so.

Bullock thus argued that the mechanism principle is initially implicit, becoming explicit only around 4 or 5 years (also see Campbell, 1992).

**Perception of Causality**

Children's mechanism-based understanding is preceded by perception of causality (Michotte, 1963). Infants as young as 6 1/2 months are sensitive to causal structure in contiguous collision events, but do not see causality when contiguity is disrupted (Cohen, Amsel, & Casasola, 1997; Cohen & Oakes, 1993; Leslie, 1982, 1984, 1988; Leslie & Keeble, 1987; Oakes & Cohen, 1990). A corresponding causal "launch" illusion in adults is also well-known (e.g., Michotte, 1963; Schloetmann & Anderson, 1993; Schloetmann & Shanks, 1992), but its interpretation is controversial (e.g., Anderson, 1990; Cheng, 1993; Joynson, 1971; Weir, 1978). It seems unsurprising to posit a separate perceptual process underlying an impression that in adults could also be based on reasoning about mechanism or analysis of event relations.

The infant data, however, raise the possibility that perception of causality might serve as a developmental process to allow rapid learning about causality despite lack of prior knowledge (Leslie, 1988). This would be helpful, precisely because the perceptual category overlaps with instances of causality that adults reason about in more sophisticated ways. This proposal is in line with recent ideas that infants are born with attentional biases that direct attention towards particular input structures, thereby constraining learning in privileged domains (e.g., Gelman, 1990). What seems superfluous for adults thus might be a useful process for children.

**Beyond Perception**

Event features important for infant perception of causality, especially spatiotemporal contiguity, are also cues for causal inference at older ages (e.g., Bullock et al., 1982; Mendelson & Shultz, 1976; Shultz, Fisher, Pratt, & Ruf, 1986; Shultz & Mendelson, 1975; Siegler, 1975, 1976; Siegler & Liebert, 1974). This use may be abstracted from perceptual causality, or may reflect a default hypothesis about the spatiotemporal configuration of causal mechanisms when specific information is missing (Anderson, 1990; Bullock, 1985b; Sophian & Huber, 1984). Because perceptual causality and knowledge of causal mechanism typically point to the same cause, it is difficult to determine which is actually used.

Nevertheless, perceptual causality and mechanism do not stand side by side in a mature concept of causality: Perception is subordinate. The underlying mechanism is involved in generating the perceptual appearance of a causal problem, and thus
interpretation of what is observed depends on what is known about this mechanism. Perceptual cues per se are ambiguous and may be accidental. Contiguity, for instance, despite its wide-spread use in causal reasoning, is neither necessary nor sufficient for causality. Its validity in any particular case depends entirely on the time course and spatial configuration of the underlying mechanism.2

The present study considers how children understand this relation between mechanism and perceptual surface. Even though by 4 or 5 children know that a mechanism is necessary for causation, they may not know that a perceptual appearance of causality is neither necessary nor sufficient. Empirically, the connection between nonobvious mechanism and perceptual surface may not be salient in children's experience. Theoretically, if perceptual causality is an early form of causal understanding, then instead of mechanism being naturally superordinate, perception and mechanism may initially stand side by side, or perception may be superordinate at first, with the two reversing positions later.

The issue can be addressed through experimental situations in which perception implicates one cause, but mechanism implicates another. Shultz (1982) argued that in such conflicts, even 3-year-olds' causal attributions are based on "generative transmission" or mechanism. However, his results may also be taken to show that children choose a cause implicated by perception plus mechanism over a cause implicated by perception but not mechanism, consistent with his later formulation that children choose a cause obviously capable of producing the effect (Shultz et al., 1986).

Even for 3-year-olds a fan that blows rather than one that is off causes a candle to go out (Shultz, 1982), a choice which may reflect concern with mechanism, but is also supported by contiguity of cause and effect. To avoid this natural confounding, Shultz used components to prevent the cause from producing the effect, i.e., a fan cannot blow out a candle if shielded by a screen. To contrast temporal contiguity and mechanism then, fan A was turned on, but did not blow out the candle because it was shielded. After 5 seconds, fan B was turned on, and at the same time the screen was moved in front of B, so that A now blew out the candle. On several problems of this type, children 5 years and older chose A as cause; younger children had slightly lower scores.

Shultz argued that children chose on the basis of generative transmission implicating A as cause, rather than contiguity of cause and effect implicating B. This view, however, assumes that the points of activating A and B are the only temporal aspects to be considered; it ignores the perceptual role of the mediating blocking device. Its movement changed which object produced the effect and it was also temporally contiguous with the effect. These results convincingly demonstrate that children are sensitive to mechanism requirements, but not that this happens independently of perceptual causality.

Experiment 1

This study presents a different test of whether children understand that the perceptual structure of a causal problem should be interpreted relative to mechanism requirements. Children choose between a temporally contiguous and a delayed, noncontiguous cause for an effect, while the mechanism linking cause and effect is varied. Two different mechanisms are used, one implicating the contiguous, the other the delayed, cause. The relevant information is given prior to test, whereas during test the mechanism is literally "hidden in the box." In this way, the perceptual configuration remains constant, only the interpretation of the problem changes.

If children know that mechanism requirements supersede other cues to causality, we should find alternate causal choices for alternate mechanisms, despite a bias towards contiguous causes when the mechanism is not known. In contrast, if children choose the contiguous cause despite knowledge of the relevant mechanism in the box, it would suggest that they consider a perceptual appearance of causality more important.

Contiguous choices despite better knowledge may, however, occur under a mechanism-based understanding as well, if children cannot apply this. For instance, they may find it difficult to focus on noncontiguous events in the presence of salient
contiguous distractors (Siegler, 1975). Thus in one control condition children simply identified the contiguous and noncontiguous events, without a causal attribution. An attentional problem should affect this noncausal task as much as the causal task. Two other controls assessed whether children have difficulties with recall and use of information about mechanism when it cannot be seen.

**Method**

Children saw a box in which a bell at one end would ring after balls were dropped into two holes at the other end (Figure 1). In the central "A-pause-B-bell problem," ball A was dropped into one hole, after about 3 seconds ball B was dropped in the other, then the bell rang immediately. Children chose whether the first ball A, not contiguous with the effect, or the second ball B, contiguous with the effect, made the bell ring. These choices were made before and after extensive experience with two devices; one rang the bell immediately, the other took 3 seconds to do so. The two mechanisms implicated alternative solutions to the A-pause-B-bell problem solely because of this difference in timing.

The experiment had three phases. In the introduction, children were familiarized with the A-pause-B-bell problem. To assess whether the A-pause-B-bell problem would elicit a natural preference for the contiguous cause, children made baseline causal choices without information about the mechanism.

In the exploration phase, children learned about the two mechanisms. This included the prediction and mechanism control tasks, in which they made judgments with one or the other mechanism hidden in the box. These tasks assessed whether children could recall the perceptual implications of the mechanisms and use this knowledge to interpret perceptual input. These two phases took about 20 to 30 minutes.

Finally, children encountered the A-pause-B-bell problem again. In the causal task, they decided which ball made the bell ring when they knew which mechanism was hidden in the box, to assess whether they would interpret the perceptual structure in terms of the mechanism. In the noncausal control task, they just indicated which of the two balls was noncontiguous/slow* or contiguous/fast,* to assess whether they could identify a delayed event in the presence of a contiguous distractor.

**Subjects**

Ninety-six children, 16 boys and 16 girls in each age group, and 16 adults took part. Five-year-olds ranged from 5 years 0 months to 5 years 11 months (mean age 5 years 7 months), 7-year-olds ranged from 7 years 0 months to 7 years 11 months (mean age 7 years 6 months), and 9/10-year-olds ranged from 9 years 0 months to 10 years 11 months (mean age 10 years 2 months). Three additional children were eliminated for not paying attention or experimenter error. Children were from private schools and day care centers of middle to lower middle class character; they were volunteers and had signed approval from one parent to participate. The adults were undergraduates in their early twenties, fulfilling a course requirement.

Children were tested individually at their school, in sessions of 30 to 45 minutes. Half of the children at each age were randomly assigned to "causal" and "noncausal" groups. Gender was counterbalanced across these groups, as was the pink/blue colour associated with each side of the box, and the order in which the toys were introduced.

**Apparatus**

The "secret mystery box" (Figure 1), 26 x 16 x 11 in. in size and cushioned to muffle sounds, had two holes at one end into which a pink or a blue ball were dropped. One hole had a pink, the other a blue rim, and the balls were always dropped in the hole of corresponding colour. The rims were interchangeable, and for half of the children in each group blue was on the left, for half on the right. This end of the box also had a door used to move the toys in and out and to let children look inside. At the far end of the box sat the "bell," a brass cup into which a lever fell when E pulled a hidden string. This end had a towel wall so that the bell inside could be touched.
Two toys were used that could equally bridge the distance between holes and bell (Figure 2). The "slow runway" had a sloped pedestal with miniature railroad tracks and perspex walls to guide the ball's path. When a ball was dropped on one end, it rolled down in 2.5 to 3 seconds, then knocked the lever into the cup thereby producing the bell sound. Thus the noncontiguous ball A was implicated as cause of the bell ringing.

Introduction. Children were shown the "secret mystery box," told the game was "all about what happens inside," that "the blue hole is for dropping the blue ball, and the pink hole is for dropping the pink ball," and to watch carefully. After an initial A-pause-B-bell sequence they were asked "what happened." Children were then told about the bell, and that "only one of the balls makes the bell ring. The other ball just falls on the ground and does nothing."

After a second A-pause-B-bell sequence children were asked "which ball made the bell ring?", also to point to where in the box they thought the bell was. Children were then shown its true location, and as it was glued down a second bell "just like the one in the box" was presented for closer inspection. Finally, children were asked for ideas about the inside of the box with E stressing that "the bell is all the way over here, but the balls fall in all the way over here. Pretty far away! How do you think the ball gets to the bell?".

The third and fourth A-pause-B-bell sequences were used for baseline assessment since children now were completely informed about the problem and task except for the mechanism. Before each trial they were instructed to watch "which ball makes the bell ring." After the fourth trial children were asked "how come it was the pink/blue one?". In two of the four initial trials the pink ball was contiguous, in two the blue ball, presented in random order. This approach was also used in subsequent tasks to associate both colours equally with the contiguous ball.

Exploration. Children then saw E take one toy out of the box, e.g., the runway. It was placed on top, and children used it to make the bell ring several times. E stressed that "with the runway the bell rings really slow, it takes a long time for the bell to ring," and slowly counted to three while the ball rolled down before the bell rang. Children confirmed that it would always be as slow by counting together with E several times. The second mechanism was introduced similarly. After initial demonstration and before counting or any mention of its timing, children were asked "is the seesaw as slow as the runway?". For the seesaw, one could barely count to one before the bell rang.

Next, timing of the mechanisms was compared. Both were placed in front of the bell, and children were asked which was faster. They checked this by dropping both balls at the same time, which led to the seesaw ringing the bell before the ball on the runway could reach it. Children were also shown how to get both balls to the bell at the same time, i.e., an A-pause-B-bell configuration, with E stressing that to do so "the slow runway ball is dropped first, and when it is almost there, then the fast seesaw ball is dropped second." Each demonstration was repeated. Next, children were given balls and told to "make the bell ring slow (fast)." Finally, E summed up that "this is a really good way of knowing what goes on inside the box. If I put the slow runway inside, the bell rings really slow, but if I put the fast seesaw inside, the bell rings really fast."

Children then made predictions of how the toys would work inside the box. The runway, for example, was put in the box with help from the child who chose which hole it should be placed under. Once it was hidden, a drawing of the toy was placed by the appropriate hole as a memory aid. Children were asked whether the bell would
ring if a ball was dropped in this hole, whether it would ring slow or fast, and whether it would ring if a ball was dropped in the other hole. E gave feedback, e.g., "yes, it can't ring because the toy is not there, so the ball can't get to the bell." Children checked this by dropping a ball, watching the result, then dropping the other ball. This was repeated with the toy moved on the other side, and for the other toy.

The prediction task tested what children expected to observe prior to perceptual input. The subsequent mechanism task tested whether they would use this knowledge to interpret perceptual input. Thus children guessed "whether the slow runway or the fast seesaw" was in the box when only one ball was dropped (A-pause-bell or B-bell). Nonverbal responses could be made by pointing to the runway or seesaw picture. Children guessed the mechanism twice for the A-pause-bell and twice for the B-bell sequence, in random order, turning around between trials to prevent seeing what E put inside the box. After the second trial of each type, if they had not already said something like "it's the fast one," they were asked "how come the seesaw/runway?".

Final phase. All children were exposed to the A-pause-B-bell problem again, half making causal, half noncausal choices. Children in the causal group saw E put one toy in the box, but could not see where it was placed; the picture of the toy was put on the middle of the box. E also described her action, e.g., 'I'm putting the slow runway in the box, but I'm not showing you under which hole.' This was done to eliminate answers on the basis of spatial rather than temporal cues. Children were told that E would drop both balls, and that they should guess "which ball makes the bell ring with the slow runway inside." There were four trials, two for each mechanism in random order with the restriction that a runway trial was last. After the second problem of each kind, children were asked whether the causal ball had gone slow or fast, and "how come it was the pink/blue one?", followed by informal detailed questioning at the end.

In the noncausal group, the mechanisms and their pictures were put out of sight and not mentioned to de-emphasize causality. Children were told that E would drop both balls, and they should watch "which ball goes slow and which ball goes fast.

This time you tell me which is the slow ball." Children were asked twice to identify the fast, twice the slow ball, in random order. After these noncausal identifications, one or more causal choices with the noncontiguous slow runway was added.

Causal and noncausal tasks both involved the A-pause-B-bell problem, and both required attention to the same timing feature for correct solution. Neither required a judgement of speed, of course, but only identification of the noncontiguous first and contiguous second ball. The terms 'slow' and 'fast' were used for convenience throughout the training, and children used them with ease to refer to the toys or the long/short time intervals between ball and bell.

Older subjects. The 9/10-year-olds received both causal and noncausal tasks, in counterbalanced order. A group of adults was tested as well, with briefer procedure. After the introduction and baseline trials, they were simply shown each toy and how it made the bell ring, and told that the seesaw was fast, the runway slow. Adults then also received both causal and noncausal tasks.

Results

Results from the Introductory Phase.

Because the study aimed to contrast perceptual intuition with children's knowledge of the underlying causal mechanism, the first step was to assess this intuition. It turned out that the A-pause-B-bell problem naturally evoked an impression that the contiguous ball made the bell ring. Little instruction was needed about the task.

Children's natural interpretation of the problem. Table 1 summarizes what children thought prior to instruction. The first row shows that many children gave spontaneous causal descriptions of the A-pause-B-bell sequence; typically statements about a noise producing action of the ball ("It hit something" "It went inside a jar"). Older did so more than younger children, but this may simply be due to better verbal skills, as older children's descriptions tended to be longer ("The blue one hit something noisy, and the pink one went through something silent."). If children were silent, or stated only the action ("They both fell in") or effect ("There was a bang")
they were prompted further; causal answers after prompting are shown in Row 2. Agreement between two coders of these descriptions was 95%.

----------- Table 1 about here -----------

Within their descriptions, some children stated which ball had produced the effect, i.e., “The blue ball hit the bell.” Spontaneous attributions increased with age, but if observers specified a cause they chose the contiguous ball at all ages (row 3). After the next A-pause-B-ball sequence, all children were instructed to make a causal attribution, and the proportion of contiguous choices was at a similar high level for all ages (row 4).

These contiguous choices could be accompanied by thoughts of a contiguous mechanism. The simplest might be a bell located directly under the hole into which the contiguous ball was dropped. Indeed, when pointing to the bell’s location, children who specified a side preferred the side of the contiguous ball over the noncontiguous side (row 5). But children specifying an end preferred the end with the bell over that with the holes (row 6), a choice probably to do with auditory cues and E’s movements setting up the bell. Thus children’s contiguous choices did not seem motivated or rationalised by an idea that the bell sat directly under the hole.

If children correctly assume the bell to be some distance from the ball, do they also assume a device to bridge this distance? When asked “How does the ball get to the bell?,” young children typically mentioned only direct action, that the ball rolled or bounced (row 7). Older children often suggested runway-like devices (row 8), but only 4 considered seesaw-like devices (row 9). Agreement between two coders was 96%.

Baseline. At this point children knew all about the problem except for the mechanisms involved, and causal choices on the next two trials thus served as baseline. There were .81, .72, .80 and .78 contiguous choices at the four ages (These group scores are representative of individual performance: 23, 20, 23, 10 observers made two contiguous choices; 3, 6, 4, 1 two delayed choices; 6, 6, 5, 5 gave both). Contiguous choices were scored as 1, delayed choices as -1. The mean expected by chance then is 0, and the grand mean E gives an overall group test against chance.3 The only effect in an Age (5/7/9/Adult) x Group (Noncausal/Causal) ANOVA was for the grand mean, $F(1,104) = 65.72$, $MSE = .52$, indicating more contiguous choices than expected by chance, with no age or group differences, all $F < 1$. (Significant effects are reported at $p < .05$)

In their justifications, 8 of 32 9/10-year-olds and 9 of 16 adults, but none of the younger children, commented on the ambiguity of the problem, stating that either ball could have hit the bell (“...I’m not really sure about this because this one had more time to get there, and this one just rang right away so...”) or wondering why the other ball had not hit (“...I think there is a block.” “Maybe you moved the bell?”). Beyond this, statements were often uninformative, because many children did not appeal clearly to a criterion for their choice, but instead seemed to describe the event (e.g., “Because it rolled down and hit the bell, the other just fell in.”). At any rate, younger children seemed unconcerned with a rationale for why it should be one or the other ball.

In sum, children naturally interpret the A-pause-B-ball sequence in causal terms; this was not a function of task demands. Most thought the noise was produced as one of the balls hit another object located some distance from where the ball was dropped, and that the ball rolled there. Most children also had a clear bias towards the contiguous cause. This makes the present situation suitable for a contrast of perceptual intuition with causal inference based on knowledge of mechanism.

Results from the Exploration Phase

Tasks during the exploration phase tested understanding of the mechanisms. Overall, children quickly saw the relevance of timing for distinguishing the mechanisms, and could recall and use this knowledge in various simple judgments.

Introduction of the mechanisms. The difference in timing of the mechanisms was salient to the children, not a subtle discrimination (see also Richie & Bickhard, 1988). Upon initial demonstration of the second toy, 26, 29 and 32 children at the three ages stated correctly that it was not slow/fast like the previous one. When the
toys were compared, all children knew which would be faster, and all children dropped balls on the correct mechanism when asked to make the bell ring slow or fast. Thus, children also understood and used the verbal labels 'slow' and 'fast' with ease.

Predictions. Next children saw how each mechanism worked in the box. Having helped set up one toy under one hole, children stated whether the bell would ring if a ball was dropped there, whether it would ring slow or fast, and whether it would ring if a ball was dropped in the other (empty) hole. Answers in Table 2 were scored as correct only if all three parts were correct.

-------------- Table 2 about here --------------

Performance with the fast seesaw was uniformly high, but younger children made some errors on the first trial with the slow runaway, sometimes expecting that the bell would still ring fast. Thus, younger children had some initial difficulty to imagine the perceptual implications of the delayed mechanism. Prior experience of contiguity in the A-pause-B-bell problem may have interfered. At any rate, on the second trial after feedback errors were rare at all ages (.95 correct on contiguous, .99 on delayed problems).

An ANOVA with Age (5/7/9) and Group (Causal/Noncausal) as between and Problem (Contiguous/Delayed) as within subjects factor on first trial performance yielded an effect for Age, \( F(2,90) = 3.69, MSe = .13 \). The effect of Problem misses significance, \( F(1,90) = 3.73, MSe = .14, p = .057 \), but clearly performance is worse only on delayed problems.

Mechanism task. The next task tested whether children could use their knowledge about mechanism to interpret perceptual input. They guessed which toy was in the box after seeing only one ball dropped, which made the bell ring contiguously or after a delay. Children were near perfect for both contiguous and delayed problems (Table 3).

In addition, 28 5-, 30 7- and all 32 of the 9/10-year-olds mentioned timing spontaneously or when asked to justify choices. Clearly, children did not only use their knowledge about timing of the two mechanisms, but were also aware of its relevance.

-------------- Table 3 about here --------------

In sum, children found the differential timing of the two mechanisms salient. Some younger children initially had partially wrong expectations about what they would observe with the slow runaway in the box, but eventually all ages knew the perceptual implications of the mechanisms, and used this to interpret perceptual input when the mechanism was hidden. Training thus gave children sufficient knowledge to disambiguate the A-pause-B-bell problem, which they then encountered again.

Main Results

Causal and noncausal choices. Results from the causal task, on the left in Table 4, show that all ages were accurate for contiguous causal problems. For delayed problems, however, the youngest children were mostly wrong, that is they chose the contiguous ball as cause, even though they had seen the experimenter put the slow runway in the box. When knowledge about causal mechanism was in conflict with temporal contiguity, children based their choices on contiguity.

-------------- Table 4 about here --------------

The 9/10-year-olds and adults showed good performance on both problems, strong evidence that children know that what is observed must be interpreted relative to what is known about mechanism. The 7-year-olds showed intermediate performance at about chance level. These age trends suggest that children's understanding of the role of causal mechanism develops well into the school years.

Results from the noncausal task, on the right in Table 4, show that children of all ages could identify both the contiguous "fast" and the noncontiguous "slow" ball. It appears that children could focus attention on a delayed event in the presence of a contiguous distractor. Since the perceptual events presented in causal and noncausal tasks were identical, children's problem in the causal task had to do with the additional causal interpretation required. This added complexity would, of course,
make the causal task generally harder than the noncausal task, but note that there was no general performance decrement in the causal task. Children made more errors only for the delayed, not for the contiguous cause.

The statistical analysis generally supported these impressions. An overall mixed model ANOVA found an Age (5/7/9) x Group (Causal/Noncausal) x Problem (Contiguous/Delayed) interaction, $F(2,90) = 3.42, MSe = .11$, consistent with the change in performance across age that was pronounced on delayed causal problems.

Follow-up analyses were conducted for the two tasks separately. In the causal group there was an effect of Age, $F(2,45) = 6.85, MSe = .09$, Problem, $F(1,45) = 14.32$, and an interaction, $F(2,45) = 5.02$, both $MSe = .17$, reflecting the improvement on noncontiguous problems over the age range.

In the noncausal group, the effects of Age and Problem were nonsignificant. The Age x Problem interaction was significant, $F(2,45) = 5.19, MSe = .05$, but this appears due to a minor crossover at the two younger ages, with 5-year-olds slightly worse on noncontiguous problems and 7-year-olds worse on contiguous noncausal problems.

When the central delayed problem was analyzed separately across both tasks, an Age effect, $F(2,90) = 9.69$, indicated more correct answers at older ages and a Group effect, $F(1,90) = 22.22$, indicated more correct answers in the noncausal than the causal task. The interaction missed significance, $F(2,90) = 3.00, p = 0.055$, all $MSe = .13$, even though the causal group is much improved at the oldest age. The complementary analysis for contiguous problems found no significant effects, reflecting uniform accuracy in both groups across the age range.

Noncontiguous causal problems in the noncausal groups. Younger children in the noncausal groups were given a delayed causal problem afterwards. The proportion correct on this trial was 0.25 for 5- and 0.44 for 7-year-olds. Thus, prior identification of the balls in the noncausal task did not improve performance on the causal problem.

What children said: speed labels and justifications. Children were also asked whether the causal ball they chose had gone slow or fast, which yields a secondary indicator of whether they take account of mechanism. Not surprisingly, when children chose the correct cause they also labelled it correctly, with only 2 errors total. When children chose a cause inconsistent with mechanism, however, often the speed label was consistent with mechanism nevertheless; especially on fast seesaw problems where 7 of 8 children incorrectly choosing the noncontiguous ball claimed that it went fast.

On slow runway problems, children were split in the labels they gave. Eight of 11 5-year-olds, 4 of 9 7-year-olds, and 4 of 5 9/10-year-olds label the incorrect contiguous ball "slow," as it should have been, the others label it "fast," as indeed it was. This split pattern also appeared for the causal choices of children in the noncausal group, even though they often had identified the slow ball correctly before. Split labelling appeared only for incorrect contiguous causal choices when the slow runway was in the box, against a backdrop of mechanism-consistent labels in other conditions and tasks. This suggests that children may have experienced some conflict on the delayed problem.

Children may have had a number of different reasons for each label when giving the wrong contiguous cause on this trial. “Slow” answers, consistent with mechanism but not the causal choice, may reflect genuine belief that the ball was slow, inference that it must have been slow even if it appeared fast, or unwillingness to engage in discussion. Similarly, “fast” answers, consistent with the choice but not mechanism, may indicate lack of concern for mechanism, or willingness to discuss the problem.

From informal questioning at the end it seemed different possibilities were involved; some examples are in Table 5. Some children trusted their perception, concluding that something happened to mechanism or box to make it go faster than it should. Others thought they had misperceived, concluding that the ball was slower than it seemed. Many children, of course, gave less involved answers and it was not clear in their statements to what extent they had noticed a conflict between what they knew should have happened and what they saw happen.
In Experiment 1, children made incorrect causal attributions on slow runway, but not on fast seesaw problems, despite extensive and equivalent experimental experience with each toy. This result might be due to preexperimental differences in experience or knowledge, however, as children were more familiar with runway-like devices.

Children might judge incorrectly on runway problems, for instance, because they know how it could be sped up. In pilot work with a less explicit procedure, children had proposed that to produce a faster result E threw the ball harder, or the runway was made steeper, or the decelerating train tracks were taken away. They might thus take the runway timing as variable but the seesaw timing as fixed. In general, differences in performance on runway and seesaw problems may be idiosyncratic to the mechanisms, rather than having to do with the relation between mechanism and perceptual structure.

This alternative account of specific differences between children's understanding of seesaw and runway devices is tested in Experiment 2 by using the reverse mechanisms. Thus, a delayed seesaw and a contiguous runway were employed.

Method

Subjects
Subjects were 64 new 5- and 7-year-olds, 16 boys and 16 girls of each age, from the same general population as in Experiment 1. Five-year-olds ranged from 5 years 0 months to 6 years 0 months with a mean age of 5 years 6 months; 7-year-olds ranged from 7 years 0 months to 7 years 11 months with a mean age of 7 years 5 months.

Apparatus
Experiment 2 used the reverse mechanisms, a “slow seesaw” and a “fast runway.” To speed the runway up, it was made steeper, with parabolic slope for maximum acceleration, and the ball rolled on a rail of two parallel wires for minimum friction. To slow the seesaw down, metal weights were attached to the ends of its arm, which pivoted on a low friction ball bearing. Weights and distances were balanced so that dropping the ball provided the least amount of force with which it was possible to set the seesaw in motion. The "fast runway" implicated the contiguous cause B, whereas the "slow seesaw" implicated the delayed cause A. Thus, the relationship of mechanism to perceptual structure was the reverse of Experiment 1.

Design and Procedure
Experiment 2 followed the design and procedure of Experiment 1. A minor difference concerned the noncausal task. In Experiment 1, children were not told or shown what was in the box, to not draw attention to the causal structure of the situation. In this situation children might be puzzled, however, about how the same colour ball could make the bell ring fast on one trial, slow on the next without E exchanging the mechanisms. Thus, in Experiment 2, children saw E put both mechanisms in the box, and equipment was rattled around between trials as if their location was changed. Also, children in the noncausal group all received at least two causal choices with the seesaw subsequent to the noncausal task.

Results

Results from the Introductory Phase
Overall, this new sample appeared comparable to that of Experiment 1. Table 6 (compare with Table 1) shows that these children's natural interpretation of the situation was similar to that found previously.
**Results from the Exploration Phase**

The new mechanisms in Experiment 2 did not affect children's performance in the exploration phase. The difference in timing of the two toys was as salient as before, with 25 5- and 29 7-year-olds stating on initial exposure to the second toy that it had not been fast/slow like the one before. When comparing the toys, 30 and 31 children at the two ages knew which would make the bell ring faster, and when dropping a ball on the appropriate mechanism to produce the effect ‘slow’ or ‘fast’, there were 2 errors in 256 total responses. Thus children had no difficulty with the speed labels.

Results from the first predictions of what would happen if one or the other ball was dropped when the child had helped put each toy under a particular hole in the box are in the top section of Table 7 (on the second prediction they were .96 and .94 correct on contiguous and delayed problems, respectively.) As in Experiment 1, performance was slightly worse on delayed problems in the younger age group, but the Age x Group x Problem ANOVA found no significant effects. The effect of problem reached significance only in a comparison of Experiments 1 and 2, due to the increase in power with doubled sample size, $F(1,120) = 4.34$, $MSe = .18$. There were no significant differences between the two experiments.

--------------- Table 7 about here --------------

Children were again highly accurate in the mechanism task (Table 8). All but two of the 5-year-olds mentioned timing of the mechanisms appropriately.

--------------- Table 8 about here --------------

In sum, results from introduction and exploration phases were equivalent to those in Experiment 1. Children's initial intuitions about the problem were similar, and reversal of the mechanisms presented no new difficulties for their understanding.

**Main Results**

Causal and noncausal choices. Children making causal choices again were usually wrong on delayed, but usually right on contiguous problems (left in Table 9). They were not affected by the change in mechanism and chose the contiguous ball as cause throughout.

--------------- Table 9 about here --------------

As in Experiment 1, 7-year-olds made about twice as many correct delayed choices as 5-year-olds, with 7-year-olds being seeming more hesitant and often wavering in their answers, choosing incorrectly on one, but correctly on the other trial. Children making noncausal choices, in contrast, are mostly accurate on both problems at both ages (right in Table 9). Again, a general attentional problem with identifying delayed events does not seem involved.

Performance on contiguous and delayed causal problems was compared in an Age x Problem ANOVA. This yielded a significant main effect for Problem, $F(1,30) = 31.66$, $MSe = .16$, reflecting worse performance on delayed than contiguous problems. The small improvement on the delayed problem from age 5 to 7 did not reach significance. The complementary analysis for noncausal problems did not yield any significant effects, reflecting equivalent performance at both ages on both problems.

Performance on delayed causal and noncausal problems was compared in an Age x Group ANOVA, which yielded effects for Age, $F(1,60) = 4.60$, and Group, $F(1,60) = 81.17$, both $MSe = .08$. Overall, 7-year-olds performed a little better than 5-year-olds, and children merely identifying the balls performed much better than those making causal choices. The complementary analysis for contiguous problems found no significant differences. An Experiment x Age x Group x Problem ANOVA found corresponding Group, Problem, Age x Problem and Group x Problem effects, $F(1,120) = 46.76$, $MSe = .10$, and $F(1,120) = 30.87$, $5.43$ and $43.97$, all $MSe = .12$, but there were no differences between the results of Experiment 1 and 2.

Noncontiguous causal problems in the noncausal group. Children in the noncausal group made two causal choices for the difficult delayed problem subsequent to their noncausal identification choses. The proportion correct on these causal attribution trials was .16 and .50 for 5- and 7-year-olds. This was significantly
less than their own previous performance in merely identifying the delayed ball, $F(1, 30) = 54.22$, $MSe = .10$, but no different from the performance of the children in the causal group, $F < 1$. In this analysis of the causal choices of all 64 children, the improvement between 5 and 7 on delayed problems was significant, $F(1,60) = 9.53$, $MSe = .13$, due to the increase in power with doubled sample size.

**Consistency of causal choice and speed label.** As in Experiment 1, speed labels indicated that children had some concern for mechanism in the causal task. When children chose the correct cause, they also gave the correct speed label, with only 1 error at any age. When choices were not consistent with mechanism, labels nevertheless often were consistent. On fast runway problems, all children said the causal ball was fast, although 6 had chosen the wrong, noncontiguous ball. On slow seesaw problems, the pattern was split, but still 20 of 28 5- and 10 of 17 7-year-olds claimed that the contiguous ball was slow.

Statistical analysis confirmed that speed labels took account of mechanism in both conditions. An ANOVA on data from the causal groups in both experiments, with Age and Experiment as between, Problem and Measure (Causal choice/Speed label) as within subjects factors, found effects of Measure, Problem, and a Measure x Problem interaction, $F(1,60) = 50.62, 51.23, 6.08, MSe = .14$. On fast problems, children gave .98 correct labels and .83 correct choices. On slow problems, they still gave .72 correct labels, but only .33 correct choices. Labels were more often correct than expected by chance, $F(1,60) = 22.01$, $MSe = .73$, even though choices on that trial were at chance level, $F(1,60) = 2.01$, $MSe = .78, p = .16$. Thus, young children paid some attention to mechanism in the causal task, even if their choices did not reflect this clearly.

**General Discussion**

Two experiments investigated whether children from 5 to 10, and adults, would make causal choices on the basis of their knowledge of mechanism or on the basis of perceptual structure. Prior to experience with two mechanisms which implicated either a contiguous or a delayed, noncontiguous cause, all ages preferred the contiguous cause. After such experience, 9/10-year-olds and adults made alternate causal choices depending on the mechanism they knew to be in the box. But the younger ages continued to choose the contiguous cause regardless of mechanism.

These results support three conclusions: First, there may be a natural link between contiguity and children's understanding of causality, as suggested by work on perceptual causality. Second, children are concerned with causal mechanism, as found in previous work on their causal concepts. Third, the way in which children integrate perceptual and mechanism-based causality may undergo developmental change.

**Mechanism and Causality**

By 4 or 5 years, children understand causality in terms of productive mechanisms (Bullock et al., 1982, Bullock, 1984, 1985b; Shultz, 1982; Shultz et al., 1986). No evidence to the contrary was found here. Even 5-year-olds had reasonable physical hypotheses to start with, and once shown the specific mechanisms quickly understood their role. Nevertheless, only 9/10-year-olds' causal attributions were governed by mechanism; those of the younger children were not.

This age difference could occur even if all ages understand causation alike, if young children cannot apply their understanding due to processing limitations or a knowledge deficit. Such performance problems do not seem plausible. Children had no difficulty attending to noncontiguous events in the presence of contiguous distractors, as shown in the noncausal task. Children had no difficulty distinguishing the mechanisms on the basis of timing. Children seemed to know more about runways than seesaws, but this did not affect the results, as shown in Experiment 2.

Detailed knowledge about the two mechanisms was conveyed experimentally, and children recalled and used this knowledge in control tasks. They were not even completely oblivious to mechanism constraints in the causal task itself. This was clearest in some children's verbal efforts to resolve the conflict between what they knew should have happened and what they saw happen, but suggested more generally
by the labelling data. Overall, children had just one problem, namely to choose a noncontiguous cause in the presence of an alternative contiguous cause.

It might be objected that the control tasks were less complex than the causal task, and that children fail because limits on the use of mechanism information emerge only in processing intensive situations. If so, however, children should fail on contiguous and delayed problems equally. But they mainly failed on delayed problems. While task complexity may affect children's performance, this effect is specific, not general.

To account for this specificity, one might argue that children fail because delayed causal problems require recall of perceptually unavailable mechanism information, and that this is not necessary on contiguous problems. However, this argument presupposes that contiguity is already linked with causality, independent of concern with mechanism. Thus this argument agrees with the present view.

**Contiguity and Perceptual Causality**

Prior work showed that children often prefer temporally contiguous over delayed causes, but the reasons for this were unclear. They might do so because they thought of a contiguous mechanism (Shultz et al., 1986), because they could not think of a delayed one (Mendelson & Shultz, 1976), or because they could not disengage attention from the contiguous event (Siegler, 1975). Finally, many studies have pitted contiguous against delayed, covarying causes (Mendelson & Shultz, 1976; Shultz et al., 1986; Siegler, 1975, 1976; Siegler & Liebert, 1974). In these cases, information for the delayed cause was more complex than for the contiguous cause, as extraction of covariation required several observations, contiguity only one. Thus, a preference for contiguous causes could be explained by processing difficulties, concern with mechanism, or both together, but it was not necessary to assume a direct link between contiguity and causality.

A different objection against such a link is that most, but not all prior work found a preference for temporally contiguous causes (e.g., Bullock et al., 1982; Mendelson & Shultz, 1976). However, temporal contiguity is not the only determinant of perceptual causality, but rather one aspect in a configuration that includes other features, e.g. spatial contiguity (Michotte, 1963; Schlottmann & Anderson, 1993). A contiguity bias would thus not be expected in all situations.

This configural role of temporal contiguity should not distract from its domain-general importance. A similar configural role for contiguity appears in conditioning, another form of causal learning (e.g., Campbell, 1963; Heyes & Dickinson, 1990; Mackintosh, 1983; Shanks, 1993). Contiguity is a good but fallible cue to causation, and this is reflected both in perceptual causality and the laws of association which make conditioning dependent on the total cue configuration rather than contiguity alone.

In the present study, at any rate, all ages had a contiguity bias, as shown in the baseline. For older observers, concern with mechanism could underlie this bias, because when knowledge of mechanism changed, attributions changed as well. For younger children, it is unlikely that the bias resulted from concern with what went on in the box, because it remained even when children had knowledge to the contrary. The result suggests a special link between temporal contiguity and causality. Young children may take some event relations as causal, simply because they look that way.

This leaves the issue of what the perceptual causality itself is based on. In one view, it is an uninterpreted perceptual Gestalt that often maps onto reasoned cases of mechanism-based causality (Michotte, 1963). In another view, it implies understanding of mechanism, albeit in an implicit and unconscious manner. Bullock (1985b), for instance, argued that the link between perception and mechanism precedes development and that toddlers' attention to contiguity -- or the later data on infants' causal perception of collisions -- already reflect their implicit knowledge of mechanism.

Whether one prefers to describe children's developing understanding as moving from implicit to explicit understanding of causal mechanism, or from perceptual causality to a concept based on mechanism, the main point of the present results is that there is no easy and smooth transition from one to the other. For some time, they
appear as separable aspects of children’s causal understanding. In everyday life these may coexist side by side, potentially applied in different circumstances. What children do not seem to know, however, is how to integrate perception and mechanism, as seen in the present difficulties with resolving a conflict between them.

**Integrating Perception and Mechanism**

Often, when causality is perceived, there is actually a causal relation there -- but not always. This makes perceptual causality advantageous early in development to guide relevant learning. It becomes restrictive later, because children must realize that a simple 1:1 mapping between appearance and mechanism is not guaranteed. Mechanism generates appearance, but operates in an environment which impinges on that appearance. This may contribute some accidental features and hide some essential ones. Thus observers, as in this study, may not focus on appropriate aspects.

Previous thought focussed on the match between perceived and underlying structure, and on the usefulness of perceptual causality for early learning. Leslie (1984; Leslie & Keeble, 1987) suggested it might be involved in children’s analyses of mechanical systems, helping to parse complex events into connected causal chains. They need not understand the underlying connection between the acts they group, and yet this would provide physical knowledge useful to constrain later reasoning about connections. Thus perceptual causality can help pave the way for a mechanism-based understanding.

The present results suggest perceptual causality can also be an obstacle, and that development is not complete once the mechanism-based understanding is achieved. Children must still put the two together and grasp that while mechanism is necessary for causation, perceptual causality is not -- when the two do not match, features inconsistent with mechanism must be accidental. In line with this principle, older children and adults treated mechanism as superordinate to contiguity. Younger children, however, treated contiguity as superordinate in their causal choice; only the speed labels indicated some sensitivity to mechanism.

Questions remain about the change between 7 and 9 years. One is whether younger children already have some dawning understanding of the superordinate role of mechanism. In the Piagetian literature, the view is that children only benefit from training if they already have some of the requisite competence (Gelman & Baillargeon, 1983). The present training gave children knowledge objectively sufficient to solve the problem, but it did not alert them to the possibility a perceptual illusion. If children already have some understanding that mechanism must be obeyed, then further training with specific focus on the conflict case and validation that there really was a mismatch between what they knew and what they saw (e.g., by opening the box and checking inside) might strengthen children's reliance on mechanism.

A second issue is whether children believe mechanism must be superordinate to perceptual cues, or whether this is an empirical generalisation from experience that it tends to be more reliable. This issue also occurs in the Piagetian literature (see Campbell & Bickhard, 1986; Shultz, Dover, & Amsel, 1979). One view is that children first understand necessity empirically and that its logical status is realized only later. However, Miller (1986) has found that even first graders give different answers to simple questions about the certainty and necessity of beliefs based on logical truths or empirical/conventional fact. A similar probe technique might be used to assess children's convictions about the status of causal mechanism.

**Two Different Perspectives: Knowledge of Causality vs Learning about Causality**

The relation between observation and mechanism is bidirectional. The causal direction from mechanism to appearance is reflected in the structure of our knowledge. The diagnostic direction from observation to mechanism is reflected in inductive strategies for learning. We switch between these perspectives of knowledge or learning, trying to understand what we see in terms of what we believe to be true, but if this is impossible, because of inconsistencies or lack of prior knowledge, we try to learn from the observation and adjust our beliefs about mechanism.
In the present task, the knowledge perspective was appropriate: Children should interpret what they see in terms of what they know, because the mechanism was an empirical fact, and because observation did not involve any real inconsistency. But to see this, children must first overcome the learning perspective built into perceptual causality.

This problem is amplified, because real life causal mechanisms are often a matter of hypothesis, not fact. Mismatches between prediction and observation may well be real, and subsequent change in the hypotheses may well be appropriate -- the trick is to know when the evidence challenges previous beliefs and when it is compatible. This raises the issue of how the present results relate to work on children's scientific thinking skills.

Kuhn (1989) argued that theory and evidence are often undifferentiated in children, with what is observed taken as illustration of "the way things are," rather than as independent evidence that can refute a theory. Accordingly, beliefs may not be revised appropriately when faced with inconsistent evidence. This description also seems to fit the finding that young children had an initial bias towards the contiguous cause and failed to revise this after learning about the slow mechanism. It is unclear, however, to what extent age-related improvements reported in this literature are due to increasing domain-specific expertise, ability to process complex data, or metacognitive skills -- which themselves may depend on expertise. At any rate, the eventual subordination of perceptual causality to mechanism may depend both on domain-specific experience and on more general improvements in scientific thinking skills.

The origin of children's difficulties here, however, is not a general inability to revise their beliefs or related skills. When knowledge and processing limits are not a concern, 6-year-olds distinguish theory from evidence, and select the appropriate test between two rival hypothesis (Sodian, Zaitchik, & Carey, 1991). Four-year-olds learn to make correct causal predictions when these involve flexibly switching between spatial response rules depending on the internal state of a marble-runway apparatus

(Frye, Zelazo, Brooks, & Samuels, 1996). The Theory of Mind and Appearance-Reality literature contains numerous examples of 4-year-olds revising initially appearance-based beliefs after contradictory evidence, while reasoning about the continued false belief of others who did not see this evidence (e.g., Perner, Leekam, & Wimmer, 1987). Finally, while in some tasks -- like this one -- children do not revise their judgment enough, in others they overadjust (e.g., Schlottmann & Anderson, 1995). More specific accounts are thus needed for why children -- and adults -- hold some views, but not others, so strongly that they have difficulties revising them.

Note that even in the present study, children's belief in causal contiguity was easily revised, as shown in the control tasks in which children switched flexibly between judgements about the contiguous and delayed relations. They could infer that in one case the fast toy, in the other the slow toy was in the box, and they could predict that in one case the ball would ring fast, in the other slow. Clearly children could think about the delayed ball causing the bell to ring -- but they could not choose this cause when perceiving a contiguous distractor. It was the perception of causal contiguity that children found difficult to overcome, not the belief in the absence of this percept. This agrees with the idea of a specific link between perceptual contiguity and causality.

Relation to Other Research on Children's Understanding of the Nonobvious

Appearance-reality conflicts as in the present study are often used in work on "children's understanding of the nonobvious" (Wellman & Gelman, 1988). This has shown that counter to traditional opinion even preschoolers are not generally tied to what is obvious in appearances but take account of underlying reality (e.g., Flavell, Green, & Flavell, 1986; Gelman & Markman, 1986; Keil, 1989).

At face value, the present results disagree, but Keil (1989) has discussed similar findings on the characteristic-to-defining shift. In his studies on biological kind, for example, children saw a picture of a horse, then heard how scientists made it look and act like a zebra through surgery and teaching. Children judged whether the result was
a horse or zebra, with zebra answers based on characteristic appearance despite absence of underlying defining features, and horse answers based on defining features despite absence of the characteristic appearance. Similarly here, when the slow toy was in the box, children chose between a contiguous cause with characteristic causal appearance but without the defining feature, and an uncharacteristic delayed cause with the defining mechanism. Keil’s results are also similar to the present ones in that 5-year-olds said the animal was a zebra, 9-year-olds said it was a horse, with 7-year-olds in between.

These results do not mean that children believe biological kind or causation are just a matter of appearance. But things normally look like what they are. Thus appearance-based reasoning is not just easy, but normally also appropriate. To detect that appearance and reality do not fit, children must have knowledge about the underlying kind or mechanism and realize its importance. The difficulty then becomes to understand how contradictory representations of the same thing can be present at once (Flavell et al., 1986; Keil, 1989). Discounting appearance as misleading is often the correct solution in such a conflict, but it is not the only solution: Children could also conclude that reality was not as initially thought or that it was surreptitiously changed. Thus they need to decide whether to trust their knowledge or the apparent evidence.

Children can trust their knowledge and discount appearance if they know just how some contextual event could affect appearance, but not reality. Thus, if the horse wore a zebra costume, 5-, and with more aid even 3-year-olds, knew it was a horse, but if its looks changed after a shot at birth, only adults were sure it was still a horse (Keil, 1989) -- and even they were unsure about an insect changed after chemical contamination (Rips, 1989). Similarly, the present causal conflict might become easier to solve if children know not only about the mechanism in the box, which training had focussed on, but also how the appearance could be misleading, which it had not.

Specific experience to promote the distinction between causal appearance and real mechanism may be hard to come by in everyday life, as the mechanisms underlying perceived causal relations are typically not open to direct inspection. With the present set-up, one could go back and forth between observing the events from the outside, and opening the box to check the inside. Everyday life equivalents, however, often require indirect methods, experimentation and inference, and children may see little need to conduct such tests when perception already indicates causality. It thus makes sense that an integration of perceptual causality and mechanism would be a late achievement in developing understanding of causality, a result of learning not its cause.

In sum, in the present study young children who understood that a causal mechanism required a few seconds to produce an effect, nevertheless chose a temporally contiguous over a properly delayed cause for this effect. Children seem to link contiguity and causality independent of their concern with mechanism; they struggle to integrate these two aspects of causality. Vestiges of this may appear in adults: Contiguous causality also seems prototypical to us. Leslie (1988) used perception of causality to argue convincingly for the "necessity of illusion" as a mechanism to promote early development. To complete development, however, it is also necessary for children to learn that sometimes perceptual causality is nothing but an illusion.
References


Author Notes

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Footnotes

1 Bullock et al.’s intuitive concept of causality contains two other principles besides mechanism, namely determinism -- that all events are caused, and priority -- that causes come before their effects. These two are not the focus of the present study. Also, it should be stressed that this discussion concerns only a psychological concept of causality, although there is a related philosophical perspective (e.g., Harré & Madden, 1975).

2 Of course, people may have a wrong belief about mechanism and this may lead to incorrect interpretation of what is observed; or they may not have a firm belief about the mechanism at all. The point here is only that as long as people believe they know about the mechanism, perceptual features of the situation are interpreted relative to it.

3 Many have documented that ANOVA procedures on proportion scores are appropriate (e.g., Lunney, 1970; Rosenthal & Rosnow, 1984).

4 The younger children were given only one task, the 9/10-year-olds were given both (whether they received causal or noncausal task first made no difference in their performance), so for comparability only data from their first task were used in the ANOVA. The adults performed at ceiling level and thus were not included.
Table 1

Children's Descriptions of the A-pause-B-bell Problem on First Exposure, Experiment 1

<table>
<thead>
<tr>
<th></th>
<th>5 years</th>
<th>7 years</th>
<th>9/10 years</th>
<th>adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion causal descriptions without prompting</td>
<td>.31*</td>
<td>.69</td>
<td>.94</td>
<td>.75</td>
</tr>
<tr>
<td>If prompted answers are included (cumulative)</td>
<td>.66</td>
<td>.91</td>
<td>1.00</td>
<td>(not prompted further)</td>
</tr>
<tr>
<td>Proportion contiguous choices of those children who identify a cause in their descriptions (frequencies in parentheses)</td>
<td>.75</td>
<td>.86</td>
<td>.83</td>
<td>1.00</td>
</tr>
<tr>
<td>2nd trial Proportion contiguous causal choices without instruction prior to the trial</td>
<td>.75</td>
<td>.72</td>
<td>.91</td>
<td>.75</td>
</tr>
<tr>
<td>Proportion contiguous side choices for bell location of all children specifying a side (frequencies in parentheses)</td>
<td>.83</td>
<td>.58</td>
<td>.95</td>
<td>.75</td>
</tr>
<tr>
<td>(10/12)</td>
<td>(11/19)</td>
<td>(18/19)</td>
<td>(6/8)</td>
<td></td>
</tr>
<tr>
<td>Proportion near end choices for bell location of all children specifying an end (frequencies in parentheses)</td>
<td>.20</td>
<td>.16</td>
<td>.08</td>
<td>.08</td>
</tr>
<tr>
<td>(4/20)</td>
<td>(3/19)</td>
<td>(2/25)</td>
<td>(1/13)</td>
<td></td>
</tr>
</tbody>
</table>

“How does the ball get to the bell”?

<table>
<thead>
<tr>
<th></th>
<th>5 years</th>
<th>7 years</th>
<th>9/10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>rolls/bounces/goes</td>
<td>.69</td>
<td>.38</td>
<td>.13</td>
</tr>
<tr>
<td>Slope/ramp/road/slide</td>
<td>.22</td>
<td>.41</td>
<td>.78</td>
</tr>
<tr>
<td>Other device</td>
<td>.03</td>
<td>.13</td>
<td>.09</td>
</tr>
<tr>
<td>Don’t know/no answer</td>
<td>.06</td>
<td>.09</td>
<td>0</td>
</tr>
</tbody>
</table>

* 32 children in each age group, and 16 adults.

Table 2

Results of Prediction Task, Experiment 1

<table>
<thead>
<tr>
<th></th>
<th>5 years</th>
<th>7 years</th>
<th>9/10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion correct on the first trial with the contiguous “fast” toy in the box</td>
<td>.88</td>
<td>.88</td>
<td>.91</td>
</tr>
<tr>
<td>Proportion correct on the first trial with the delayed “slow” toy in the box</td>
<td>.63</td>
<td>.78</td>
<td>.94</td>
</tr>
<tr>
<td>Number of children with no errors</td>
<td>15*</td>
<td>23</td>
<td>27</td>
</tr>
<tr>
<td>Number of children with “fast” error(s) only</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Number of children with “slow” error(s) only</td>
<td>13</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Number of children with both errors</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

* 32 children in each age group, each child can make two errors of each kind.
Table 3
Results of Mechanism Task, Experiment 1

<table>
<thead>
<tr>
<th></th>
<th>5 years</th>
<th>7 years</th>
<th>9/10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion correct on the contiguous/&quot;fast&quot; problem</td>
<td>0.97*</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Proportion correct on the delayed/&quot;slow&quot; problem</td>
<td>0.92</td>
<td>0.97</td>
<td>1.00</td>
</tr>
<tr>
<td>Number of children with no errors</td>
<td>27**</td>
<td>30</td>
<td>32</td>
</tr>
<tr>
<td>Number of children with &quot;fast&quot; error(s) only</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Number of children with &quot;slow&quot; error(s) only</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Number of children with both errors</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* each proportion is based on two trials per child
** 32 children in each age group, each child can make two errors of each kind

Table 4
Results of Causal and Noncausal Tasks, Experiment 1

<table>
<thead>
<tr>
<th></th>
<th>Causal</th>
<th>Noncausal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 years</td>
<td>7 years</td>
</tr>
<tr>
<td>Proportion correct contiguous/&quot;fast&quot; choices</td>
<td>0.88*</td>
<td>0.81</td>
</tr>
<tr>
<td>Proportion correct delayed/&quot;slow&quot; choices</td>
<td>0.25</td>
<td>0.44</td>
</tr>
<tr>
<td>Number of children with no errors</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Number of children with &quot;fast&quot; error(s) only</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Number of children with &quot;slow&quot; error(s) only</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Number of children with both errors</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total number of subjects</td>
<td>16**</td>
<td>16</td>
</tr>
</tbody>
</table>

* two trials per subject contributed to each proportion
** 5- and 7-year-olds participated in one task only, 9/10-year-olds and adults participated in both, each subject can make two errors of each kind
Table 6
Children's Descriptions of the A-pause-B-bell Problem on First Exposure, Experiment 2.

<table>
<thead>
<tr>
<th>Description</th>
<th>5 years</th>
<th>7 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st trial - &quot;what happened?&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Proportion causal descriptions without prompting</td>
<td>.38*</td>
<td>.59</td>
</tr>
<tr>
<td>(2) If prompted answers are included (cumulative)</td>
<td>.81</td>
<td>.88</td>
</tr>
<tr>
<td>(3) Proportion contiguous choices of all children identifying a cause in their descriptions (frequencies in brackets)</td>
<td>1.00</td>
<td>.86</td>
</tr>
<tr>
<td>2nd trial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4) Proportion contiguous causal choices without instruction prior to the trial</td>
<td>.78</td>
<td>.91</td>
</tr>
<tr>
<td>(5) Proportion contiguous side choices for bell location of all children specifying a side (frequencies in brackets)</td>
<td>.88</td>
<td>.89</td>
</tr>
<tr>
<td>(6) Proportion near end choices for bell location of all children specifying an end (frequencies in brackets)</td>
<td>.11</td>
<td>.29</td>
</tr>
<tr>
<td>&quot;How does the ball get to the bell?&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(7) Rolls/bounces/goes</td>
<td>.78</td>
<td>.59</td>
</tr>
<tr>
<td>(8) Slope/ramp/road</td>
<td>.06</td>
<td>.31</td>
</tr>
<tr>
<td>(9) Other device</td>
<td>.06</td>
<td>.09</td>
</tr>
<tr>
<td>(10) Don’t know/no answer</td>
<td>.09</td>
<td>0</td>
</tr>
</tbody>
</table>

* there were 32 children in each age group.
### Table 7
Results of Prediction Task, Experiment 2.

<table>
<thead>
<tr>
<th></th>
<th>5 years</th>
<th>7 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion correct on the first trial with the contiguous/&quot;fast&quot; toy in the box</td>
<td>.81</td>
<td>.81</td>
</tr>
<tr>
<td>Proportion correct on the first trial with the delayed/&quot;slow&quot; toy in the box</td>
<td>.69</td>
<td>.84</td>
</tr>
<tr>
<td>Number of children with no errors</td>
<td>12*</td>
<td>21</td>
</tr>
<tr>
<td>Number of children with “fast” error(s) only</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Number of children with “slow” error(s) only</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Number of children with both errors</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

* there were 32 children in each age group, each child can make two errors of each kind.

### Table 8
Results of Mechanism task, Experiment 2.

<table>
<thead>
<tr>
<th></th>
<th>5 years</th>
<th>7 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion correct on the contiguous/&quot;fast&quot; problem</td>
<td>.92</td>
<td>.98</td>
</tr>
<tr>
<td>Proportion correct on the delayed/&quot;slow&quot; problem</td>
<td>.86</td>
<td>.95</td>
</tr>
<tr>
<td>Number of children with no errors</td>
<td>23</td>
<td>28</td>
</tr>
<tr>
<td>Number of children with “fast” error(s) only</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Number of children with “slow” error(s) only</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Number of children with both errors</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

* each proportion is based on two trials per child
** 32 children in each age group, each child can make two errors of each kind.
Table 9
Results of Causal and Noncausal Tasks, Experiment 2.

<table>
<thead>
<tr>
<th></th>
<th>Causal task</th>
<th>Noncausal task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 years</td>
<td>7 years</td>
</tr>
<tr>
<td>Proportion correct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>contiguous/&quot;fast&quot;</td>
<td>.81</td>
<td>.84</td>
</tr>
<tr>
<td>choices</td>
<td>.78</td>
<td>.88</td>
</tr>
<tr>
<td>Proportion correct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>delayed/&quot;slow&quot;</td>
<td>.16</td>
<td>.38</td>
</tr>
<tr>
<td>choices</td>
<td>.88</td>
<td>.97</td>
</tr>
<tr>
<td>Number of children</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with no errors</td>
<td>1*</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Number of children</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with &quot;fast&quot; error(s)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>only</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Number of children</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with &quot;slow&quot; error(s)</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>only</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Number of children</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with both errors</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

* each proportion is based on two trials per child

** 16 children per group, each child can make two errors of each kind

Figure 1. The "secret mystery box" and the “A-pause-B-bell” problem. (Ball A is dropped into one hole, after about 3 seconds ball B is dropped into the other hole and the bell rings immediately. Thus, ball A is noncontiguous with the effect, ball B is contiguous with the effect. Which ball causes the bell to ring depends on which mechanism is put in the box.)
Figure 2. The two mechanisms used in Experiment 1. (With the "slow runway" the bell rings after about 3 seconds, and the noncontiguous ball is implicated as cause. With the "fast seesaw" the bell rings immediately and the contiguous ball is implicated as cause.)