Preschoolers' Understanding of Simple Object Transformations

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Gelman, Rochel; Bullock, Merry; and Meck, Elizabeth. *Preschoolers' Understanding of Simple Object Transformations.* Child Development, 1980, **51,** 691–699. The ability of 3- and 4-year-old children to reason about the components of event sequences involving simple transformations was tested in 2 experiments. In Experiment I children saw picture "stories" of the form object, instrument, and transformed object, with 1 item deleted. They filled in the missing position from 3 choice cards. Children in both groups correctly filled in all positions and therefore could: (1) predict the transformed state of an object, (2) retrieve the initial state of an object, and (3) understand the implicit actions that mediate 2 object states. This was true for transformations that (1) either altered or restored an object, and (2) represented familiar or unusual events. In Experiment II only the instrument item was deleted. Children demonstrated an ability to represent reciprocal transformations (e.g., break-fix); they chose the 2 of 4 instruments that altered and restored the same object. The younger children were less able to describe the events and found it somewhat easier to reason about transformations that altered objects.

Part of reasoning about physical events in the world involves understanding the transformations that may or may not be applied to objects (Piaget 1974). Consider, for example, a simple event sequence: a rock shatters a window. One way to describe this event is in terms of a transformation that changes an object from one state to another. The object of this transformation, the window, has beginning and end states (whole and broken), which are related by a transformation, breaking. In this example the transformation is instantiated by an instrument, a rock. Many physical events can be characterized in this way. Objects are wetted, broken, written on, and so forth. In all cases we can think of an object in two states that are related by a transformation.

We concur with Piaget (1974), Premack (1976), and Schank and Abelson (1977), who assume that knowledge about transformations and their relation to object states underlies the ability to make causal inferences that go beyond a particular data base. There are at least three interrelated inferences that can be based on such knowledge. In the case where we see a particular object in two different states at time *a* and time *b*, we assume that some action involving the use of a certain kind of instrument was responsible for the transformation from one state to another. If, for example, we see a window, walk away for a moment, and return to see a broken window, we infer that some instrument, such as a rock, was thrown at the window. Note that in this inference our choice of an instrument is constrained by the type of transformation observed. The instrument has to be one that *could* break a window.

Second, when we consider two objects, for example, a window and a rock, we are able to predict how one might be used to transform the other. For instance, we can imagine a rock heading for a window, and we can predict the outcome, a broken window. Similarly it is possible to predict the events that could occur given various types of objects, such as a plain piece of paper and a crayon, or a broken cup and a bottle of glue. Finally, if we observe just a transformed object, we are able to re-

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construct what the object's initial state once was, and what kind of instrument may have altered it.

In sum, physical events can be thought of in components. Our reasoning about these simple sorts of events is flexible: given any two components of a sequence, we can infer what the third might be.

The very young child's understanding of the relationships that hold between components of event sequences has not been studied directly. Yet, assumptions about this sort of knowledge figure in developmental theories of linguistic competence and causal reasoning. On the one hand, young children are granted implicit knowledge of the semantic categories that components of events fit into, for example, agent, object, location, and instrument (e.g., Ammon & Slobin 1979; Clark & Clark 1977; Bowerman, Note 2). Similarly they are granted sensorimotor schemes for related object-action events (Piaget 1952). On the other hand, children of the same ages are characterized both as unable to *reason* about causes and consequences, and as unconcerned about the specific nature of a transformation that might connect two states of an object (Piaget 1974). The following studies were conducted to determine whether children as young as 3 years can reason about the components of event sequences. Specifically, when given incomplete information about events, can children infer the missing components?

Our procedure was adapted from one used by Premack (1976), who investigated causal inference in apes by asking them to analyze possible action sequences (see also Premack & Woodruff 1978). Premack's animals were shown an array consisting of an intact (real) object (e.g., an apple), a blank space, and the "same" object in a changed state (e.g., cut apple). The chimp was expected to complete the sequence by placing one of several alternatives (e.g., knife, bowl of water, and writing instrument) in the blank space. Since chimpanzees did well on this task, leading Premack to grant them the ability to reason about the components of an event sequence, we assumed that a variation of it would be suitable for preschoolers—an assumption that was confirmed in pilot tests.

Experiment I

Design considerations.—We addressed preschoolers' abilities to reason about event sequences by asking them to fill in missing elements in a three-item "story." The stories consisted of pictures arranged left to right, representing an object, an instrument, and the same object in another state. Three examples of the kinds of stories we used are illustrated in figure 1.

We included sequences that represented common events, such as things being broken, as shown in figure 1. We also included more unusual sequences, such as cut bananas being sewn together, or fruit being written on. By including the unusual sequences we hoped to learn about the reasoning children engaged in when dealing with different types of events in general, not just their remembering of everyday events.

In pretraining we taught children to "read" our stories in a left-right direction. Then we presented test stories with either the first-, middle-, or final-position item missing to assess different aspects of the children's understanding of the sequences. Figure 2 illustrates several test sequences. A child who correctly fills in a missing last-position item and both predicts and shows the end state of a transformation shows an understanding of the effect an instrument will have on an object (see fig. 2A for an example). A child who correctly fills in a missing-position item can reason about or

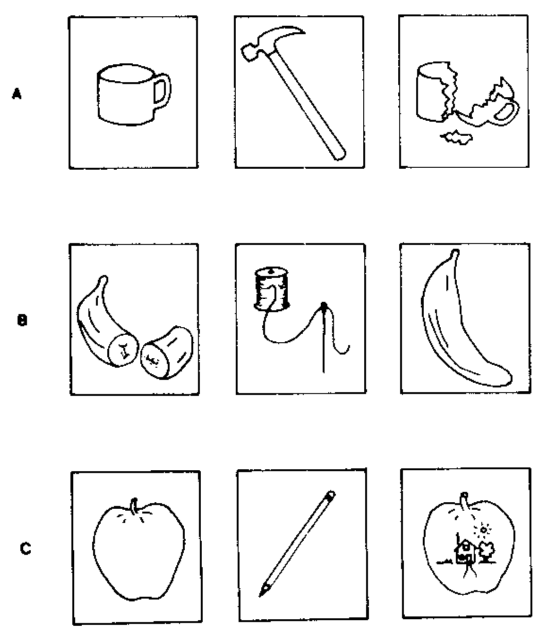

FIG. 1.—Three examples of story sequences presented in Experiment I.

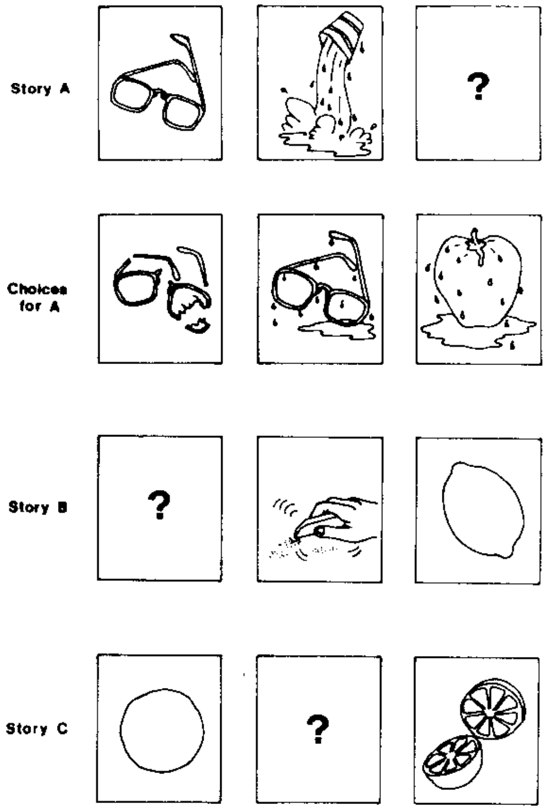

FIG. 2.—Examples of test sequences for Experiment I. The correct answer for Story B is a lemon with a drawing on it.

reconstruct the initial state of a transformed object (see fig. 2*B*). Finally, a child who correctly fills in a missing middle-position item can compare two states of an object and select the instrument whose action was implied by the transformation (see fig. 2*C*).

Note that not all transformations on objects are equivalent. Some transformations alter an object from a standard, or canonical, form, for instance, those that wet, break, mark, or cut things. Other transformations restore an object from its altered state *to* a more canonical form, for example, those that fix, erase, dry, and so forth. These two types of transformations may influence how well children can reason about the events in which they occur: it may be easier, for example, to predict the final state in a sequence where the object is changed from its canonical form, since the effects of the transformation will be directly visible in the altered final state of the object.

To see whether these two types of transformations differentially affect children's reasoning about events, Experiment I included two test conditions. In condition *A*, the canonical condition, all the sequences involved instruments that transformed an object to an altered state. Condition *B*, the noncanonical condition, included only stories in which the instruments returned an altered object to its canonical form. Children were assigned to one of these conditions. Figure 3 illustrates these two types of sequences.

The stimulus sets were selected to meet two criteria: First, we wanted to use the same object sets in both the canonical (group *A*) and noncanonical (group *B*) conditions. To do this, we designed sequences that depicted the same objects in "altering" or "restoring" transformations. For instance, group *A* (canonical) subjects worked with the sequence *cup, hammer, broken cup,* while group *B* (noncanonical) subjects were tested with the sequence *broken cup, glue, cup.* What differed was the *order* of the two object states and the transformation that related them.

Second, we designed half the sequences to represent common events, and half to represent object transformations that children would be less likely to have encountered. These included such sequences as *orange, pencil, drawn-on orange* and *cut banana, needle and thread, banana.*

Within these constraints, children in each condition saw an equal number of stimulus sets

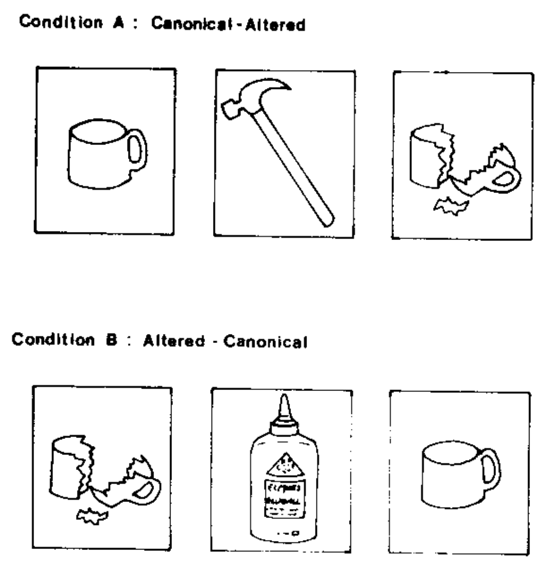

FIG. 3.—Examples of altering (canonical) and restoring (noncanonical) story sequences used in Experiment I.

with the first, second, and third positions empty. They were to choose one of three choice cards to fill in the missing slot. When the beginning or end position was blank, the choice cards depicted the correct object in an appropriate state, the correct object in an inappropriate state, and an incorrect object in an appropriate state. The choice cards for the sequences that omitted the instrument (middle) position included pictures of one appropriate and two inappropriate instruments. Table 1 lists the transformations represented in conditions *A* and *B*.

Subjects.—Forty-eight children, including 24 3-year-olds (mean age, 3-7) and 24 4-year-olds (mean age, 4-5) participated in Experiment I. Half the children in each age group were assigned to condition *A* (canonical), and the other half, to condition *B* (noncanonical). All children attended one of two day-care centers that serve a mixed socioeconomic population. Written permission was obtained from parents for each child's participation. The experimenter was familiar to the children: she spent several days in the classrooms before taking children out individually.

Apparatus.—The pictures for the story and choice cards were line drawings on 10-cm × 20-cm white cards. The story cards were placed on a 23-cm × 38-cm wooden rack, which held the cards at a slight slant away from upright and had three clearly marked sections, one for each component of a three-item story.

Procedure.—The experiment was conducted in two phases. The first phase was designed to teach the children to "read" the stories from left to right and to play the game. The second, the experimental phase, was conducted 1–6 days later.

TABLE 1

TRANSFORMATIONS REPRESENTED IN EXPERIMENT I

Condition	Transformation	Instrument
A	Breaking/cutting	Hammer Knife Scissors
	Wetting	Water
	Marking	Pencil Paintbrush
B	Fixing	Needle and thread Glue Tape
	Drying	Towel
	Erasing	Eraser

The first phase involved training trials with nine story sequences. To begin this phase, a child was asked to identify each of the instrument pictures used in the stories. In pilot work we determined that 3- and 4-year-old children could label the *objects* that were transformed in the "story." Some children seemed to have difficulty labeling some of the instruments. Therefore this phase served to guarantee that the children knew the names for all the pictures in the stories. This identification task continued until all cards were labeled correctly. The experimenter then explained how to play the game by placing three choice cards on the table in front of the rack and two story cards on the rack. The placement of choice cards on the table was counterbalanced so that a child could not pair systematically the position of the empty slot with the choice card underneath it. As the experimenter presented each story card, the child labeled it; the experimenter then described the sequence and asked the child to find the choice card that depicted the missing component in the story.

The experimenter's descriptions were designed to accomplish two goals: (1) to ensure that the child adopted a left-to-right "reading" convention, and (2) to make the child understand that the task involved a consideration of event *sequences.* An example of a description is, "First you have a cup, then a hammer does something to it, and then you end up with ______?"

Training consisted of nine trials, three each for the beginning, middle, and end positions. On each trial the experimenter described the sequence, and the child was given a chance to make a choice. If the choice was correct, the child was asked "to tell the story." If the child erred, he or she was asked to make another choice and tell the story. If the child still was wrong, the experimenter put the correct picture in place and asked the child for the story. The experimenter provided the story when the child did not. Given the feedback conditions, all children saw and heard the same number of correct stories.

The second experimental phase was a repetition of the training trials with 12 new story sequences. The experimenter described each sequence as it was introduced, but did not give feedback for the child's choices. On each trial a child filled in the missing item by choosing from three cards, and was asked to tell the story shown. The position in the story of the missing component was counterbalanced and consistent across children. Phase 2 lasted about 20 min. All sessions were tape-recorded for later transcription.

Results and discussion.—Children did very well at filling in the missing items. Only one 3-year-old in condition *A* and two 3-year-olds in condition *B* performed at chance level over the entire set of 12 trials. Otherwise, the probability of each child doing as well as he or she did by chance, according to a binomial expansion, was less than .01. Figure 4 shows the mean number of errors made on first-, second-, and third-position trials in the two different conditions. The data show several trends. First, the older children made fewer errors. When they did err, it tended to be in retrieving the initial state (position 1) of a transformed object. This was true whether the transformation involved common or unusual sequences, or altered or restored an object. While the 3-year-olds' responses, unlike those of the older children, showed no difference depending on common or unusual sequences, they were influenced by whether the transformation altered or restored an object. The younger children in condition *B* (noncanonical) tended to make more errors than in condition *A* (canonical). This suggests that 3-year-olds have an easier time reasoning about event sequences that involve altering the state of an object rather than restoring an altered object.

Given that there were so few errors overall, we did a further analysis to see if the trends reported above would persist. In table 2 we report the number of children who were correct on at least three of their four trials for each position. In considering these entries, the reader should bear in mind that the probability

TABLE 2

Number of Children Who Made at Least Three Correct Choices out of Four on Each Position in Experiment I, Conditions *A* and *B*

Condition and Position	Age: 3-Year-Olds	Age: 4-Year-Olds
A:		
1	8	11
2	11	12
3	10	12
B:		
1	7	12
2	9	12
3	7	12

(according to the binomial expansion) of seven or more children receiving scores of 3 or 4 out of 4 simply by chance is .0002. Thus, no matter what the age or condition, we see again that the children did remarkably well. Still, some of the same trends noted above show through. In particular, 3-year-old children in condition *B*, the noncanonical condition, did not do quite as well as did 3-year-olds in condition *A*, the canonical condition, and overall the 4-year-olds did better. Since we allowed our subjects to make one error in this particular analysis, we no longer see any effect of position in the 4-year-olds' results. There still remains a slight tendency for the 3-year-olds to do best when filling in the instrument slot.

Recall that children were asked to "tell a story" in each trial after they had filled in the missing card. We looked at the *content* of these stories for the correct trials to see how children were relating the elements. We coded stories by how complete they were. A *complete story*

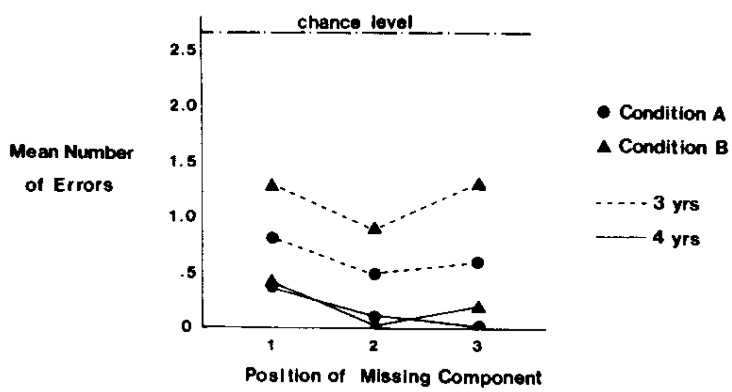

Fig. 4.—Mean number of errors made for first-, second-, and third-position trials in Experiment I

was one in which a child mentioned both object states and the transformation that related them, for example, "There was that cut banana and then it got sewed back together," or, "First you have that banana and the needle and thread sewed it." Less complete stories included an *instrument-plus-action statement*, for example, "The needle and thread sewed it," or *lists*, for example, "Banana, sewing, banana."

We determined whether a child gave a complete story on his/her own or after one prompt. In a prompted story a child typically mentioned one element of the sequence; the experimenter then simply asked, "What happened?" If the child then completed the story, the protocol was scored as *complete with prompt*.

Table 3 presents the average proportion of complete stories with and without prompts for conditions *A* and *B*. The categorization of story content shows the same trends as the choice data: 4-year-olds tell more complete stories than 3-year-olds, and the younger, but not older, children do better at describing the sequence when its contents involve a change from canonical form of an object. Moreover, the 3-year-olds benefit from a prompt from the experimenter more in condition *A* than in condition *B*.

In sum, we find that preschool children are able to make the sorts of inferences that knowledge of the components of event sequences would allow. They predict or infer the states of objects changed by a transformation, and can also infer the kind of transformation that relates two object states. This is true for object-instrument relations that are and are not likely to be part of their everyday experience. While 4-year-olds were essentially at ceiling in all conditions, the younger children erred more overall. Moreover, they had more trouble with sequences that involved restoring an altered state of an object than with those that involved the canonical form, perhaps because the effects of transformations are more directly available when the state is altered. A broken cup shows the effect of breaking, whereas an intact cup—especially when drawn in outline—does not show the effect of gluing.

TABLE 3

AVERAGE PROPORTION OF COMPLETE STORIES WITH AND WITHOUT PROMPTS FOR CONDITIONS *A* AND *B*

Condition and Age	Complete	Complete and Complete with Prompt
A:		
3-year-olds	44	69
4-year-olds	89	91
B:		
3-year-olds	37	48
4-year-olds	71	78

We were especially interested in the fact that all children found it rather easy to pick an instrument that could mediate two states of an object, even when the sequence was an unusual one, as in the case of needle and thread for an intact and a cut banana. This suggests that the preschoolers' knowledge of event sequences involves more than a memory for contiguously associated events. Given that even 3-year-olds could infer the implicit actions in the instruments we used, it becomes possible to probe the young child's understanding of the reciprocal or compensatory nature of various pairs of transformations, such as cutting and sewing, drawing and erasing, or wetting and drying.

Experiment II

Piaget's theory of cognitive development emphasizes the development of structures that make it possible for the child to think of operations as related and reversible (e.g., addition and subtraction). Preschool thought is often characterized as irreversible (Piaget 1974, 1976). In the case of the young child's understanding of causality, the child is presumed to be unable to consider together reversible or reciprocal transformations that apply to objects. Within the context of the present research this hypothesis can be specified as follows. The young child might be able to relate a cause and effect, for example, hammering yielding a broken bowl or gluing fixing a broken bowl. Still, he or she should have difficulty thinking of the two operations as a pair that reverse the effects of each other. To test this hypothesis we made a slight modification in the procedure used in Experiment I. We presented children with stories in which the missing card was always the middle item, the instrument. Children were asked to choose the missing component from four choice cards. As before, the choice cards included an appropriate instrument for reading the sequence from left to right. In addition, there was an appropriate instrument for reading the sequence from right to left, that is, in the reverse order. On each trial the child was asked first to choose an instrument that would complete the left-right reading of the story. Then his or her choice card was removed and placed face down while the experimenter asked the child to pick the card that was correct for a right-left reading of the story. Thus we asked a child to think of the *same* object pair, for example, plain paper and written-on paper, in two different ways. In this example the choice cards included both a pencil and an eraser.

Subjects.—Children in this experiment were drawn from the same sample used in Experiment I. There were 12 3-year-olds (mean age, 3-4) and 12 4-year-olds (mean age, 4-6).

Stimuli and apparatus.—Children received 16 story sequences. These included eight sets of object pairs. The transformations represented are listed in table 4 and included (*a*) wetting and drying, (*b*) drawing and erasing, (*c*) hammering and gluing, and (*d*) cutting and sewing. Each pair of transformations was illustrated with two different sets of objects, and each pair of object cards was shown twice. For half the stories the canonical state of the object was shown in the left slot and the altered object in the right slot. For the other half the altered object was shown on the left, the canonical form on the right. For example, on one trial a child saw "dog, ———, wet dog." Then, on a later trial he or she saw "wet dog, ———, dog." By looking between trials at the first instrument choices, we could see whether children preferred to treat a sequence as one that changed a canonical state of an object into an altered state or one that restored the altered state to the canonical state; by looking at a child's two choices within trials, we could see whether they were able to consider the same object pair in two reciprocal ways.

As in Experiment I, half the stories involved uncommon sequences. All stimuli were line drawings on 10-cm × 20-cm white cards, and were shown on the same display rack. In addition we used a large red arrow, mounted on a movable stand, to indicate whether a child should "read" the story from the left or right. Children in Experiment II were given four choice cards at the beginning of each trial. These included appropriate instruments for reading the story left to right and right to left, and two inappropriate instruments. The choice cards were arranged randomly in front of the child.

TABLE 4

TRANSFORMATION PAIRS REPRESENTED IN EXPERIMENT II

Transformation	Altering Instrument	Restoring Instrument
Breaking/fixing	Hammer	Glue
	Scissors	Tape
	Knife	Needle and thread
Wetting/drying	Water	Towel
Marking/erasing	Pencil	Eraser
	Paintbrush	

Procedure.—Children received training much like that given in Experiment I. A child first had to identify the instruments depicted on the cards. Then he or she was given six training trials, in which each story was missing the middle component. All training stories were "read" from left to right.

The test phase, which began 1–6 days later, used the same procedure as Experiment I, with the following modifications: (1) Testing involved two eight-trial sessions, each on a separate day. (2) All trials involved a missing middle slot (the instrument position), and children were asked for two choices on each trial, one to each direction. The red arrow was used to mark the side on which the child was to start his or her story. (3) There were four choice cards.

To begin a trial the arrow was placed on the left. The experimenter pointed to the left-hand card and said, "First we have a ———, and then something happened, and we end up with ———," and asked for a choice. Once a child had made a choice and told the story, the arrow was moved to the right; the chosen card was removed from the rack and placed out of sight. The child was asked now to "tell a story from this [right] side." The experimenter pointed to the right-hand card and said, "First we have a ———, and then something happened and we end up with ———," and told the child to make another choice and describe the story. If a child's choice for the left-to-right instruction represented the correct answer for a right-to-left reading, we followed the child's inclinations. He or she was asked to tell the story for the chosen instrument and was then tested on the left side again, this time with the three remaining choice cards. In other words, we allowed children to reverse the order in which they completed and described their two stories within each trial.

Results and discussion.—At the start of each trial, the child was asked to fill in the picture that completed a left-right reading of the stimulus array. We scored a response as correct if the child supplied the choice card appropriate for a left-right story. Children in this experiment did not do as well at filling in the middle-position item as did children in the first experiment. Overall, the 3-year-olds were correct on 49% of the trials, and the 4-year-olds, on 75%. An analysis of children's choices, however, indicated that most errors consisted of a child's picking a card appropriate for a right-left reading of the story. Thus, when young children were given choices that could serve either a left-right or a right-left reading, they tended to pick a card for their preferred interpretation of the sequence, not always following our instructions to interpret the left-right story only. This tendency was more pronounced in the 3-year-olds than in the 4-year-olds. Almost 30% of the 3-year-olds' first responses reflected a right-left reading, while 15% of the 4-year-olds' did so. Thus, were we to allow a child to respond in his or her preferred direction, 80% and 90% of the 3- and 4-year-olds' choices, respectively, would be correct. (The tendency of children to interpret some sequences in a right-left manner mitigates a possible problem with our procedure. It could be argued that children who, in the second part of this experiment, failed to make a correct second choice [i.e., did not reverse] did so because they were trained only on left-right readings of the array. Children's spontaneous right-left readings indicate that this is not a problem.)

To determine whether children showed a reliable ability to interpret the object transformations in two reciprocal ways, we calculated reversal scores twice, using "strict" and "relaxed" criteria. For the strict-criterion case, we calculated the probability that a given child would make a correct left-right *and then* correct right-left choice for each stimulus set as often as he or she did over the 16 trials. For the relaxed criterion, we again calculated the probability that a given child would make two correct choices for each object pair as often as he or she did over the 16 trials. Now, however, a child was scored as "correct" if he or she provided the two appropriate instrument cards for each sequence, regardless of the order in which those cards were chosen.

In table 5 we show the results of the strict- and relaxed-criterion analyses of the children's ability to reverse. The numbers in the cells represent the number of children who reversed on more of their trials than expected by chance (with $p < .01$). All cell entries but one, the 3-year-old strict-criterion cell, are reliable.

TABLE 5

Number of Children Who Reliably Reversed in Experiment II

Age	Criterion	
	Strict	Relaxed
3-year-olds	2	7
4-year-olds	9	10

If we consider only the results obtained in the strict-criterion analysis, we would conclude that, although 4-year-olds are able to represent reciprocal transformations vis-à-vis two states of a given object, 3-year-olds are not. However, it turns out that 3-year-olds can represent pairs of reciprocal transformations when we allow them to do the task in their preferred order. It is noteworthy that four of the five 3-year-old children who failed to meet even the relaxed reciprocal criterion were younger than the median age of this group. Thus, it is possible that still younger children would not be able to represent pairs of reciprocal transformations.

What are we to make of the 3-year-olds' tendency "to do this task in their own way"? A sign test on the tendency of children to interpret trials as transformations from canonical to altered state more often than vice versa revealed a significant bias in the 3-year-olds to interpret any transformation as altering the canonical form of an object ($p < .015$). Four-year-olds did not show this bias ($p < .246$). In Experiment I we noted a trend for 3-year-olds to do better in the canonical-altered condition (condition *A*) than in the altered-canonical condition (condition *B*). The results of the present experiment allow us to accept the hypothesis that 3-year-olds favor the representation of transformations that alter rather than restore an object. Taking this preference into account, we see that children as young as 3 years are able to consider reciprocal transformations. This finding adds to the growing list of reports that preschoolers understand some of the fundamental features involved in a successful causal inference about physical event sequences (e.g., Bullock & Gelman 1979; Hood & Bloom 1979; Siegler 1976; Bullock, Note 3).

Summary

Three- and 4-year-old children demonstrated an ability to reason about the relationship between a transformation and two states

of an object. As shown in Experiment I, they can predict the effect of a transformation, can retrieve the initial state of a transformed object, and can infer the instrument that could mediate two object states. Since the children were able to reason about unusual sequences, such as sewing a cut banana back together, we conclude that our task tapped a general ability to code event sequences in terms of object states and transformations. The youngest children we tested more readily revealed this ability when they considered a sequence involving a transformation of a canonical state as opposed to an altered state of an object.

In Experiment II, children were asked to consider how an object might be transformed in two reciprocal ways. When shown, for instance, a picture of an intact bowl along with a picture of a broken bowl, they were able to select the instruments that could be used to transform either state to the other. The fact that 3- and 4-year-old children related two different states of an object in more than one way suggests that the preschooler's ability to reason about event sequences is not tied to immediate experience. Instead, the representations of at least simple event sequences are abstract enough to enable the child to think of reciprocal pairs of transformations.

Together, the results of the two experiments suggest that preschoolers' knowledge of events is sufficently rich to allow them to make inferences relating the components of event sequences.

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