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Understanding Transitivity of a Spatial Relationship: A Developmental Analysis

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Pears and Bryant (1990) found that children as young as 4 years old could make correct transitive inferences on a task examining their understanding of the relation "higher than," if the premises were presented in the form of sets of two block towers. This study extended their investigation by looking at children's transitive inferences in situations in which the representation of the premises provided contradictory information depending on whether relative or ordinal position of the A and B elements of the three part series, A > B > C was used. The results showed that performance on problems similar to those used by Pears and Bryant was very high for 6- and 8-year-olds. However, the 6-year-olds had great difficulty with the more complex problems, whereas the 8-year-olds did significantly better. These results are interpreted as indicating the presence of a developmental sequence of algorithms that enable children to resolve progressively more complex transitive inference problems.

Transitivity refers to a property of relations that involve at least ordinal scaling of elements. Specifically, if elements a, b, and c are such that aRb and bRc, then transitivity permits the logical deduction that aRc (where R refers to the relation in question, e.g., "is bigger than"). The ability to make appropriate transitive deductions is a cornerstone of logical competence and affects children's understanding of many mathematical concepts (Piaget, Inhelder, & Szeminska, 1960), particularly those involving scaling (length, height, etc.). Piaget considered that the understanding of transitivity was one of the cognitive capacities appearing at the stage of concrete operations. According to Piaget (1921), pre-operational children (i.e., 4- to 7-year-olds) are not able to make appropriate transitive inferences, often confusing absolute referents with the relational referents

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required by transitivity, or making judgments based on dyadic comparisons. More specifically, the classical Piagetian analysis of transitivity supposes that one of the major problems that young children have in making transitive inferences involves understanding that the middle term in a transitive series, A < B, B < C may be both smaller than and larger than at the same time.

The Piagetian analysis of transitivity has been contested by many subsequent researchers. Theorists opposed to the Piagetian viewpoint tend to claim that very young children can do what Piaget claimed could be done only by older children. Indeed, Bryant and Trabasso (1971), in a very well-known study, claimed that young children's difficulties with transitive inferences could be accounted for mostly by difficulties in retaining the premises in short-term memory. They provided 4-year-olds with extensive training with the premises in a task involving length and found that their subjects gave a very high proportion of correct inferences even with five-term series problems, which were chosen in order to eliminate anchoring effects, although their interpretation of the results has been contested (de Boyssson-Bardies & O'Reagan, 1973).

The problem of controlling for memory capacity and use in young children has been a difficult one, and the various methods used to do so have not been completely satisfactory. Several sorts of problems exist. Having subjects rehearse the premises, as did Bryant and Trabasso (1971), leaves open the possibility that supplementary information may be inadvertently provided during this phase. Attempts to provide subjects with direct representations of the premises, which may be consulted by the subject during the task and thus alleviate the problem of working memory capacity (Halford, 1984), have raised problems of interpretation (Gellatly, 1992; Pears & Bryant, 1990). Providing concrete instances of the premises may give subjects direct cues as to the relations between the items, whereas using symbolic representations of the premises leads to the question of how subjects may interpret these. Recent studies using memory probes do indicate that children's retention of verbal premise information appears to be unrelated to their reasoning performance (Brainerd & Reyna, 1992, 1993). However, these results have been contested (Chapman & Lindenberger, 1992a). In addition, it is not completely clear what the relationship is between children's capacity to retrieve verbal information when asked to do so and their capacity to retrieve and use appropriate information in working memory during actual reasoning (Chapman & Lindenberger, 1992b).

In a recent study, Pears and Bryant (1990) proposed an ingenious method that appears to enable reasoning with direct access to relevant premises. They investigated young children's understanding of transitivity of a spatial relationship (higher, lower). They presented children with a series of two-block towers. In each tower, the blocks were of two different colors and represented the spatial relation between the two (i.e., a blue block on top of a green block). Thus, a series of such towers were used to present children with a series of the form: Green is higher than Blue, Blue is higher than Brown, Brown is higher than Red, etc. The children were told that they were to construct a single tower consisting of one block of each different color, in which the relative height indicated by the premise towers was to be respected. The critical part of the study involved asking children to infer the relative position of two blocks which never appeared together in the premises (e.g., Is Blue higher or lower than Red?), before building the final tower. Pears and Bryant (1990) found that 4-year-olds were able to come up with correct responses to such questions at a level much higher than chance, even when five- and six-term series were used.

The interest of this method is that it provides children with a direct representation of premises that can be continuously consulted, but does not provide a way of directly "reading off" correct inferences involving blocks that are not part of the same premise tower. Pears and Bryant's (1990) results thus give clear support to the idea that very young children are capable of making correct transitive inferences in at least this domain (i.e., spatial relationship), when they are given such support. As their analysis, and most of the analyses on transitivity, have concentrated on inferential performance, their data do not provide any information as to how children make these inferences.

This of course leads to a more basic problem of the definition of just what constitutes a transitive inference. The debate about transitivity has often been couched in a dichotomous manner (see Gellatly (1992) for a useful analysis of this debate). The classical Piagetian position has usually been interpreted to suggest that younger children are not able to make transitive inferences, compared to older children who can do so. Theorists opposed to this viewpoint tend to claim that younger children can do what Piaget claimed could be done only by older children. It is, however, possible to approach this problem by attempting to describe the sequence of evolving algorithms that might be used by the subject to make inferential judgements, without attempting to characterize any one of these as being transitive or not. The nature of the algorithms available to the child determines the kind of response that is given to a specific task. From such a perspective, it becomes relevant to explore the characteristics of the algorithms used in a specific task by children as a function of age. Furthermore, in order to explore these characteristics, it becomes important to examine response patterns across a variety of problem types that include variables that may be considered to be important to a particular form of reasoning.

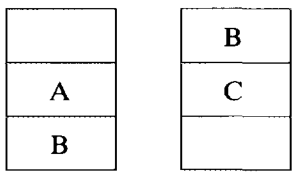
Thus, for the purpose of the present study, we concluded from Pears and Bryant's (1990) results that children as young as 4 years possess an algorithm that enables them to make correct inferences in the specific situation they used. In fact, Pears and Bryant's study concentrates on the middle term of the series, that is the term which, according to Piaget, creates difficulty for young children. Specifically, what Pears and Bryant's results indicate is that very young children possess an algorithm that enables them to isolate the two relevant premises within a larger set of premises. For example, when children are asked whether B will be lower or higher than D in the final tower, a correct inference implies that they can choose relevant B/C and C/D towers among the four following towers:

A	B	C	D
B	C	D	E

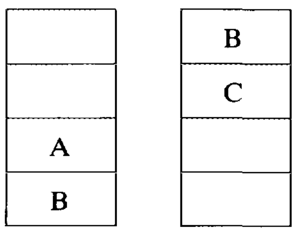
This conclusion follows since the problem above controls for anchoring effects, in that neither B nor D appears consistently at the top or the bottom of premise towers (as do A and E). In this situation, a strategy that involves using absolute position and simply reading off the answers would result in a random (50%) level of correct response. It is thus possible to conclude that subjects who produce correct responses in this context are making an inferential judgement based on the two critical towers. In order to do this, they are obliged to accept the fact that the two C blocks actually refer to a single unifying element linking B and D, despite its presence "below" B and "above" D, something that Pears and Bryant's children can do relatively well in this situation. As will be discussed later on, this is not a simple acquisition, and appears to create problems for many young children. Thus, an initial development might involve recognition of the role of a common block as a unifying element between two points, despite its appearance in two different relative positions. This would enable children to recognize that a comparison between B and D requires examining only blocks with a common C element.

However, although this provides a basis for an inferential strategy that uses relative as opposed to absolute position, another question remains open. Specifically, we suppose that children develop an initial strategy that enables them to chose the relevant premise towers on the basis of the presence of a shared element (C in this example). They are then faced with the problem of inferring the relative positions of the elements in the resulting three element system. There are (at least) two possible ways that this can be done. The simplest one would involve using the relative positions of B and D in the two critical premise towers, without considering their positions with respect to C. That is, subjects might use the presence of the common C block simply as a marker for choosing the relevant B-C and C-D towers. They could then base their judgements about the positions of B and D in the final (to be constructed tower) on the basis of the relative positions of these two blocks in the two relevant premise towers. In the situation described here, B is higher than D when only the B-C and C-D towers are examined. This would thus lead to the correct inference that B will be higher than D in the final tower. A more complex method would involve using the relative positions of each of B and D, with respect to C, in order to recreate an explicit 3-point ordinal scale B, C, D. This would require subjects to coordinate the two relations "B is higher than C" and "C is higher than D" in a single representation. In the present example, both strategies would lead to the same inferential response.

Now, the first of these strategies clearly involves less cognitive capacity than does the second, and it might be expected that younger children would use something like it before they could handle the more complex strategy. In order to differentiate between these possibilities, we considered it necessary to construct situations in which these two would result in different responses. Specifically, we were interested in examining how children dealt with situations in which the extremities of the relevant premise towers had relative positions that were in (partial or complete) contradiction to their position as defined by a 3-point ordinal scale. This was done by introducing neutral white blocks, which enabled the construction of premise towers that maintained relative positions that are consistent with a transitive relation, but in which the position of the B and D blocks could be varied in ways that are illustrated in the two sets of blocks shown here:



A and C are in relative positions that are ambiguous with respect to their position on an ordinal scale



A and C are in relative positions that are contradictory with respect to their position on an ordinal scale

In order to examine developmental differences, we looked at children aged 4,6, and 8 years.

METHOD

Subjects

A total of 82 children from a middle-class French language elementary school were examined. Of these 20 were in kindergarten (average age: 58 months; 11 girls, 9 boys), 30 were in Grade 2 (average age: 81 months; 17 boys, 13 girls) and 32 were in Grade 4 (average age: 103 months; 15 boys, 17 girls).

Procedure

Each child was seen individually for a single session lasting about 15 min by a female experimenter. Subjects were first administered two practice problems in order to make them familiar with the experimental problems. In each of these, subjects were presented with two towers, each tower consisting of two different colored blocks one on top of the other. For example, they might be given a red block on top of a blue block and a blue block on top of a green block. Subjects then received explicit descriptions of the relative positions of the blocks in each tower (e.g., "the red block is higher than the blue block here, and the blue block is higher than the green one here"). Following this, they were given three colored blocks (red, blue, green) and asked to build a single tower in which these spatial relations were conserved. Pretesting indicated that young children often did not understand such general instructions, so the children were also specifically told that in the final tower, the red block should be higher than the blue and the blue higher than the green. All 6- and 8-year-olds readily mastered these two problems, whereas some of the 4-year-olds had difficulties, occasionally requiring several repetitions before giving the correct response.

Following this initial phase, each child was then given a sequence of nine experimental problems (P1 to P9). The first six problems included two towers (i.e., two premises), whereas the last three problems included three towers (see Appendix for further illustration). In all these problems, once the towers had been introduced, subjects were asked to make an inference about the relative position of two single blocks in the final tower and then to construct the final tower. That is, subjects were given representations of $A < B$, $B < C$ (e.g., in the two-tower problems) and were asked to infer what the relation was between A and C (specifically, whether A was higher or lower than C), before constructing a single tower containing A, B, and C.

P1 (i.e., the first problem) consisted in a set of two two-block premise towers (e.g., red on top of brown, brown on top of blue). Once the two premise towers had been introduced, subjects were asked to infer whether the red block would be on the top or on bottom of the brown in the final tower. Then they had to build the final tower. If they made a mistake in building the final tower they were given feedback about their mistake and were given a second and final chance to build the tower. This problem was a direct replication of the kind of problems used by Pears and Bryant (1990). P2, P3, and P4 consisted also of two premise towers. However some white blocks were included in both towers. These were presented in a variety of ways (see Appendix), but in each case, the colored blocks were so dispersed that there was no contradiction between their relative positions in the premise towers and their relative positions in the final tower. Children also received feedback if they failed to build up the final tower correctly and were given a second and final chance.

P5 also consisted of two premise towers containing both colored and white blocks. However, the information provided by the relative position of the colored blocks in the premise towers was ambiguous as to their ordinal placement in the final tower. Specifically, if the three colours are represented by A, B, and C, blocks A and C were both at the same distance off the ground in their respective towers. P6 consisted of two premise towers containing both coloured and white blocks. In this case, the information provided by the relative position of the coloured blocks was in direct contradiction to their ordinal placement in the final tower. That is, block C was higher off the ground than was block A, although according to the premise towers A could be inferred to be higher than C. In P5 and P6 only one attempt was allowed to build the final tower and no feedback was given.

Following this, subjects were presented with the last three problems (P7 to P9) which all included three towers (i.e., three premises). Four colors were used to construct the three towers so that the final tower contained four blocks. Each problem gave a series of the form $A < B$, $B < C$, $C < D$. For each of these, subjects were asked to make inferences about the relative placement of A and C, and about the relative placement of B and D. P7 repeated the Pears and Bryant condition (i.e., presentation of towers consisting of two colored blocks). P8 contained both colored and white blocks set in a way that the relative positions were similar to that in the first problem. However, P9 was so constructed that the positions of A and C contraindicated their relative position (i.e., C was higher off the ground than was A in the premise towers), while the positions of B and D was ambiguous (B was higher than D in one instance and lower than D in another).

Briefly, in P1, P2, P3, P4, P7, P8, the relative position of the two target blocks in the premise towers was consistent with that in the final tower. However, P5 provided ambiguous information, P6 provided contradictory information, and P9 provided both ambiguous information about one pair of blocks and contradictory information about a different pair of blocks.

Four-year-old children received P1 to P6, whereas 6- and 8-year-olds received all nine problems (order from P1 to P9). The spatial position (i.e., right or left) of the premise towers was counterbalanced across subjects for each problem. For the two-tower problems the spatial location of the two-tower was counterbalanced across subjects whereas for the three-tower problem the position of the far left and far right tower was counterbalanced across subjects. The order of the terms in the inferential questions (i.e., the name of the two target colors) was also controlled. For example, on a given question, half the subjects were asked whether the blue block was higher or lower than the green block, whereas the other half were asked whether the green block was higher or lower than the blue block. Thus, within each sequence of problems, half the questions required the answer "higher than," and half required the answer "lower than."

RESULTS

An initial observation concerned the difficulty of these problems for the 4-year-olds that were studied here. Contrary to Pears and Bryant's subjects, the 4-year-olds we examined had a great deal of difficulty in understanding the instructions, and when they did so, in applying these subsequently to other than the simplest problems. Of the 20 subjects that we examined at this age level, only 12 understood the problem sufficiently after the practice phase to continue on to the experimental problems, with two premise towers. (None of the 4-year-olds were asked any of the three premise tower problems, since they all exhibited fatigue and concentration problems after the two premise tower problems.) The main problem for the 4-year-olds involved accepting that two blocks of the same color should be represented by a single block in the final tower, most of the 8 subjects who had problems with the task refused to make a single tower because there were blocks missing. Data on the 12 subjects who solved at least the two-tower problems was included for descriptive purposes, but the following analysis concentrated on the 6- and 8-year-olds.

The percentage of correct responses to the inferential questions for children in the three age levels is given in Table 1. Examination of this table generally corroborates the results obtained by Pears and Bryant (1990). Performance on the problems for which relative positions were consistent with those given in this latter study was uniformly high for both two and three tower problems, among both 6- and 8-year-olds. (Although many 4-year-olds in this study did not understand the problem, those who did so also performed very well on these problems). In addition, it can be seen that children did not find problems with the white blocks any more difficult than the initial set. One-way McNemar tests were used to examine differences among problem types. This indicated that there was no significant difference for both 6- and 8-year-olds between the initial

TABLE 1

PROPORTION OF CORRECT RESPONSES TO EACH OF THE INFERENTIAL QUESTIONS FOR THE PROBLEMS WITH TWO AND THREE PREMISE TOWERS BY AGE

Problem	Question	Absolute placement	Age 4 (n = 12)	Age 6 (n = 30)	Age 8 (n = 32)
	Problems with two premise towers (A < B, B < C)				
P1	A ? C	Consistent	.92	.90	.88
P2	A ? C	Consistent	1.00	.90	.91
P3	A ? C	Consistent	.83	.77	.94
P4	A ? C	Consistent	.83	.83	.94
P5	A ? C	Ambiguous	.42	.46	.75
P6	A ? C	Contradictory	.33	.27	.63
	Problems with three premise towers (A < B, B < C, C < D)				
P7	A ? C	Consistent	—	.80	.75
P7	B ? D	Consistent	—	.70	.69
P8	A ? C	Consistent	—	.87	.78
P8	B ? D	Consistent	—	.77	.78
P9	A ? C	Contradictory	—	.30	.56
P9	B ? D	Ambiguous	—	.53	.75

two- and three-tower problems and any of the following problems with neutral white blocks that were consistent with the initial problem.

However, among the 6-year-olds, the ambiguous and contradictory problems resulted in clearly lowered success rates. Performance on the ambiguous two-tower problem was significantly worse than that on the last consistent problem (P4), $\chi^2(1) = 7.12$, $p < .005$. In addition, performance on the contradictory two-tower problem was significantly worse than for the corresponding ambiguous problem, although the difference was less marked, $\chi^2(1) = 3.60$, $p < .05$. A similar pattern was found for the three-tower problems. Performance on the ambiguous problem was significantly worse than for the last consistent problem, $\chi^2(1) = 5.40$, $p < .025$, while performance on the contradictory problem was worse than on the ambiguous problem, $\chi^2(1) = 5.44$, $p < .01$. For the 8-year-olds, the pattern was different. For these subjects, analyses showed that performance on the 2 tower ambiguous problem was significantly worse than for the previous two-tower problem, $\chi^2(1) = 3.6$, $p < .05$ and performance on the three-tower contradictory problem was worse than on the ambiguous problem, $\chi^2(1) = 3.6$, $p < .05$ and performance on the three-tower contradictory problem was worse than on the ambiguous problem, $\chi^2(1) = 6.00$, $p < .01$. No significant differences were found on any of the other comparisons.

In addition, there were clear developmental effects. One-way χ^2 analyses showed that the 8-year-olds performed significantly better than the

TABLE 2

PROPORTION OF CORRECT RESPONSES TO THE INFERENTIAL QUESTIONS FOR THE PROBLEMS WITH TWO AND THREE PREMISE TOWERS BY AGE FOR SUBJECTS RESPONDING CORRECTLY TO THE FIRST FOUR PROBLEMS

Problem	Question	Absolute placement	Age		
			4 (n = 9)	6 (n = 19)	8 (n = 23)
	Problems with two premise towers (A < B, B < C)				
P5	A ? B	Ambiguous	.33	.47	.78
P6	A ? B	Contradictory	.33	.11	.78
	Problems with three premise towers (A < B, B < C, C < D)				
P7	A ? C	Consistent	—	.95	.78
P7	B ? D	Consistent	—	.68	.78
P8	A ? C	Consistent	—	1.00	.78
P8	B ? D	Consistent	—	.84	.82
P9	A ? C	Contradictory	—	.16	.56
P9	B ? D	Ambiguous	—	.53	.74

6-year-olds on the ambiguous two-tower problem, $\chi^2(1) = 5.24, p < .025$; on the contradictory two-tower problem, $\chi^2(1) = 8.03$, p < .005; on the ambiguous three-tower problem, $\chi^2(1) = 4.34$, p < .025; and on the contradictory three-tower problem, $\chi^2(1) = 3,18, p < .05$.

The overall data, although interesting, may contain a certain amount of noise, due to the possibility that an unknown proportion of subjects may have responded in ways other than adopting the consistent strategy proposed here (guessing, using various figural cues, etc) which might obscure this analysis. In order to account for this possibility, we decided to specifically examine those subjects who gave the correct inference on each of the first four problems. These children could be considered to show reliable use of a strategy that enabled them to make correct transitive inferences on problems of the sort used by Pears and Bryant. Analysis of these results indicated that 75% of the 4-year-olds (9 of 12), 63% of the 6-year-olds (19 of 30), and 72% of the 8-year-olds (23 of 32) responded correctly to all four problems. The relatively high proportion of children at all three age levels who performed consistently well indicates clearly that they do possess a reliable strategy for making correct transitive inferences in this particular situation. The results of these subjects on the remaining problems are detailed in Table 2.

Examination of Table 2 gives a clearer picture of how subjects who consistently give correct inferences on the initial problems react to problems where the position of the critical elements are either ambiguous or contradictory. For the 6-year-olds, performance on the two ambiguous problem was very close to 50% (47 and 53%, respectively) and was not significantly different from chance in either case (χ^2 = .03, n.s., for both

TABLE 3

RELATION BETWEEN TOWER CONSTRUCTION AND INFERENTIAL RESPONSES (IN ABSOLUTE NUMBERS) FOR THE CONTRADICTORY AND THE AMBIGUOUS PROBLEMS BY AGE

		Response to inferential question			
		6-year-olds		8-year-olds	
Problem type	Tower construction	Correct	Incorrect	Correct	Incorrect
	Problems with two premise towers (A < B, B < C)				
Contradictory	Correct	6	7	18	6
	Incorrect	1	16	2	6
Ambiguous	Correct	8	5	21	3
	Incorrect	5	12	3	5
	Problems with three premise towers (A < B, B < C, C < D)				
Contradictory	Correct	7	6	18	5
	Incorrect	2	15	0	9
Ambiguous	Correct	9	4	22	1
	Incorrect	7	10	2	7

cases). Performance on the contradictory problems was very low in both cases (11 and 16%, respectively), and was not significantly different from zero (χ^2 = .53, n.s. for the two-tower problem, χ^2 = 1.45, n.s. for the three-tower problem). For the 8-year-olds, performance on both the ambiguous and contradictory problems was superior to that of the 6-year-olds. In fact, performance on the ambiguous and contradictory two-tower problems and on the ambiguous three-tower problem was close to 75% for the older children. Only on the three-tower contradictory problem did performance fall below this level.

Tower Construction and Inferences

Although the inferential task did not itself necessitate tower construction, it is interesting to examine more closely the relation between the two. This is particularly the case, since constructing the appropriate tower requires understanding the relations between the premises in the same way required for making correct inferences, while providing the possibility for concrete manipulation. Table 3 shows the relation between tower construction and inferential performance for the contradictory and ambiguous problems. It should be noted that in the case of the three premise towers problem, only one tower was constructed, while two inferential questions were asked.

We concentrated our analyses initially on the contradictory problems. Inspection of Table 3 indicates some interesting patterns. First, there is a clear relation between inferential performance and tower construction. Among the 6-year-olds who responded correctly to the inferential question, the proportion who constructed correct towers was 86% (6 of 7) on the two-tower problem, and 78% (7 of 9) on the three-tower contradictory problem. The corresponding proportions among the 8-year-olds were 90% (18 of 20) and 100% (18 of 18) respectively. Thus, it was the case that on these problems correct inferential performance was a good guarantee of correct tower construction. The inverse relation was however not quite as strong. Among the 6-year-olds who correctly constructed the final tower, the proportion who responded correctly to the inferential questions was 46% (6 of 13) on the two-tower problem, and 54% (7 of 13) on the three-tower contradictory problem. The corresponding proportions among the 8-year-olds were 75% (18 of 24) and 78% (18 of 23) respectively. Thus, for the 6-year-olds, tower construction appears easier than inferential performance, while there is little difference for the 8-year-olds who do well on both inference and construction. The McNemar test was used to examine the differences among the 6-year-olds. This indicated that tower construction was significantly easier than inferential performance on the two-tower problem, $\chi 2 = 4.50$, $p < .05$, although this was not the case on the three-tower problem, $\chi^2 = 2.00$, $p < .20$.

The corresponding data concerning the ambiguous problems is less clear-cut. No significant differences were found between ease of tower construction and inferential performance. In addition, the relation between incorrect tower construction and inferential response was somewhat different for the ambiguous problems. For the two- and three-tower contradictory problems 6 and 12%, respectively, of these subjects gave a correct inferential response, a level close to zero. The corresponding proportions on the ambiguous problems were higher than this, 29 and 41%, respectively.

Figural Effects

Another question that can be asked here concerns the possibility that the children's inferences might be affected by the spatial configuration of the premise towers, or by the phrasing of the inferential questions. Although no such phenomena have (to our knowledge) been previously reported in this context, and Pears and Bryant did not find any such effect in their study, there is clear evidence that figural effects do exist in syllogistic reasoning (Johnson-Laird & Steedman, 1978). The explicit controls that we integrated into this study permit at least summary examination of this question.

Accordingly we performed an Anova with number of correct responses as dependent variable and Spatial position and Form of the inferential question as independent variables, for each of the 12 inferential questions. This indicated no significant effects of either variable on the problems that were consistent with the Pears and Bryant ones. On the two-tower contradictory and ambiguous problems and on the three-tower contradictory problem, there were significant effects of both Spatial position and Form of the question. Given the small number of subjects, these results cannot be taken as more than indicative, but they do indicate that some sorts of figural effects might come into play on the more complex problems.

DISCUSSION

Before examining the results of this study in more detail, it is worthwhile to reiterate the context in which this study was undertaken. The purpose of this study was not to continue the polemic about whether or not young children can or cannot make transitive inferences. We considered that the Pears and Bryant (1990) study created a convincing method for presenting children with a representation of the premises required for transitive inferences while reducing (if not eliminating) the possible influence of short-term memory limitations. We also found that their conclusion that young children could *in this situation* make correct transitive inferences with a relatively high degree of probability is convincing. The results of the present study generally confirm this, if not for 4-year-olds, then certainly for 6-year-olds. We concluded from these results that young children possess a cognitive strategy that enables them to make correct inferences with the specific configuration of premises presented in the Pears and Bryant study. This strategy must involve at least recognition of the role of the middle term in a three-term transitive series as a marker for correct premise choice. We then wished to examine whether these children used a strategy based on the relative position of the two extreme terms in the series, or whether they possessed a strategy that involved placing all three elements on an ordinal scale by composing their relative positions with respect to the middle term. In order to do this, we presented children with problems that were consistent with those used by Pears and Bryant and some that presented different kinds of relationships between the relative positions of the extreme terms and their ordinal position. For the 6-year-olds in this study, the results are particularly clear, especially if we examine the performance of children who responded correctly to the first four inferential problems, which were consistent with those used by Pears and Bryant. Performance on the contradictory problems was, for both two- and three-tower versions, very close to 0. Performance on the ambiguous problems was close to 50% in both cases. This is clearly consistent with a strategy that considers the relative position of the A and C terms in the sequence $A > B$, and $B > C$, as corresponding to their relative position in the final tower, irrespective of their positions with respect to the middle term, B. Note that in the case of the 4 initial problems, such a strategy would give consistently good results, which is what was in fact observed. In the case of the contradictory problems, use of this strategy would lead to subjects consistently making the wrong inference. In the case of the ambiguous problems, such a strategy would presumably lead to an indeterminate result, which would lead to either guessing, or to some figurally based strategy which would in either case give a random result, which is once again consistent with what was observed. Before considering the performance of the older children, it is important to place this strategy in a developmental perspective. As previously mentioned, we found that the 4-year-olds in this study did have a great degree of difficulty in understanding the nature of the task. A critical problem concerned the difficulty that many had in accepting that two distinct blocks of the same color could in fact represent a single element in the final tower. This, along with similar results concerning young children's relative difficulty in memorizing sequences of the form A > B, B > C (Perner & Mansbridge, 1983), suggests that the strategy that we describe here is preceded by one which uses absolute position as the main indicator for inferential performance. Thus, the younger children's strategy can be viewed as a positive step on what appears to be a multi-levelled developmental sequence.

In this context, another point concerns the relative strength of the recognition that a common middle term defines a three point series among the younger children. Specifically, the three-tower ambiguous problem that we used in this study (see Appendix) is in some ways similar to those used by Pears and Bryant in that there is ambiguity only if the subject does not recognize the role of the middle term. The relatively poor performance of the 6-year-olds on this problem lead us to believe that they did not do so very often in the present context. One possible explanatory factor lies in the more complex configuration of the problem. This might be expected to have an effect particularly if the corresponding strategy is not well established. This lead us to re-examine Pears and Bryant's results. In fact, their data indicate that when young children responded to inferential problems which were not anchored (i.e., did not involve an end-point in the tower), their performance, while above chance level, was not consistently so. For example, on the four-tower problem (A < B< C < D < E), the B-D comparison was responded to at above chance level on only two out of four trials. Similar results were obtained on the five-tower problem. These results are thus consistent with the notion that young children's recognition of the middle term is not firmly established and that its use might well be subject to constraints, including figural effects.

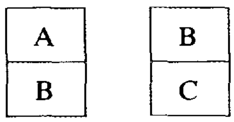
Examining the performance of the older children is more difficult, partially because their overall performance was quite good on all the problems. Clearly, these children possess a strategy that allows them to generate a generally consistent ordinal scale involving relative positions among all three elements. However, the question of what the nature of this strategy might be remains interesting, and the data here provide some clues as to this. A first remark concerns the relative ease of tower construction, compared to inferential performance, on the contradictory problems among the younger children. In this case, correct tower construction requires the same basic cognitive operation that making inferences does. The fact that tower construction is easier supports the idea that the strategy that is deployed to solve the contradictory problems may well be figurally based, as opposed to some kind of abstract representation of the relative positions of the elements in the series used here. This supposition is also consistent with the greater difficulty that the older subjects had with the three-tower contradictory problem compared with the two-tower contradictory problem, and with the existence of figural effects on the contradictory and ambiguous problems.

A final point concerns the relation between the results of this study and the debate about whether young children can make transitive inferences. Both in the introduction and in the discussion, we have been fairly careful about not addressing this point. Indeed, we can distinguish three possible interpretations of our results. The first would claim that the younger children in this study are able to make transitive inferences, and that the experimental manipulations that we have introduced into the Pears and Bryant task simply add a level of complexity that masks their basic competence (Brainerd & Kingma, 1984; Bryant & Trabasso, 1971). In this view, the difficulties that young children have in making correct inferences would be attributable to retrieval failure rather than to any competence deficit. The second would claim that only the older children in this study possess real transitive competence, since only they are able to unambiguously coordinate relative information in a way that leads to correct transitive inferences in situations for which there are no direct or indirect cues (Breslow, 1981; Chapman & Lindenberger, 1992; Halford, 1984). These two interpretations have underlaid much of the debate about transitivity, and there is no way that we can think of that would eliminate either, since the problem may be essentially one of definition (Gellatly, 1992). The third interpretation would simply claim that children develop a series of progressively more complex algorithms that enable them to make adequate transitive inferences in progressively more complex situations. In this context, the question of what constitutes a real transitive inference is best left undecided, until some consensus about definition is arrived at. Although we clearly prefer the third interpretation, we can propose no way of deciding between them.

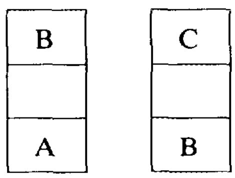
Finally, the proposed sequence of algorithms is of course based on the specific experimental paradigm used here. However, the basic ideas are applicable to any kind of transitive relation that can be expressed figurally. In fact, the mental models paradigm considers that any transitive relation can be so modeled (Johnson-Laird, 1993, personal communication), which implies that such a developmental sequence may, at least theoretically, apply to all transitive relations.

APPENDIX

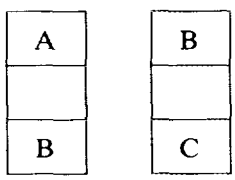
Premise Towers and Inferential Questions for the Nine Experimental Problems (Note for Half the Subjects the Questions Used "Lower Than")

P1.


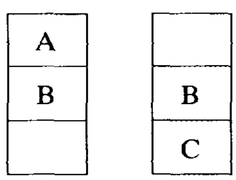
Is A higher than C?

P2.


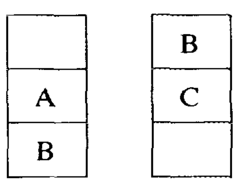
Is A higher than C?

P3.


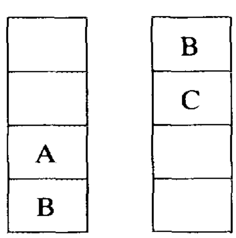
Is A higher than C?

P4.


Is A higher than C?

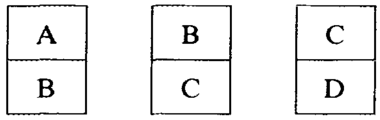
P5.


Is A higher than C?

P6.


Is A higher than C?

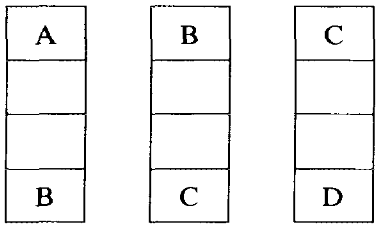
P7.



Is A higher than C?

Is B higher than D?

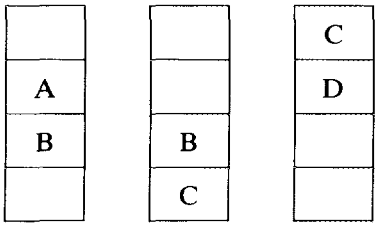
P8.



Is A higher than C?

Is B higher than D?

P9.



Is A higher than C?

Is B higher than D?

REFERENCES

de Boysson Bardies, B., & O'Regan, K. (1973). What children do in spite of adults' hypotheses. *Nature*, **246**, 531–534.

Brainerd, C. J., & Kingma, J. (1984). Do children have to remember to reason? A fuzzy-trace theory of transitivity development. *Developmental Review*, **4**, 311–377.

Brainerd, C. J., & Reyna, V. F. (1992). Explaining "memory free' reasoning. *Psychological Science*, **3**, 332–339.

Brainerd, C. J., & Reyna, V. F. (1993). Memory independence and memory interference in cognitive development. *Psychological Review*, **100**, 42–67.

Breslow, L. (1981). Re-evaluation of the literature on the development of transitive inferences. *Psychological Bulletin*, **89**, 325–351.

Bryant, P. E., & Trabasso, T. (1971). Transitive inferences and memory in young children. *Nature*, **232**, 456–458.

Chapman, M., & Lindenberger, U. (1992a). Transitivity judgements, memory for premises, and models of children's reasoning. *Developmental Review*, **12**, 124–163.

Chapman, M., & Lindenberger, U. (1992b). How to detect reasoning-remembering dependence (And how not to). *Developmental Review*, **12**, 187–198.

Gellatly, A. (1992). The misleading concept of cognitive competence. *Theory and Psychology*, **2**(3), 363–390.

Halford, G. S. (1984). Can young children integrate premises in transitivity and serial order tasks? *Cognitive Psychology*, **16**, 65–93.

Johnson-Laird, P. N., & Steedman, M. (1978). The psychology of syllogisms. *Cognitive Psychology*, **10**, 64–99.

Pears, R., & Bryant, P. E. (1990). Transitive inferences by young children about spatial position. *British Journal of Psychology*, **81**, 497–510.

Perner, J., & Mansbridge, D. G. (1983). Developmental differences in encoding length series. *Child Development*, **54**, 710–719.

Piaget, J. (1921). Une forme verbale de la comparaison chez l'enfant. *Archives de Psychologie,* **18,** 141–172.

Piaget, J, Inhelder, B., & Szeminska, A. (1960). *The child's conception of geometry.* London: Routledge & Kegan Paul.

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