DOCUMENT RESUME

ED 174 663 TM 009 539

AUTHOR	Sternberg, Robert J.
TITLE	The Development of Linear Syllogistic Reasoning. Technical Report No. 5. Cognitive Development Series.
INSTITUTION	Yale Univ., New Haven, Conn. Dept. of Psychology.
SPONS AGENCY	National Science Foundation, Washington, D.C.
PUB DATE	Apr 79
GRANT	NSF-BNS76-05311
NOTE	31p.
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	*Abstract Reasoning; *Age Differences; Algorithms; *Cognitive Development; *Cognitive Processes; Elementary Secondary Education; Linguistic Patterns; *Models; *Problem Solving; Reaction Time; Thought Processes; Visualization
IDENTIFIERS	*Syllogistic Reasoning

ABSTRACT

About 25 children in each of grades 3, 5, 7, 9, and 11 were tested in their ability to solve linear syllogisms, such as: John is taller than Mary. Mary is taller than Pete. Who is tallest--John, Mary, or Pete? Response latencies and error rates decreased across grade levels and sessions. Component latencies also generally decreased with increasing age. Four alternative information-processing models were fit to the group latency data at each grade level. These models were: (1) spatial, whereby the terms of a linear syllogism are represented in the form of a linear spatial array; (2) linguistic, whereby linear syllogisms are solved via inferences on functional relations represented by linguistic deep structures; (3) algorithmic, whereby people solve linear syllogisms by applying a series of simple, essentially mechanical steps; and (4) mixed, which combines selected features of the spatial and linguistic models, and adds new features of its own. The latency data supported the mixed model at each grade level, although in grade 9 the model was not the preferred one until the second session of testing. (Author/MH)

The Development of Linear Syllogistic Reasoning

Robert J. Sternberg
Yale University

Running head: Linear Syllogistic Reasoning

Send proofs to Robert J. Sternberg
Department of Psychology
Yale University
Box 11A Yale Station
New Haven, Connecticut 06520

Abstract

Between 24 and 26 children in each of grades 3, 5, 7, 9, and 11 (with mean ages of 8.5, 10.2, 13.0, 15.0, and 16.6 years, respectively) were tested in their ability to solve linear syllogisms, problems such as "John is taller than Mary. Mary is taller than Pete. Who is tallest? John, Mary, Pete." Response latencies and error rates decreased across grade levels and sessions. Component latencies also generally decreased with increasing age. Four alternative information-processing models were fit to the group latency data at each grade level. These models were (a) a spatial model, according to which people represent the terms of a linear syllogism in the form of a linear spatial array; (b) a linguistic model, according to which linear syllogisms are solved via inferences on functional relations represented by linguistic deep structures; (c) an algorithmic model, according to which people solve linear syllogisms by applying a series of simple, essentially mechanical steps; and (d) a mixed model, which combines selected features of the spatial and linguistic models, and adds new features of its own. The latency data supported the mixed model at each grade level, although in grade 9 the model was not the preferred one until the second session of testing.

The Development of Linear Syllogistic Reasoning

If one is told that John is taller than Mary, and that Mary is taller than Pete, one will probably infer that John is taller than Pete. Such an inference is called a transitive inference, because it involves a chain of reasoning in which the relation between two objects in an array that are not explicitly linked is inferred from the relations between two pairs of objects that are explicitly linked. The importance of the child's ability to make transitive inferences appears first to have been recognized by Burt (1919), who used transitive inference problems such as the one above on a subtest of intelligence. In this particular kind of transitive inference problem, called a linear syllogism, children are usually asked to identify the person (or object) at either end of the underlying linear continuum. Thus, in the example above, children would be asked either "Who is tallest?" or "Who is shortest?" The child would then respond with either "John" or "Pete," respectively.

The developmental literature on transitive inference has focused upon two key questions. The first, and by far the more thoroughly researched, is that of the age at which the ability to make transitive inferences first appears. The second, and less thoroughly researched question, is that of how children of different ages actually make transitive inferences.

The literature on the first question is usually traced back to the research of Piaget (1921, 1928, 1955, 1970). According to Piaget's theory of the development of intelligence and logical operations, transitive inferences are beyond children's logical capabilities until the concrete-operational stage of development, which usually begins at about six or seven years of age. This theoretical claim was challenged by Bryant and Trabasso (1971), who provided compelling evidence that the failure of preoperational children to perform transitive inferences is due to memory rather than logical limitations. When memory requirements in transitive inference problems are greatly reduced, preoperational children become able to solve the problems. Subsequent research by Trabasso and his colleagues has supported the earlier finding of Bryant and Trabasso (1971) (see Riley & Trabasso, 1974; Trabasso, 1975).

The developmental literature on the second question can be traced back at least to Hunter (1957), who proposed a model of linear syllogistic reasoning that he tested on 11- and 16-year olds. The model, which asserts that people solve linear syllogisms by rearranging premises into a canonical form whereby the second term of the first premise matches the first term of the second premise (as in "John is taller than Mary, Mary is taller than Pete"), has not held up under subsequent investigation, and is no longer considered to be viable (see Clark, 1969a, 1969b; Huttenlocher, 1968; Johnson-Laird, 1972). Subsequently, Trabasso and Riley proposed a model of transitive inference according to which people are alleged to represent objects in a mental analogue to a visual array. The array is constructed from the ends, inward (see Riley, 1976; Trabasso, 1975; Trabasso & Riley, 1975; Trabasso, Riley, & Wilson, 1975). The data sets collected so far seem to support this model for children as young as six years of age. Tests of the model have been on arrays of objects such as colored sticks and faces: The applicability of the model to the linear syllogistic form of transitive inference has not been tested, nor is it clear exactly what form the model would take were it to be applied to linear syllogistic reasoning.

The bulk of the literature on transitive inference in general, and on linear syllogistic reasoning in particular, has concerned itself with information processing in normal adults. There are currently four major models of linear syllogistic reasoning. First, DeSoto, London, and Handel (1965) proposed a spatial model of linear syllogistic reasoning, according to which people represent the terms of a linear syllogism in the form of a linear spatial array. The spatial model has been refined and expanded by Huttenlocher (1968) and by Huttenlocher and Higgins (1971). Second, Clark (1969a, 1969b) has proposed an alternative linguistic model, according to which linear syllogisms are solved via inferences on functional relations represented by linguistic deep structures. Third, Quinton and Fellows (1975) have suggested an algorithmic model for the solution of linear syllogisms that seems almost to bypass the need for reasoning altogether. Using this model, people can solve determinate linear syllogisms (those in which the complete ordering of the three terms can be inferred) by applying a series of simple, essentially mechanical, steps. Finally, Sternberg (in press-a, in press-b) has proposed a mixed model of linear syllogistic reasoning that combines selected features of the spatial and linguistic models, and contains new features of its own. A series of experiments varying a variety of experimental conditions provided strong support for this model over its competitors (Sternberg, in press-a, in press-b; Sternberg & Weil, Note 1), and the model was also found to be preferred when applied to data sets previously reported in the literature.

Of these four models of linear syllogistic reasoning (i.e., the spatial, linguistic, algorithmic, and mixed models), only the linguistic model has been tested developmentally. Keating and Caramazza (1975) found that the linguistic model was consistent with the pattern of error rates obtained under a 10-second deadline paradigm. In this paradigm, children were given ten seconds to solve each problem. They were considered to have made an error if either they failed to respond within the 10-second time limit, or if they responded incorrectly during this time. The algorithmic and mixed models could not, of course, have been tested by Keating and Caramazza, since these models had not yet been proposed; the spatial model could have been tested, but wasn't. The tests the authors did conduct must be interpreted with at least some caution: It has been found subsequently that the model best fitting error data collected under the deadline paradigm is not the same as the model best fitting latency data collected under a standard response-time paradigm, in which subjects are given as long as they need to solve each problem (Sternberg, in press-a).

To summarize, the mixed model has been found to account best for the performance of adults solving linear syllogisms (Sternberg, in press-b). We do now know, however, which model best accounts for the information processing of children, nor do we even know whether children of varying ages use a single model. It is possible, for example, that the mixed model develops out of either a pure linguistic model or a pure spatial model, or that use of these latter two models alternates in the developmental sequence, to be followed by a convergence attained through the use of the mixed model. Flavell (1977) notes that "we have to ask what range and diversity of cognitive phenomena we may be tapping when we try to measure 'transitive inference' in children of different cognitive-developmental levels. What are the different possible meanings and manners of 'having,' of 'possessing,' something like transitive inference" (p. 226)? Smedslund (1969) has noted the importance of determining "the exact content and sequencing of the mental processes involved in solving a given task" (p. 244), which has led Flavell (1977) to ask "what actually happens, in cognitive-process terms, between problem presentation and the subject's response? When confronted with the problem, he or she presumably assembles and executes cognitive processes of some sort, processes that are integrated and sequenced in some fashion. What are those processes and how are they organized, e.g., in the case of transitive inference" (pp. 228-229)? Thayer and Collyer (1978) have specifically recommended a developmental process analysis of verbal problems of the kind represented by linear syllogisms, and it is this kind of analysis that was done in the present experiment.

The Mixed Model of Linear Syllogistic Reasoning

This section describes the recently proposed mixed model of linear syllogistic reasoning (Sternberg, in press-b). Because the alternative models are based upon previously published work,[1] descriptions of these models are relegated to an appendix.[2] The mixed model will be described with reference to the linear syllogism, "*C* is not as tall as *B*; *A* is not as short as *B*; Who is shortest?" In this problem, *C* is shortest (and *A* is tallest).

According to the mixed model of linear syllogistic reasoning, the terms of a linear syllogism are first decoded into linguistic deep-structural propositions and are then encoded into spatial arrays. The individual begins solution by decoding the surface-structural premises into deep-structural strings, initially ignoring negations. For example, the premises of the example item would be represented as (*C* is tall+; *B* is tall); (*A* is short+; *B* is short). Marked adjectives (i.e., the contrastive senses of adjectives, such as *short* and *shorter*) are assumed to increase processing time over that required for unmarked adjectives (i.e., the positive senses of adjectives, such as *tall* and *taller*) through increased linguistic decoding time. The terms in each linguistic string are then arranged into a two-item array. The initial arrangement disregards the negation, if one is present. Then, the first pair of terms is arranged as $\begin{matrix}C\\B\end{matrix}$ and the second pair as $\begin{matrix}B\\A\end{matrix}$. Arrangement for relations represented by marked adjectives is assumed to take longer than arrangement for relations represented by unmarked adjectives. (Thus, the effect of marking in adjectives is both linguistic and spatial.) Next, if a negation appears in a premise, a new array is constructed in which the terms of the old array are flipped around in space. In the example, two new arrays, $\begin{matrix}B\\C\end{matrix}$ and $\begin{matrix}A\\B\end{matrix}$, are constructed.

In order for the person to combine the terms of the premises into a single spatial array, the person needs the pivot, or middle term, available. The pivot is either immediately available from the spatial encoding of the premises, or else it must be located. The pivot is immediately available in all (a) affirmative problems and (b) negative problems in which the second premise begins with the pivot (see Sternberg, in press-b, for a description of the mechanism of pivot search). In the example problem, the second negative premise does not begin with the pivot, but with an end term, so that the pivot must be located as the term that overlaps between the two two-item spatial arrays. Once the pivot has been located, the person seriates the terms from the two two-item spatial arrays into a single three-item spatial array. In forming the array, the person starts with the terms of the first premise and ends with those of the second premise. The person's mental location after seriation, therefore, is in that half of the array described by the second premise (which is the top half in the example). The person next reads the question. If there is a marked adjective in the question, the person will take longer to decode the adjective linguistically, and to seek the response to the problem at the nonpreferred (usually bottom) end of the array. The response may or may not be immediately available. If the correct answer is in the half of the array where the person just completed seriation (his or her active location in the array), then the response will be immediately available. If the question requires an answer from the other half of the array, however, the person will have to search for the response, mentally traversing the array from one half to the other and thereby consuming additional time. In the example, the person ends up in the top half of the array, but is asked a question about the bottom half of the array ("Who is shortest?"), requiring search for the response.

Under certain circumstances (see Sternberg, in press-b), the person checks the linguistic form of the proposed response against the form of the adjective in the question. If the two forms are congruent, the person responds with the designated answer. If not, the person first makes sure that congruence can be established, and then responds. In the example, congruence must be established, since the shortest term, _C_, has previously been decoded in terms of the adjective, _tall_. Once congruence has been established, _C_ can be recognized as the correct answer to the example problem.

Method

Subjects

Subjects were 24, 25, 26, 25, and 24 children in each of grades 3, 5, 7, 9, and 11, respectively. Mean ages at each of the respective grades were 8.5 years, 10.2 years, 13.0 years, 15.0 years, and 16.6 years. Children from grades 3 and 5 were from two elementary schools in a middle-class suburb of New Haven, Connecticut; children from grades 7 and 9 were from the junior high school into which the two elementary schools fed; andchildren from grade 11 were from the high school into which the junior high school fed. Children were approximately equally balanced between sexes.

Materials

Stimuli were two-term series problems and three-term series problems (linear syllogisms). The 32 types of three-term series problems varied dichotomously along five dimensions: (a) whether the first premise adjective was marked or unmarked; (b) whether the second premise adjective was marked or unmarked; (c) whether the question adjective was marked or unmarked; (d) whether the premises were affirmative or negative; (e) whether the correct answer was in the first or second premise. The 8 types of two-term series problems varied dichotomously along three dimensions: (a) whether the premise adjective was marked or unmarked; (b) whether the question adjective was marked or unmarked; (c) whether the premise was affirmative or negative. There were two replications of each item type, one using the adjective pair _taller-shorter_, the other using the adjective pair _better-worse_ (where _worse_ is the marked form).

All terms of the problems were boys' or girls' names, although a given problem contained the names of members of only one sex. For example, a typical three-term series problem would be "John is taller than Bill; Sam is shorter than Bill. Who is tallest? John, Sam, Bill." A typical two-term series problem would be "John is taller than Bill. Who is shortest? John, Bill." The ungrammatical superlative was used in the question for the two-term series problems, as is standard, in order to provide maximum comparability to the three-term series problems.

Apparatus

Problems were administered via a homemade, portable tachistoscopic device with attached centisecond clock. Stimulus cards were initially hidden by a wooden shutter. Dropping of the shutter by the experimenter would reveal the stimulus to the subject, and would also start the clock.

Procedure

Children were tested individually. The experimenter first talked to the child, attempting to establish communication and rapport. She then showed each child examples of two- and three-term series problems, and told the child that the task was to solve problems of these types. Problems were presented in the form of a game. Children were encouraged to be as accurate as possible and to answer as soon as they had attained the correct answer, but no sooner. Testing was done in two sessions, with problems based upon one adjective pair presented in one session, and problems based upon the other adjective pair presented in the other session. Order of adjective pairs was counterbalanced over subjects. Items were blocked by number of terms (two or three), with order of blocks varying across sessions within subjects: Half of the subject received the two-term problems first in the first session and second in the second session; the other half of the subjects received the reverse ordering.

Design

The primary independent variables were grade level and testing session. The primary dependent variable was response latency. A secondary dependent variable was error rate.

Quantification of Models[3]

Parameter estimation was done by linear multiple regression, using solution latency for each item type as the dependent variable, and structural aspects of the items as independent variables. Solution latency was predicted as the sum of the number of times each hypothetical operation had to be executed, which was given as an independent variable, times the duration of each hypothetical operation, which was estimated as a parameter.

Consider, for example, how response latency would be estimated for the sample problem, "C is not as tall as B; A is not as short as B; Who is shortest?" According to the mixed model, solution of the problem requires encoding of two premises, processing of two marked adjectives, processing of two negations, search for the pivot, search for the response, establishment of congruence, and a response. Hence, the mixed model predicts that for this problem,

Response Latency = (2) (Premise Encoding Time) +
(2) (Adjective Marking Time) +
(2) (Negation Time) +
(1) (Pivot Search Time) +
(1) (Response Search Time) +
(1) (Congruence Time) +
(1) (Response Time)

Parameter estimation becomes possible by systematically varying the number of operations required over various item types.[4] Since only one response is ever required, response component time is estimated as the regression constant.

Results

Table 1 shows basic statistics and model fits for the experiment. Observations for latency data take into account correct responses only. Identical analyses were performed for all responses, including erroneous ones: These results are not presented separately, since the patterns of data were practically indistinguishable from those presented in the table.

Insert Table 1 about here

Response latencies show a general decline both across grades and across sessions. An analysis of variance on the latencies for the three-term series problems reveals both effects to be statistically significant, $F(4,119) = 12.34$, $p < .001$ for grade, $F(1,119) = 11.76$, $p < .001$ for session. As expected, the interaction between grade and session is not significant, however, $F(4,119) = .65$, $p > .05$. Sets of data for two- and three-term series problems combined show the same pattern of significant and nonsignificant effects, as do the sets of data for error rates.

Each of the four alternative models of linear syllogistic reasoning was fit to the group latency data for children at each grade level. With one exception, the results of these analyses are straightforward. The mixed model performs better than the three alternative models at each of the grade 3, grade 5, grade 7, and grade 11 levels. The linguistic model is better at the grade 9 level. An examination of the data for the separate sessions reveals that the superiority of the linguistic model at this level is time-bound: The linguistic model performs better than the mixed model in the first session, but worse in the second session. Because the superiority of the linguistic model in the first session is greater than the superiority of the mixed model in the second session, the linguistic model performs better overall. But since there is no evidence of this or any other strategy shift at any other grade level. It seems wise to interpret the strategy shift with caution, pending replication of the result. The result seems as likely to be due to chance as to systematic variation. At the present time, it appears that the mixed model is probably the preferred model of linear syllogistic reasoning at each of the grade levels; at the grade 9 level, it is possible that this model is not used until some practice with the items is achieved.

The values of R^2 (proportion of variance in the data accounted for by each model) are much higher when two- and three-term series problems are combined than when three-term series problems are considered alone. The reason for the difference in R^2 is that when the two types of problems are combined, it becomes possible to separate an encoding parameter from the general response constant. This encoding parameter is the largest of the regression parameters (in both raw and standardized regression weights), and hence when it is separated from the global constant, it greatly increases the proportion of variance accounted for in the data.

The values of R^2 need to be considered in conjunction with the reliabilities of the data, since the internal consistency reliability of a data set provides a theoretical upper limit on the value of R^2 for that data set.[5] Coefficient alpha reliabilities (computed for possible subsets of subjects) for the three-term series problem data were .42, .51, .76, .73, and .80 for grades 3, 5, 7, 9, and 11, respectively. These reliabilities indicate that the mixed model performed about as well as it could have at the two lowest grade levels, and performed quite creditably at the other grade levels as well. The mixed model is almost certainly not the "true" model of performance, especially at the upper grade levels. But information-processing models such as this one almost inevitably represent simplifications of the complex, possibly nonlinear processing that people do. At best, these models capture the major features of the model or models people actually use.

Figure 1 plots latencies for the response and encoding components, and for the other components combined (and referred to as "comparison"). These other components were not estimated reliably enough to justify separate plots of their latencies. The figure also shows composite response latency (which is the sum of the component latencies) for the two- and three-term series problems combined. Component times show a generally decreasing

---

Insert Figure 1 about here

---

pattern, with one perturbation in each of the encoding and comparison curves. It is of some interest that the numerous comparison components (accounting for five of the seven estimated parameters) accounted for relatively little of the total processing time. A similar pattern of results has been found in investigations of reasoning by analogy (see Sternberg, 1977a, 1977b; Sternberg & Rifkin, 1979; Sternberg & Nigro, Note 2). The particularly long latency of the response component reflects the fact that it is confounded with other elementary component latencies (see footnote 4).

Discussion

The research of Trabasso and Riley has suggested that from the age of about six, onward (see Riley, 1976; Trabasso, 1975; Trabasso & Riley, 1975), children seem to use a single kind of representation in solving transitive inference problems. This representation, a visualized linear order, seems to hold across the various kinds of objects that these investigators have studied. Similarly, the present study suggests that a single information-processing model accounts for the linear syllogistic reasoning of children from the age of about eight, onward: There is no convincing evidence of a strategy change with age. The fit of the preferred, mixed model, increases substantially from grade 3 to grade 5, and then increases again from grade 9 to grade 11. This increase appears to reflect increased consistency in the use of any strategy at all, rather than increased use of the mixed model as opposed to alternative ones. This conclusion follows from the fact that the internal-consistency reliabilities for the combined sessions show patterns of increase identical to those of the values of R^2 for the combined sessions. This increasing systematization appears to be a general developmental trend (see Sternberg & Rifkin, 1979; Sternberg & Nigro, Note 2). As they grow older, children become more consistent in their use of strategy, and for linear syllogisms, this strategy appears to be that represented by the mixed model.

Appendix

This appendix provides a verbal description of three alternative models of linear syllogistic reasoning: a spatial model, a linguistic model, and an algorithmic model.[6] Flow charts and more detailed descriptions of the first two of these models, plus the mixed model, can be found in Sternberg (in press-b). The models will be described by reference to the sample problem, "C is not as tall as B; A is not as short as B; Who is shortest?" In this problem, C is shortest and A is tallest.

Spatial Model

In the spatial model, the terms of the linear syllogism are arranged into an imaginal, linear spatial array that is an analogue of a physical, linear array. Thus, the terms of the sample problem will be arranged into an imagined array in which A is at the top, B is in the middle, and C is at the bottom.

The person must first read the terms of the problem. The terms in each premise are first arranged in a two-item array. The initial arrangement disregards the negation, if one is present. Thus, the first pair of terms is arranged as $\begin{smallmatrix}C\\B\end{smallmatrix}$ and the second pair as $\begin{smallmatrix}B\\A\end{smallmatrix}$. Arrangement of terms from the top down (as is done when the adjective tall or taller appears in the premise) is easier and hence faster than arrangment of terms from the bottom up (as is done when the adjective short or shorter appears in the premise). Next, if a negation appears in a premise, a new array is constructed in which the terms of the old array are flipped around in space. In the example, two new arrays, $\begin{smallmatrix}B\\C\end{smallmatrix}$ and $\begin{smallmatrix}A\\B\end{smallmatrix}$, are constructed.

The person next attempts to integrate the two arrays. This integration will be easier if the person worked from the ends of the combined array inward, rather than from the middle outward, in constructing the two individual arrays.

A possible reason for this directional effect is that working from the ends inward brings one to the pivot, or middle term of the series. If one ends up on the middle term, then it is immediately available for use as the pivot of the larger array. If one does not end up on the middle term, one must search for it, taking additional time. In an affirmative problem, this means that the preferred order of terms in a premise is the outermost term followed by the middle term. In a negative problem (such as the sample problem), the preferred order is reversed, since the flipping of terms reverses the last term to be encoded in working memory.

Just as it was easier to work from the top down within each of the two two-item arrays, so it is easier to work from the top down across the two two-item arrays. In this way, processing is facilitated if the first premise consists of the _A_ and _B_ (top two) terms of the array, rather than the _C_ and _B_ terms, as in the example. The person integrates the two arrays into a single array,

A
B
C

reads the question, and then seeks the answer to the question in the array. In the example, the correct answer is _C_.

Linguistic Model

In the linguistic model, the terms of the syllogism are stored by way of functional relations that represent the relation between the terms at the level of linguistic deep structure: (_B_ is tall+; _C_ is tall); (_B_ is short+; _A_ is short). In the linguistic model, unlike in the spatial model, information from the two premises is left unintegrated.

The person begins solution by encoding the surface-structural strings into linguistic deep structures of the kind shown above. Marked adjectives (such as _short_ and _shorter_) are assumed to be stored in more complex form than unmarked adjectives (such as _tall_ and _taller_), and hence are assumed to take longer to encode. The initial encoding disregards the negation, if one is present. Thus, the first pair of terms is arranged as (C is tall+; B is tall) and (A is short+; B is short). Upon encountering the negations, the person effects a linguistic transformation that brings the propositional strings to the form shown in the preceding paragraph.

It is assumed in this model that in order to conserve space in working memory, the encoding of the first premise is compressed, so that only the first relation, in the example, (B is tall+), remains in working memory. Since B is the middle term, the pivot of the three-item relation is retained in working memory, and locating it does not present a problem. But if the first premise had been "B is not as short as C," only (C is short+) would have been retained in working memory, resulting in the person's needing to search long-term memory for the missing pivot term (B). This search for the pivot consumes additional time.

Having found the pivot, the person reads the question. If the question contains a marked adjective, additional time is spent encoding it. In the example, the person seeks the individual who is shortest. All propositional information is now made available for the final search. Solving the problem requires finding the individual who is short+ relative to the pivot, but no such individual is found in the example. The reason no such individual is found is that the form of the question is incongruent with the way in which the answer term has been encoded. Whereas the shortest term, C, was previously encoded as tall (relative to the tall+ B), the question asks for the person who is shortest. The person must therefore make the question congruent with the problem terms as encoded. He or she does so by looking for the least tall individual--someone who is tall- relative to a tall pivot, or tall relative to a tall+ pivot. The person can now respond with the correct answer, C.

Algorithmic Model

In the algorithmic model, the person is theorized to read the final question first. If the question contains a marked adjective, processing time is assumed to be greater than if the question contains an unmarked adjective. The person then reads the first statement, and answers the question in terms of the first statement. Additional time is taken for processing of a marked adjective and for processing of a negation. In the sample problem, _C_ is shorter than _B_, and hence _C_ is the answer to the question as applied to the first statement. Next, the person scans the second statement, again taking longer if there is a marked adjective or negation. If the answer to the first statement _is not_ contained in the second statement, then the answer to the first statement is the correct response to the entire problem. If the answer to the first statement _is_ contained in the second statement, then the other answer choice in the second statement is the correct response to the entire problem. In the sample problem, _C_ is not contained in the second statement. Hence, _C_ is the correct response to the problem.

Reference Notes

1. Sternberg, R. J., & Weil, E. M. An aptitude-strategy interaction in linear syllogistic reasoning. (NR 150-412 ONR Technical Report No. 15.) New Haven: Department of Psychology, Yale University, 1979.

2. Sternberg, R. J., & Nigro, G. Developmental patterns in the solution of verbal analogies. (Cognitive Development Technical Report No. 3.) New Haven: Department of Psychology, Yale University, 1979.

References

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

Burt, C. The development of reasoning in school children. Journal of Experimental Pedagogy, 1919, 5, 68-77.

Clark, H. H. The influence of language in solving three-term series problems. Journal of Experimental Psychology, 1969, 82, 205-215. (a)

Clark, H. H. Linguistic processes in deductive reasoning. Psychological Review, 1969, 76, 387-404. (b)

DeSoto, C. B., London, M., & Handel, S. Social reasoning and spatial paralogic. Journal of Personality and Social Psychology, 1965, 2, 513-521.

Flavell, J. H. Cognitive development. Englewood Cliffs, N.J.: Prentice-Hall, 1977.

Hunter, I. M. L. The solving of three term series problems. British Journal of Psychology, 1957, 48, 286-298.

Huttenlocher, J. Constructing spatial images: A strategy in reasoning. Psychological Review, 1968, 75, 550-560.

Huttenlocher, J., & Higgins, E. T. Adjectives, comparatives, and syllogisms. Psychological Review, 1971, 78, 487-504.

Johnson-Laird, P. N. The three-term series problem. Cognition, 1972, 1, 57-82.

Keating, D. P., & Caramazza, A. Effects of age and ability on syllogistic reasoning in early adolescence. Developmental Psychology, 1975, 11, 837-842.

Piaget, J. Une forme verbal de la comparison chez l'enfant. Archives de Psychologie, 1921, 141-172.

Piaget, J. Judgment and reasoning in the child. London: Routledge & Kegan Paul, 1928.

Piaget, J. The language and thought of the child. New York: Meridian Books, 1955.

Piaget, J. Genetic epistemology. Translated by E. Duckworth. New York: Columbia University Press, 1970.

Quinton, G., & Fellows, B. 'Perceptual' strategies in the solving of three-term series problems. British Journal of Psychology, 1975, 66, 69-78.

Riley, C. A. The representation of comparative relations and the transitive inference task. Journal of Experimental Child Psychology, 1976, 22, 1-22.

Riley, C. A., & Trabasso, T. Comparatives, logical structures, and encoding in a transitive inference task. Journal of Experimental Child Psychology, 1974, 17, 187-203.

Smedslund, J. Psychological diagnostics. Psychological Bulletin, 1969, 71, 237-248.

Sternberg, R. J. Component processes in analogical reasoning. Psychological Review, 1977, 84, 353-378. (a)

Sternberg, R. J. Intelligence, information processing, and analogical reasoning: The componential analysis of human abilities. Hillsdale, N.J.: Erlbaum, 1977. (b)

Sternberg, R. J. A proposed resolution of curious conflicts in the literature on linear syllogisms. In R. Nickerson (Ed.), Attention and performance VIII. Hillsdale, N.J.: Erlbaum, in press. (a)

Sternberg, R. J. Representation and process in linear syllogistic reasoning. Journal of Experimental Psychology: General, in press. (b)

Sternberg, R. J., & Rifkin, B. The development of analogical reasoning processes. Journal of Experimental Child Psychology, 1979, 27.

Thayer, E. S., & Collyer, C. E. The development of transitive inference: A review of recent approaches. Psychological Bulletin 978, 85, 1327-1344.

Trabasso, T. Representation, memory, and reasoning: How do we make transitive inferences? In A. D. Pick (Ed.), _Minnesota symposia on child psychology_ (Vol. 9). Minneapolis: University of Minnesota Press, 1975.

Trabasso, T., & Riley, C. A. On the construction and use of representations involving linear order. In R. L. Solso (Ed.), _Information processing and cognition: The Loyola Symposium_. Hillsdale, N.J.: Erlbaum, 1975.

Trabasso, T., Riley, C. A., & Wilson, E. G. The representation of linear order and spatial strategies in reasoning: A developmental study. In R. Falmagne (Ed.), _Reasoning: Representation and process_. Hillsdale, N.J.: Erlbaum, 1975.

Footnotes

This research was supported in part by Grant BNS76-05311 from the National Science Foundation to Robert J. Sternberg. I am grateful to Diane Svigals for testing subjects, to Elizabeth Charles for assistance in data analysis, and to Janet Powell for comments on an earlier version of the manuscript. I thank especially Dr. Joseph Cirasuolo, Director of Learning Services for the Hamden Public Schools, for allowing access to these schools. I also thank the students, teachers, and principals of the schools in which the research was conducted: They were always courteous and helpful in facilitating the progress of the research.

[1]The spatial model is based upon the spatial model of DeSoto, London, and Handel (1965) and of Huttenlocher (Huttenlocher, 1968; Huttenlocher & Higgins, 1971); the linguistic model is based upon the linguistic model of Clark (1969b); the algorithmic model is based upon a "perceptual" model of Quinton and Fellows (1975). Although these earlier models formed the basis for the present models, it was necessary to add certain details to all of the models in order to make them capable of quantification. Hence, the present models are not identical to the earlier ones.

[2]Complete descriptions, including flow charts and linear equations used in predicting response times, can be found in Sternberg (in press-b).

[3]Full details of the quantification procedure can be found in Sternberg (in press-b).

[4]The actual number of theorized elementary operations used in solving linear syllogisms is greater than seven. However, certain elementary operations could not be isolated via the experimental procedures, and hence the parameters corresponding to their latencies were estimated in confounded form. Encoding in-

cludes both premise reading and formation of spatial arrays. Marking includes both added linguistic decoding time and added spatial recoding time for marked adjectives. Response includes response component time, plus anything else that is constant across two- and three-term series item types, such as question reading time, planning time, decision time, etc.

[5]In practice, the values of R^2 can exceed the values of reliability coefficients to the extent that a set of data violates the assumptions of classical test theory. Since most data sets violate these assumptions to at least some degree, values of R^2 exceeding reliabilities by relatively small amounts are possible, and were in fact obtained in the present experiment.

[6]These descriptions are drawn from Sternberg (in press-a).

Table 1

Fits of Models to Latency Data

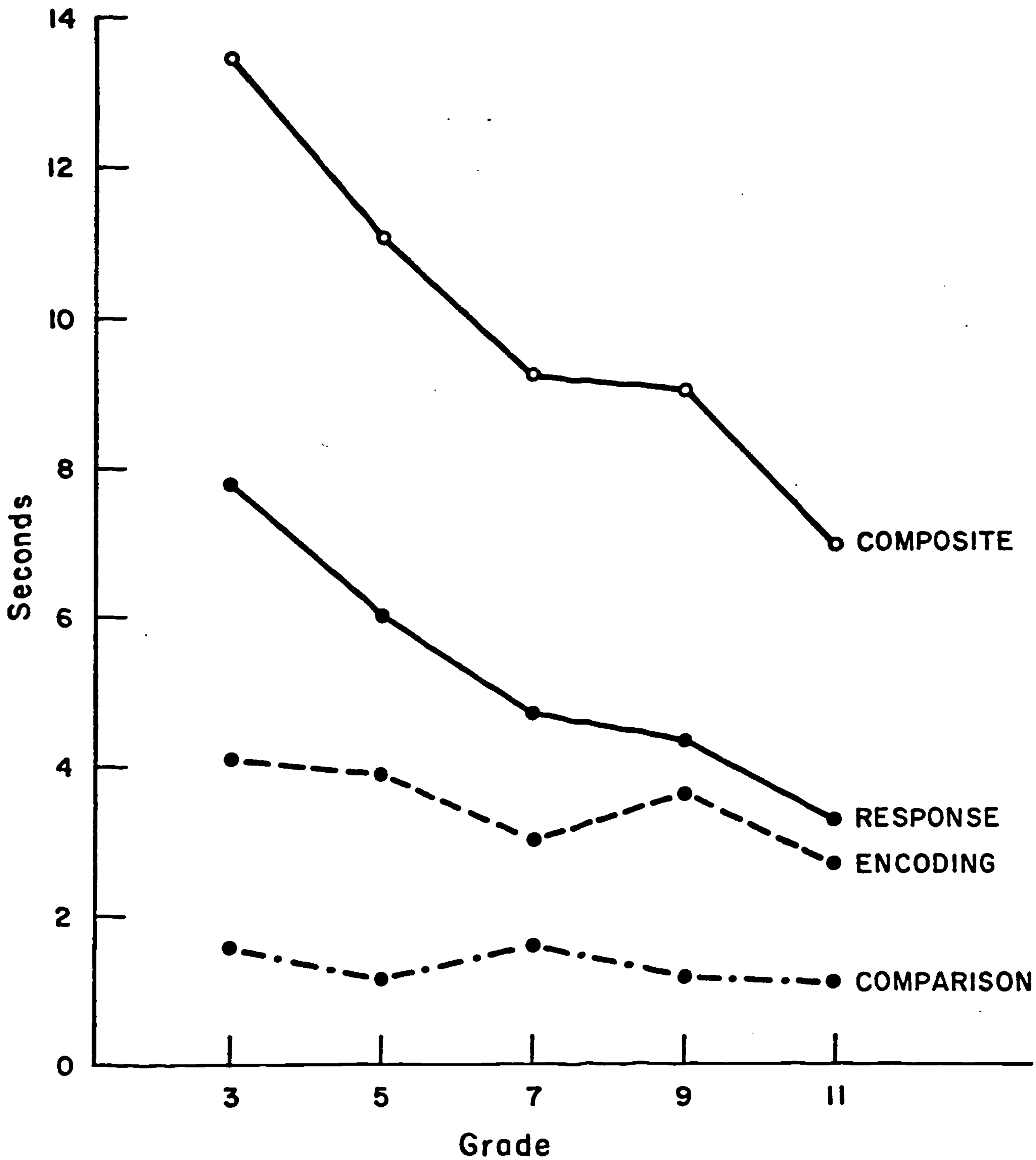
Data Set	Grade	Basic Statistics		Model Fit (R^2)			
		Mean Latency (sec)	Error Rate	Mixed	Linguistic	Spatial	Algorithmic
3-Term Series Combined Sessions	3	14.51	.40	*.46*	.29	.42	.18
	5	11.98	.25	*.62*	.52	.42	.26
	7	10.02	.23	*.62*	.40	.44	.30
	9	9.88	.18	.53	*.63*	.47	.09
	11	7.54	.16	*.72*	.58	.37	.20
3-Term Series Session 1	3	14.85	.42	*.26*	.12	.15	.14
	5	11.75	.28	*.44*	.40	.21	.20
	7	10.66	.24	*.58*	.40	.47	.22
	9	10.16	.20	.29	*.45*	.26	.12
	11	7.94	.19	*.57*	.49	.30	.16
3-Term Series Session 2	3	14.39	.38	*.44*	.28	.35	.12
	5	12.40	.23	*.29*	.24	.26	.11
	7	9.47	.21	*.36*	.23	.28	.24
	9	9.75	.17	*.46*	.37	.30	.07
	11	7.17	.14	*.68*	.46	.35	.21
2- & 3-Term Series Combined Sessions	3	13.25	.31	*.85*	.81	.83	.79
	5	10.91	.19	*.94*[a]	.94[a]	.91	.90
	7	9.11	.17	*.89*	.84	.86	.82
	9	8.89	.14	.91	*.92*	.89	.85
	11	6.78	.12	*.93*	.90	.86	.82

Note: The best fitting model at each grade is reported in italics.

[a]The value of R^2 for the mixed model is higher than that for the linguistic model in the third decimal place.

Figure Caption

Figure 1. Composite and component latencies at each grade level for two- and three-term series problems combined.


14
12
10
8
6
4
2
0
Seconds
COMPOSITE
RESPONSE
ENCODING
COMPARISON
3
5
7
9
11
Grade

Technical Reports Presently in the Cognitive Development Series

#1. Sternberg, R. J., & Rifkin, B. The development of analogical reasoning processes. June, 1978.

#2. Sternberg, R. J. Developmental patterns in the encoding and combination of logical connectives. October, 1978.

#3. Sternberg, R. J., & Nigro, G. Developmental patterns in the solution of verbal analogies. April, 1979.

#4. Sternberg, R. J. The development of human intelligence. April, 1979.

#5. Sternberg, R. J. The development of linear syllogistic reasoning. April, 1979.