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ABSTRACT

Data were obtained on the reasoning processes of 92 normal seventh graders (IQ range, 90-130), 14 adjusted seventh graders (IQ range, 70-90), and 54 educable mentally retarded (EMR) junior high students (IQ range, 55-80) to determine whether spatial imagery differentially influenced the solution of three-term series problems, to determine the relative difficulties of three-term series problems as a function of age, sex, verbal IQ, and nonverbal IQ, and to determine whether the directionality preferences of mentally retarded subjects were related to their specific reasoning errors. Explained were factors to be considered in the study of deductive reasoning and the predictive ability of isotropic theory, theory of spatial paralogic, theory of spatial images, and deep structure theory. Findings indicated that instructions to use spatial imagery in problem solving systematically facilitated problem solution for the adjusted subjects. On the average, each of the 54 EMR subjects used four categories for spatial assignments so that prediction of series problem errors from spatial assignments was severely handicapped. Absolute errors were generally greater for subjects who had lower verbal IQ scores. No consistent differences in absolute or relative errors resulted when age was used to organize the data. (GW)

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SPATIAL IMAGERY AND LINGUISTIC PROCESSES IN DEDUCTIVE REASONING IN THE MENTALLY RETARDED CHILD

Perhaps the most general statement that can be made about learning is that the same general principles hold both for normal and for mentally retarded subjects (*S*s); and this, whether or not the cause of the mental retardation (MR) involves genetic-cultural or physical (trauma) determinants. Indeed, it seems safe to broaden the above generalization to include non-human organisms. Still, there are areas where the MR child suffers relatively more than does the normal child (i.e., more, relative to the MR's own base line), or relatively less than the normal child (again, less, relative to the MR's own base line); and, quite naturally, it is to such areas as these that the researcher of applied bent is drawn.

The research in developmental psychology epitomized best by Piaget (Piaget and Inhelder, 1969) and by Bruner (Bruner, Olver, Greenfield, et al., 1966) suggests one such area. In the developmental progression described by Bruner et al., the earliest mode of representation is *enactive*. This is followed by *visual-iconic* and *symbolic* (verbal) modes. And, although Bruner et al. do not say as much, there would seem to be a fourth, or *post-linguistic visual-iconic* mode. This sort of conceptual scheme suggests that, at a given age level, the MR child might benefit more than the normal child from an instructional set to use visual imagery.

In earlier efforts researchers dealt with imagery in the area of paired associate learning (PAL). It was known from earlier research that imagery and other elaborative instructional sets produced three- and four-fold increases in learning. The researchers contributing this body of studies used primarily PAL, as just indicated, and they employed normal children and adults. The present researchers wished to determine the degree of generality of these findings. They asked: Do elaboration techniques (particularly visual imagery) work with retarded children? The researchers found that they did.

The research reported here (two studies, one of which is two-part) attempts to extend the understanding of researchers in the area to include more complex learning; in particular, syllogistic reasoning. To anticipate, the researchers found no differential effects as between "normal" and "MR" children. However, the present study presents data and theoretical considerations that may be of use in planning instruction for the MR child.

Three-Term Series Problems

How a person is able to reason deductively is a theoretical question that has eluded many investigators. Recent studies (Hunter, 1957a,b; Donaldson, 1963; DeSoto, London & Handel, 1965; Handel, DeSoto, & London, 1968; Huttenlocher, 1968; Smedslund, 1968; Clark, 1969a,b; Jones, 1970) of how people solve three-term series problems (e.g., If A is better than B, and B is better than C, then who is best?) seem to suggest what some of these reasoning processes may be like.

A three-term series problem consists of two premises that describe an ordered relation among three elements (e.g., A, B, C) and a question that asks for the position of one of these elements. Problems may differ in at least the following dimensions--identity of the elements (e.g., ABC, DEF, XYZ), type of relational term (e.g., better-worse, higher-lower, farther-nearer), composition of a premise (e.g., elements A and B or B and C), order of elements in a premise (e.g., A-B, B-A, B-C, C-B), order of the premises (premise 1, premise 2; or premise 2, premise 1) and form of the question (e.g., Who is best, worst?). Determinate problems are those whose premises specify the order of all three elements. Each premise must contain the middle item (B) and an end item (A or C) to yield a complete ordering. Thirty-two determinate problem types are presented in Table 1. Disregarding for the moment differences due to element identity and the relational terms in a problem, we see that four problem types (I, II, III, IV) result from varying the order of elements in a premise. Interchanging the order of the premises yields eight distinct problem types (Ia, Ib, IIa, IIb, IIIa, IIIb, IVa, and IVb). Sixteen problems (IaB, IaW, IbB, IbW . . . IVbW) are constructed when the questions "Who is best/worst?" are used alternately with each of these eight problem types. Finally, Clark (1969a) expanded the problem set to 32 by substituting the negative equative "isn't as bad as" in place of the positive comparative "better than" and "isn't as good as" in place of "worse than." These additional 16 negative equative problem types (I'aB, I'aW, I'bB, I'bW . . . IV'bW) possess superficial structures that are the same as their positive comparative counterparts, but are quite different in deep structure (Clark, 1969a; Chomsky, 1965).

Principles of Syllogistic Reasoning

Early investigators of formal, syllogistic reasoning (Burt, 1919; Woodworth and Sells, 1935; Sells, 1936) observed that certain syllogistic forms were consistently either easy or difficult for most Ss. Each proposed principles of reasoning to account for these differences in problem difficulty. Burt cited problem complexity, nature of the subject matter, and linguistic form. He noted that some problems were more complex than others. There were great differences in the lengths of problems and the amount of detail in each. Long and involved problems were more difficult, he said, partly because the subject had to remember at a single moment all its facets in order to grasp the problem in its entirety. When he spoke of the influence of subject matter, Burt pointed out that all problems were stated within some experiential context. Subjects would find the problem more difficult if it was presented in an unfamiliar setting. The influence of subject matter on problem difficulty was most noticeable with young children whose experiences were still quite limited. By linguistic form, Burt meant that certain ways of arranging verbal statements and questions facilitated problem solution. When the premises and questions were stated in specific ways, there resulted a "suggestive dominance" that S would respond with a particular answer or at least test the appropriateness of one particular answer before the others. In discussing how one would solve the problem--Tom runs faster than Jim, Jack runs slower than Jim, Who is the slowest? (IIIa, Table 1)--Burt (1919) comments:

> Read in conjunction with the questions given, certain forms of phrasing are apt to have what may be termed a "suggestive dominance."

Table 1

Determinate Three-Term Series Problems

Problem type	Form of problem	Form of question	Analysis
I	(a) A better than B; B better than C (b) B better than C; A better than B	(B) Best? (W) Worst? (B) Best? (W) Worst?	A is good B is good C is good
II	(a) C worse than B; B worse than A (b) B worse than A; C worse than B	(B) Best? (W) Worst? (B) Best? (W) Worst?	A is bad B is bad C is bad
III	(a) A better than B; C worse than B (b) C worse than B; A better than B	(B) Best? (W) Worst? (B) Best? (W) Worst?	A is good B is good, bad C is bad
IV	(a) B worse than A; B better than C (b) B better than C; B worse than A	(B) Best? (W) Worst? (B) Best? (W) Worst?	A is bad B is bad, good C is good
I'	(a) A not as bad as B; B not as bad as C (b) B not as bad as C; A not as bad as B	(B) Best? (W) Worst? (B) Best? (W) Worst?	A is bad B is bad C is bad
II'	(a) C not as good as B; B not as good as A (b) B not as good as A; C not as good as B	(B) Best? (W) Worst? (B) Best? (W) Worst?	A is good B is good C is good
III'	(a) A not as bad as B; C not as good as B (b) C not as good as B; A not as bad as B	(B) Best? (W) Worst? (B) Best? (W) Worst?	A is bad B is bad, good C is good
IV'	(a) B not as good as A; B not as bad as C (b) B not as bad as C; B not as good as A	(B) Best? (W) Worst? (B) Best? (W) Worst?	A is good B is good, bad C is bad

> With the statement "Jack runs slower . . ." ringing in the memory, a child asked "Who is the slowest?" naturally tends to say "Jack is slowest," or at least to try that statement as a hypothesis, and, finding nothing in the other premise to contradict it, easily solves the problem (p. 126).

Woodworth and Sells (1935) studied the reasoning errors Ss made in syllogisms constructed from four categorical propositions--universal affirmative (all S's are P's), universal negative (no S's are P's), particular affirmative (some S's are P's) and particular negative (some S's are not P's). They attributed specific reasoning errors to an "atmosphere effect" which was a global impression of the premises presented in the syllogism. Reasoning errors resulted from drawing invalid conclusions because of the mental set or "atmosphere" induced by the premises. When major and minor premises were of the same category, a categorical atmosphere resulted (e.g.,affirmative premises produced an affirmative atmosphere and negative premises a negative atmosphere). Combination of universal and particular premises yielded a particular atmosphere. Affirmative and negative premises together yielded a negative atmosphere. Ss tended to agree with syllogism conclusions that were in categorical agreement with the atmosphere induced by the premises. Sells (1936) reformulated the principle of atmosphere effect to include "caution," a tendency to accept weak, guarded conclusions (particular affirmative and negative--some are and some are not) more readily than strong conclusions (universal affirmative and negative--all are and none are). Sells reported the revised principle of atmosphere effect successful in predicting specific reasoning errors on 16 paired combinations of the four categorical propositions. Subsequent investigations of atmosphere effect (Chapman and Chapman, 1959; Simpson and Johnson, 1966; Begg and Denny, 1969) arrive at different conclusions about its accuracy. Although Hunter (1957a) reported a "particularly compelling" instance of atmosphere effect in the study of syllogistic reasoning in adults, another study (Hunter, 1957b) using children revealed no effect due to atmosphere. Chapman and Chapman (1959) concluded that neither atmosphere effect (Woodworth and Sells, 1935) nor a revised atmosphere effect (Sells, 1936) satisfactorily predicted reasoning errors. They proposed instead errors of conversion and probabilistic inference as explanatory principles. A conversion error occurred when S erroneously reversed the arguments in a premise (e.g.,all A's are B's converts to all B's are A's). By probabilistic inference, S mistakenly reasons that arguments sharing common qualities are likely to be similar, while arguments that lack common qualities are not likely to be the same. Both Simpson and Johnson (1966) and, recently, Begg and Denny (1969) point out that atmosphere effect as well as invalid conversion and probabilistic inference are useful in predicting specific errors in syllogistic reasoning. However, since specific predictions of both explanations differ only slightly, it is difficult to compare them on the basis of error data. They suggest that manipulation of other dependent variables and use of dependent measures such as response latency constitute more powerful ways of tapping the reasoning process.

Although it is clear that certain favorable and unfavorable effects result from the form in which a problem is presented, it is not at all clear that suggestive dominance or atmosphere effect remain useful as theories of syllogistic reasoning.

Recent Theories

Recent explanations of how people solve three-term series problems focus on the covert, psychological acts of transposing a problem into easier form (Hunter, 1957b), constructing spatial images of the elements (e.g., A, B, C) of the problem (DeSoto et al., 1965; Handel et al., 1968; Huttenlocher, 1968), or storing and retrieving information about the elements in the problem (Clark, 1969a,b).

Hunter (1957b) assumed there are two ideal forms, both isotropic, in which a problem is presented. Isotropic problems ($A > B > C$ & $C < B < A$; types Ia and IIa, Table 1) present the elements in a linear order and contain the same relational term in each premise. The assumption that isotropic form is easiest to solve dates back to James' (1891) axiom of skipped intermediaries in which any number of elements could be deleted from such a sequence without altering the relations of those elements that remained. Whenever S encounters a problem not isotropic, he covertly reorganizes it to isotropic form before solution is reached. Since lack of isotropism in a problem is not apparent until one encounters the second premise, it is this premise that S tends to reorganize. Reorganization of the second premise for the problems of Table 1 involves converting (reversing the grammatical subject/object positions of the elements and changing direction of the relational term) in problem-types IIIa, III'a, IIIb, and III'b, re-ordering (inverting premise order) in problem-types Ib, I'b, IIb, and II'b, and both converting and re-ordering in types IVa, IV'a, IVb, and IV'b. Types Ia, I'a, IIa, and II'a are already in isotropic form, so Ss should find them very easy. According to Hunter's analysis, the more reorganizing S must do to reach isotropic form, the harder the problem becomes.

DeSoto et al. (1965) and Handel et al. (1968) proposed a theory of spatial paralogic to explain Ss' reasoning in three-term series problems. They observed that when a task required linear arrangement of elements, Ss frequently reported constructing a spatial image of the elements, ordered along a vertical or horizontal axis. The authors advanced two principles, directionality and end-anchoring, to describe this type of linear reasoning. When Ss were asked to describe their spatial images in greater detail, consistent preferences for a vertical axis were reported when the relational terms "better-worse" were used in the syllogism. Ss less consistently preferred a vertical or horizontal axis for other relational terms such as "lighter-darker," "earlier-later" and "faster-slower." Whichever axis was used, Ss preferred to assign evaluatively "better" terms (e.g., better, lighter, earlier, faster) to the top position of vertical axis or the left position of a horizontal axis. Evaluatively "worse" terms (e.g., worse, darker, later, slower) were placed at the bottom of a vertical axis or at the right on a horizontal axis. The directionality principle predicts that spatial images of linear orderings are easiest to construct in a top-to-bottom (vertical axis) or left-to-right (horizontal axis) direction. Problems should be easier, therefore, when top (or left) elements are presented before bottom (or right) elements. Notice there are two ways in which directionality applies to three-term series problems -- between premises (A and B presented in the first premise, B and C in the second premise) and within premises

(A presented before B or B before C). The second principle, end-anchoring, predicts that a premise is easy if an end element (A or C) is mentioned before the middle element (B). It is hard if B is presented first and then A or C. Facilitation by end-anchoring is consistent with the often-cited serial position effects so commonly observed in serial learning.

Huttenlocher (1968) agrees that Ss construct spatial images of the elements ordered along a vertical or horizontal axis but suggests subtle, important differences in how they go about it. After reading the first premise (e.g., B is better than A), S imagines a spatial axis appropriate to the relational term and proceeds to place A and B along this axis. When the relational term regularly suggests a particular axis (e.g., vertical), S tends first to place the top element (A) in his image regardless of its position in the premise. Should the relational term not suggest a specific axis to S, he chooses one and tends first to place the element that first appears in the premise (B). S then reads the second premise (e.g., C is worse than B) and "moves" the third element, C, into place in relation to the fixed elements, A and B.

Clark (1969a,b) does not deny that spatial images play a part in reasoning but takes the position that storage and retrieval processes based on a linguistic analysis of the premises provide a more powerful explanation than either spatial theory. Central to Clark's theory are the linguistic concepts of "surface" and "deep" structure (Chomsky, 1965) or alternately, "superficial structure" and "underlying structure" (Postal, 1964). Both refer to the observation that sentences having identical phrase structure (surface, superficial) may nevertheless differ in meaning (deep, underlying structure). It is the deep, underlying meaning of a sentence that seems to survive in memory. We commonly observe that people recall the essential meaning of a sentence without preserving its original syntactic form (Mehler, 1963; Sachs, 1967; Clark and Card, 1969; and others). Clark uses two principles, functional relations and lexical marking, to describe the storage of deep structures, and a third principle, congruence, to account for their retrieval. For the problem -- A is better than B, B is better than C, Then who is best? -- functional relations predicts that the deep structures (also called base strings) "A is good, B is good, C is good" and the comparative "more than" are stored in memory. The principle of lexical marking predicts that the unmarked (see Clark, 1969a, p. 389) form of an adjective (e.g., good) is stored in a less complex form and is easier to retrieve from memory than its marked counterpart (bad). Finally, the congruence principle predicts that S will retrieve the answer more quickly when both question and base strings contain the same adjectival form. So the above problem should be easier when the question is "Who is best?" since both the question and base strings contain a form of the adjective, "good."

The Prediction of Reasoning Difficulty

Predictions of reasoning difficulty for the determinate three-term series problems are summarized in Table 2. Predictions based on principles of suggestive dominance and atmosphere effect are not included since as descriptive statements they contribute little to a theoretical explanation of reasoning.

In each instance, "easy" implies that Ss commit fewer errors and require less time to respond than on "difficult" problems. Clark (1969a) reported a close parallel between solution times and errors when in the latter procedure Ss were given only 10 seconds to respond to a problem.

Isotropic Theory

For example, isotropic theory (Hunter, 1957a) predicts that problems Ia and IIa are very easy. They are already in isotropic form and require no reorganization prior to solution. Of the remaining (heterotropic) problems, IVa and IVb require both converting and reordering to achieve isotropic form and are hardest. Each of the remaining problems must be either reordered (Ib and IIb) or converted (IIIa and IIIb). Because all require but one reorganization, they are intermediate in difficulty. Since the negative equative problems parallel the positive comparatives in surface structure, isotropic theory predicts that I'a and II'a are easy while I'b, II'b and III' are intermediate and IV' is difficult.

Spatial Paralogic

Spatial paralogic (DeSoto et al., 1965) also makes specific predictions about the relative difficulties of the problems as shown in

Table 2

Predicted Difficulties of Three-Term Series Problems

Reasoning Principles	Predicted level of difficulty		
	Easy	Intermediate	Difficult
Isotropic reorganization	Ia, IIa, I'a, II'a	Ib,IIb,III I'b,II'b,III'	IV, IV'
Spatial paralogic			
Directionality			
between	Ia,IIb,IIIa,IVa		Ib,IIa,IIIb,IVb
within	I,I'	III,IV, III',IV'	II, II'
End-anchoring	III,III'	I,II,I',II'	IV,IV'
Spatial images			
End item as grammatical subject	Ib,IIb,III I'b,II'b,III'		Ia,IIa,IV I'a,II'a,IV'
Deep structure			
Lexical Marking	I, II'	III,IV,III',IV'	II, I'
Congruence	IaB,IbB,IIaW, IIbW,III,I'aW, I'bW,II'aB, II'bB,IV'		IaW,IbW,IIaB, IIbB,IV,I'aB, I'bB,II'aW,II'bW III'

Table 2. Directionality predicts that Ia is easy since it proceeds from better to worse both between and within premises. Problem IIa goes from worse to better in each instance and is very difficult. Problems Ib and IIb are intermediate in difficulty since in one type, Ib, there is favorable directionality within but not between premises, while for IIb the reverse is true. According to DeSoto et al. the principle of end-anchoring does not differentiate among these four problems because each contains one premise that is end-anchored and one that is not. However, problems IIIa and IIIb are end-anchored in both premises and are easy, while IVa and IVb have none of this attribute in either premise and are difficult. And since problems IIIa and IVa proceed from "better" to "worse" between premises while IIIb and IVb do not, IIIa and IVa are easier than IIIb and IVb, respectively. As before, predictions for the 16 negative equative problems parallel the predictions of their positive comparative counterparts.

Spatial Images

According to the theory of spatial images (Huttenlocher, 1968), three-term series problems are easy when the "movable" third element (A or C) is the grammatical subject of the second premise. This condition is met when the second premise is end-anchored. It is harder for S to "move" the third element into his spatial image when A or C is the grammatical object of the second premise. Therefore, those problems whose second premises are end-anchored (Ib, IIb, IIIa and IIIb) are easier than problems whose second premises are not end-anchored (Ia, IIa, IVa and IVb). Correspondingly, problems I'b, II'b, III'a, and III'b are easier than I'a, II'a, IV'a, and IV'b.

Deep Structure Theory

Linguistic theory also makes predictions about which problems of Table 2 should be easy and which should be difficult.

The principle of lexical marking predicts that problems whose base strings contain unmarked relational terms (e.g., good) will be solved faster and with fewer errors than problems with underlying marked relational terms (e.g., bad). Therefore, problems I and II' each with "good" underlying structures should be easier than I' and II both containing "bad" in deep structure.

The congruence principle predicts that a problem is easier if similar relational terms appear in the question and in the deep structure. For this reason, problems I and II' are easier when followed by the question "Who is best?" and I' and II are favored when the question is "Who is worst?" Similarly, congruence predicts that problems III and IV' will be easy since their base strings are congruent with either question, "Who is best? (worst?)," and III' and IV difficult because their base strings are incongruent with either question.

Observation of Reasoning Difficulty

Several investigations of the difficulties subjects encounter in solving three-term series problems have been reported. Data on the relative difficulties of these problems have been extracted from six studies and are summarized in Table 3. Because of methodological variation from study to study and the use of different dependent measures, actual data from the several studies should not be compared directly.

Table 3

Observed Difficulties of Three-Term Series Problems

Investigation	Observed level of difficulty		
	Easy	Intermediate	Difficult
Hunter (1957b) Age 11 Ss (n = 64)	IIIa	Ia, IIb	IVa
Age 16 Ss (n = 32)	Ia	IIIa,IIb	IVa
DeSoto (1965) (n = 117)	IIIa,IIIb,la	Ib,IIb	IIa,IVa,IVb
Handel (1968) (n = 122)	IIIa,Ia	IIIb,Ib,IIb	IIa,IVa,IVb
Huttenlocher (1968) (n = 48)	Ib,IIb,III		Ia,IIa,IV
Clark (1969a) (n = 13)	Ib,IIIa,IIIb	IIb,IVa	Ia,IVb,IIa, I',II',III', IV'
Clark (1969b) N = 100)	IIIa,IIIb,Ib	Ia,IIb,IVa, I'a,II'a,II'b, IV'a,IV'b	IIa,III'a, III'b,IVb, I'b

Instead, three-term series problems are identified only as "easy," "intermediate" or "difficult." Classification of problem-types into these three categories is frequently arbitrary but was done to facilitate simple comparisons of actual data with the difficulty predictions of Table 2. While these categories are descriptively useful, different categories do not necessarily reflect significant differences in problem difficulty. This is particularly true for problem-types within any category and for differences between either extreme category and "intermediate."

Isotropic Theory

Isotropic theory predicts, among other things, that Ia is easy, IIb and IIIa are intermediate, and IVa is difficult. Excepting a minor reversal between problem-types Ia and IIIa for 11-year-old Ss, this is just what Hunter (1957b) found.

Spatial Paralogic

Both DeSoto et al. (1965) and Handel et al. (1968) reported that IIIa and Ia were easy, Ib and IIb were intermediate and IIa, IVa, and IVb were difficult for subjects who were college undergraduates. Problem-type IIIb falls into the "easy" category for the DeSoto study and the "intermediate" category for Handel's investigation.

Spatial Images

Huttenlocher (1968) found that problems were easy if their second premise began with an element that was the grammatical subject (Ib, IIb, III) and difficult if this element was the object of the premise (Ia, IIa, IV).

Deep Structure Theory

Clark has reported two studies which provide evidence of the difficulty levels of all 32 three-term series problems. In both studies, problems Ib and III were easy, IIb and IVa were intermediate while IIa, IVb, and III' were difficult. The earlier investigation (1969a), based on a sample of 13 college undergraduates, also found that Ia and all negative equative problems were difficult. The second investigation (1969b), based on 100 college undergraduates, placed Ia and some negative equatives (I'a, II', IV') into the "intermediate" category.

Series Problems: Easy and Difficult

Some of the differences in problem difficulty from study to study probably result from differences in administering the problems, use of different relational words and different dependent variables. Nevertheless, problems I and III are often observed to be easy, while IIa, IV, III' and I'b are consistently difficult. Falling somewhere between these two extremes are the intermediates--IIb, I'a, II', and IV'.

Incompleteness of the Theories

A striking feature of these reasoning theories is their incompleteness. They seem incomplete in several respects. First, all theories, with the possible exception of spatial paralogic, ignore differences in problem difficulty that might arise from using different relational words. The reasoning principles apply equally to problems containing the pairs "better-worse," "lighter-darker," "earlier-later," "farther-nearer" and so on. For that matter, symbolic relational terms such as the inequality signs "greater than" (>) and "less than" (<) could be used and these principles would still be applied.

Second, no theory except Clark's linguistic theory takes into consideration differences between surface and deep structure of the problems. The predicted difficulties of negative equatives parallel the predictions for their positive comparative counterparts.

Third, although the initial problem set has been expanded from 8 to 32, reasoning theories still predict no more than three levels of problem difficulty. DeSoto's spatial paralogic proposed that the eight premise combinations could be divided into easy, intermediate and difficult problems. Working with an expanded set of 32 problems, deep structure principles offer, at best, three levels of discrimination, no more than do the other reasoning theories. If a theory predicts three levels of difficulty, at the same time it must predict levels of equivalence. That is, when isotropic theory, for example, predicted three levels of difficulty for four problem-types (Ia, IIb, IIIa, and IVa), it also predicted an equivalence condition between problems IIb and IIIb since at that time isotropic theory contained no principles which discriminated between them. Similarly, deep structure principles predict equivalencies within several groups of problems because there are no principles in the theory which apply differentially to problems in each group. For example, equivalence should exist among these groups--IIIaB, IIIaW, IIIbB, and IIIbW; IVaB, IVaW, IVbB, and IVbW; III'aB, III'aW, III'bB, and III'bW; and IV'aB, IV'aW, IV'bB, and IV'bW. One might argue that it is unreasonable to expect an increasing number of equivalencies among series problems which appear relatively diverse. Although it is an unparsimonious move, we may find it more reasonable that additional reasoning principles will be identified with which more levels of difficulty will be discriminated.

There is yet a fourth respect in which the reasoning theories seem incomplete. Most of the reasoning principles can be applied to some but not all of the problem-types. What results is this--problem difficulties are influenced by combinations of different reasoning principles and the theories provide no basis for predicting the net or summated effect of a combination of principles. For example, within spatial paralogic there are two principles, directionality and end-anchoring. Since directionality applies both between premises (e.g., the "better" pair, A-B, being presented in the problem before the "worse" pair, B-C) and within premises (e.g., the "better" elements, A and B, being presented in each premise before their respective "worse" elements, B and C), this principle influences problem difficulty in at least three ways--once between premises and twice within premises. The other principle, end-anchoring, can be applied to each of the two premises so that it has at least two effects. These two principles of spatial paralogic, then, influence problem difficulty in at least five ways--three for directionality and two for end-anchoring. Table 4 depicts analyses of eight problem-types (Ia, Ib, IIa, IIb, IIIa, IIIb, IVa, and IVb) in terms of the principles of spatial paralogic. Each problem has been analyzed with respect to the five ways that directionality and end-anchoring influence problem difficulty. Notice that each problem consists of a unique combination of these five effects. Since a complete analysis of problem difficulty must take into account all the effects of these principles, we must determine how to combine their separate effects if we wish to determine the overall difficulty of a problem. To illustrate this dilemma, consider the analyses presented in Table 4. Each problem has been ranked in terms of the total number of desirable properties it contains. A rank of 1 is assigned to problems Ia and IIIa since each contains four desirable properties, according to the principles of spatial paralogic. Similarly, the remaining problems are assigned ranks of 3, 2 or 1. Problems IIa and IVb receive the lowest rank, 4, since each possesses but one facilitating property. Since spatial paralogic does not specify the

Table 4

Difficulty Analysis for Eight Series Problems*

Problem Type		Analysis			Rank**
		Directionality		End-Anchoring	
		Within	Between		
Ia	A better than B B better than C	better to worse better to worse	better to worse	ends to middle middle to ends	1
Ib	B better than C A better than B	better to worse better to worse	worse to better	middle to ends ends to middle	2
IIa	C worse than B B worse than A	worse to better worse to better	worse to better	ends to middle middle to ends	4
IIb	B worse than A C worse than B	worse to better worse to better	better to worse	middle to ends ends to middle	3
IIIa	A better than B C worse than B	better to worse worse to better	better to worse	ends to middle ends to middle	1
IIIb	C worse than B A better than B	worse to better better to worse	worse to better	ends to middle ends to middle	2
IVa	B worse than A B better than C	worse to better better to worse	better to worse	middle to ends middle to ends	3
IVb	B better than C B worse than A	better to worse worse to better	worse to better	middle to ends middle to ends	4

*Analysis is based on spatial paralogic theory.

**Rank of 1 represents least difficult problems, rank of 4 is most difficult.

relative magnitude of the several effects of directionality and end-anchoring, we are at a loss to estimate their joint effect on problem difficulty. If unit weights were assigned to each of the five effects, there would be four levels of problem difficulty corresponding to ranks 1 through 4. However, we still would not know if differences between adjacent levels were of practical or statistical importance. In addition, it is not unreasonable that principles interact with each other--the effects due to end-anchoring, for example, may vary with the presence of between or within premises directionality. If present, these and other interactions among reasoning principles could be extremely troublesome, since we recall that each of the problems in Table 4 contains a unique combination of the five effects of directionality and end-anchoring.

Because the relative sizes and potential interactions among reasoning principles have not been specified in the several theories of syllogistic reasoning, each predicts an incomplete ordering of problem-type difficulty.

A powerful reasoning theory should be one which predicts not only <u>differences</u> in problem difficulty but problem equivalencies as well. In terms of the desirable properties these series problems contain, problems may differ only slightly or be quite diverse. The sense in which most of the reasoning theories are incomplete is that they seldom specify when these differences are important and when they should be regarded as equivalent.

Rationale of the Present Study

Current explanations of the cognitive processes underlying the solution of three-term series problems are unable to predict successfully the relative difficulties of all problem-types. This may be due in part to a failure to recognize that Ss are using one or more strategies. To the extent that these strategies employ different cognitive processing, varying patterns of relative difficulty among problems would be expected. This point is consistent with the observation of Smedslund (1968) that there were dramatic shifts in conceptual strategy by Ss who performed a large number of three-term series problems. While one of the reasoning theories, spatial paralogic for example, might satisfactorily describe the conceptual strategy of a single person at a particular moment, the single theory is not sufficiently comprehensive to predict his subsequent performance or the performance of other persons.

This paradox of predicting syllogistic reasoning performance for undifferentiated groups of Ss appears to be analogous to the more general instance where individual effects are masked by group data. As a result of examining the learning curves of an undifferentiated group of Ss, several studies have concluded that the experimental material was acquired by a gradual, incremental process. A plausible alternative conclusion is that learning is an all or none affair which occurs on different trials for different Ss. Group learning curves are a summation of individual curves and the gradual slope is an artifact of the procedure for representing the experimental data.

Similarly, in the case of syllogistic reasoning it can be argued that the error data of an undifferentiated group of Ss is artifactual. It is a statistical summation of conceptually different strategies--differences both between and within individuals. Since most theories of syllogistic reasoning (Clark's deep structure theory is a notable exception) appear to be extrapolations on the introspective reports of Ss, it is not surprising that a particular theory adequately predicts the reasoning performance of that sample around which the theory was built but isn't generalizable to other, more disparate samples. Spatial paralogic or spatial images theories work well when Ss employ some form of spatial representation of the problems but do not predict well when Ss use non-spatial strategies. We know that college-level Ss spontaneously use more sophisticated conceptual strategies, including spatial imagery, than young children. If spatial theories appear to work well with college Ss, much of their predictive success may result from the fact that a large proportion of individual Ss are using spatial as opposed to non-spatial strategies. Indeed, DeSoto and others observed through post-experimental interviews that at least half of their undergraduate Ss reported using some sort of spatial strategy in solving the problems.

Paivio (1969) and others have begun to demonstrate that spatial imagery can be a very influential component in associative, verbal learning. Often recall can be increased greatly when Ss receive instructions to use one of several spatial images strategies. Recently, Paivio and other researchers (e.g., Paivio and Csapo, 1969; Begg and Paivio, 1969; Paivio and Rowe, 1970) have extended these studies into verbal discrimination, memory coding, and psycholinguistics, and in each case they have found imagery instructions to be a significant variable in learning. It seems reasonable, then, that instructions to use spatial imagery may also be an important variable to consider in syllogistic reasoning studies.

At least two questions come to mind which give direction to the present study. The first is derived from Clark (1969a) when he said, "The only firm conclusion we can draw at this time is that it has not been demonstrated that the use of spatial imagery differentially affects the solution of three-term series problems (p. 402)." The present study addresses itself first to this issue--does spatial imagery differentially influence the solution of three-term series problems? Clark (1969b) determined by post-experimental interviews that 49% of the Ss reported using spatial imagery to solve the problems. In another study, Jones (1970) found that 72% of her Ss wrote the three names on paper in systematic, vertical or horizontal orderings. Yet in neither case does it appear that reasoning data were analyzed separately for Ss, all of whom appeared to employ spatial strategies. One procedure for looking into the first hypothesis might involve replicating Clark (1969a), determining by post-experimental interviews which Ss used spatial imagery to solve the problems, and then blocking Ss who report employing or not employing spatial strategies into groups for separate analyses. Since post-experimental interviews are notoriously unreliable, a better procedure, the one used in this study, is to assign Ss randomly to one of two groups--a control group given no strategic instructions and an experimental group that receives explicit instructions to use spatial imagery to solve the problems. Finding significant main effects for the variable, instructions to use spatial imagery, would suggest there is a general facilitation of syllogistic reasoning. Ss would commit fewer errors on all problem-types when they employed spatial strategies. Although this finding would be interesting enough by itself, to demonstrate that spatial imagery differentially influenced linear reasoning, a significant imagery instructions-problem type interaction must occur. That is, instructions to use spatial imagery would facilitate solution of some problem-types more than others. A reasonable sub-hypothesis might be that if such an interaction were found, imagery instructions would facilitate the solution of difficult and intermediate problems (Table 2) more so than easy problems.

The second question with which this study will attempt to deal is a much broader one and stems from the assumption that individual human differences play a fundamental role in how each person reasons deductively. It was suggested earlier that the relative difficulties of three-term series problems may be determined not by some all-encompassing, general theory but by the specific cognitive strategy or strategies actually employed by a particular subject at a particular moment. It may be possible, however, to develop more general explanations of just why it is that a person selects a specific strategy over alternative strategies.

This second question really consists of two component questions:

Is there a developmental effect on the relative difficulties observed for three-term series problems? There are several studies which report difficulty patterns for college undergraduates, but few which provide a basis for comparing the reasoning errors committed by a wide range of Ss. The present study will obtain reasoning data on "normal" seventh-graders (IQ range, approximately 90-130), "adjusted" seventh-graders (IQ range approximately 70-90), and 12-14 year-old educable mentally retarded Ss. The emphasis here is primarily descriptive--to examine the relative difficulties of three-term series problems as a function of age, sex, verbal IQ, and non-verbal IQ--and then to either rule out or generate alternate hypotheses for subsequent experimental study.

Is it possible to use a subject's directionality preferences to predict his subsequent errors? According to the theory of spatial paralogic, the consistent preferences that S shows in assigning relational terms such as "better" and "worse" to ends of a vertical or horizontal continuum may be useful in predicting relative difficulties of the problem-types. Handel, DeSoto and London (1968) first had their subjects solve 68 three-term series problems and then gave each subject a spatial assignment task to see how they arranged each relational word (e.g., better, worse, earlier, later, faster, slower) to vertical or horizontal axes drawn on a sheet of paper. Their attempt to use spatial assignments to predict each S's reasoning errors met with only limited success. They concluded "that using S's spatial representations alone does not adequately tap the reasoning process (p. 357)." The present study will examine the directionality preferences of mentally retarded Ss, compare these preferences with those obtained on college undergraduates (Handel et al., 1968), and then see if directionality preferences of the mentally retarded Ss are related to their specific reasoning errors.

It must be obvious that the questions one might ask in relation to syllogistic reasoning go far beyond those few posed in this study. The preceding concerns for spatial imagery, developmental effects, and directionality preferences have been selected since they extend in a fairly direct manner the research questions already posed in one or more related studies on reasoning. Perhaps the most valuable goal in the present investigation, however, is simply to accumulate sufficient data on how a wide range of people solve three-term series problems so that alternative hypotheses are posed for further study.

Method Experiment 1

Subjects

S̲s were 92 "normal" seventh-graders, IQ's ranging from approximately 90-130 and 14 "adjusted" seventh-graders, IQ's ranging from approximately 70-90. Normal and adjusted S̲s were assigned at random to control and experimental groups of equal size.

Experimental Task

Three blocks of the 32 three-term series problems presented in Table 1 were solved by each S̲. Common four-letter men's names were substituted for the arguments A, B, and C. No pair of names occurred more than once in any problem. Problems contained the relational pair, "better-worse" or , alternatively, "higher-lower" to introduce variety to the task. The problems were divided into 3 blocks of 32 such that each problem-type was included in each block. Order of the problems was random and different for each S̲, and for the same S̲, the order was different for each of the three blocks. Three blocks of problems were used both to increase reliability of observation and to counterbalance for the position in which a correct response occurred among the alternatives that follow the question.

Procedure

Simple procedural instructions were given to control and experimental S̲s. As each group received either control or experimental instructions (see Appendices A and B), they solved the same 4 three-term series problems in order to minimize any practice effects that might occur on the actual set of 96 problems. Control S̲s were not instructed to employ any systematic strategy in solving the problems, while experimental S̲s were instructed in using spatial imagery. Experimental instructions included the following statements:

> One way to solve these problems is to imagine a picture in your mind of the three names arranged in a vertical list with one name on top, one name in the middle and one name on the bottom. To answer the question, simply pretend you are looking at the list of names in your mind and choose the correct answer.

A test-problem booklet for both groups consisted of 96 problem slips stapled at the left edge. At a signal each 10 seconds from a tape recorder, S turned the page to the next problem, read it silently and circled the answer he believed was correct. A brief rest period was provided after each sixteenth problem. After completing the entire 96 problems, experimental Ss were interviewed to determine whether or not they actually employed a spatial strategy to solve the problems.

Results

Experiment 1

Errors--relative and absolute

The percentages of errors in solving the 32 three-term series problems are presented separately for 92 normal (Table 5) and 14 adjusted Ss (Table 6). As expected, college undergraduates (Clark, 1969b; Table 5) committed fewer errors than normal or adjusted junior high students, while within the latter group, normals made fewer errors than adjusted Ss. These differences in absolute error rates (i.e., errors across all problem-types) are not as interesting, however, as is the virtual lack of inter-group differences in relative errors (i.e., the relative difficulties of problem-types within each group). Some of these similarities among orders of problem-type difficulty are shown in Table 7. Although junior high Ss always committed

Table 5

Percentage of Errors in Solving Three-Term Series Problems*

Problem Type		Form of Problem	Form of Question						Average			Overall Average		
			Best?			Worst?								
			Imagery	No Imagery	Clark (1969b)	Imagery	No Imagery	Clark (1969b)	Imagery	No Imagery	Clark (1969b)	Imagery	No Imagery	Clark (1969b)
I	a	A better than B; B better than C	27	34	15	32	29	29	30	32	22	32	32	17
	b	B better than C; A better than B	28	23	7	39	38	18	34	31	12			
II	a	C worse than B; B worse than A	43	40	43	54	49	48	49	45	46	44	40	33
	b	B worse than A; C worse than B	43	35	21	33	33	21	38	34	21			
III	a	A better than B; C worse than B	18	14	8	21	26	10	20	20	9	23	24	10
	b	C worse than B; A better than B	25	25	10	24	28	12	25	27	11			
IV	a	B worse than A; B better than C	43	39	30	40	40	25	42	40	28	42	43	32
	b	B better than C; B worse than A	36	40	32	48	50	43	42	45	38			
I'	a	A not bad as B; B not bad as C	42	37	28	26	28	21	34	33	24	40	40	31
	b	B not bad as C; A not bad as B	54	48	39	38	43	36	46	46	38			
II'	a	C not good as B; B not good as A	32	36	14	43	40	32	38	38	23	40	39	26
	b	B not good as A; C not good as B	35	36	26	47	41	31	41	39	28			
III'	a	A not bad as B; C not good as B	47	33	34	43	32	45	45	35	40	47	41	40
	b	C not good as B; A not bad as B	47	44	34	49	48	45	48	46	40			
IV'	a	B not good as A; B not bad as C	45	30	26	34	30	30	40	30	28	37	33	28
	b	B not bad as C; B not good as A	33	30	23	35	39	35	34	35	29			

*Data for 92 "normal".

Table 6

Percentage of Errors in Solving Three-Term Series Problems*

Problem Type		Form of Problem	Form of Question						Average			Overall Average		
			Best?			Worst?								
			Imagery	No Imagery	Clark (1969b)	Imagery	No Imagery	Clark (1969b)	Imagery	No Imagery	Clark (1969b)	Imagery	No Imagery	Clark (1969b)
I	a	A better than B; B better than C	37	47	15	19	60	29	28	54	22	50	52	17
	b	B better than C; A better than B	67	47	7	74	53	18	71	50	12			
II	a	C worse than B; B worse than A	37	67	43	41	53	48	39	60	46	49	64	33
	b	B worse than A; C worse than B	59	73	21	56	60	21	58	67	21			
III	a	A better than B; C worse than B	15	40	8	48	47	10	32	44	9	33	56	10
	b	C worse than B; A better than B	33	67	10	33	67	12	33	67	11			
IV	a	B worse than A; B better than C	70	87	30	70	80	25	70	84	28	73	74	32
	b	B better than C; B worse than A	74	67	32	78	60	43	76	64	38			
I'	a	A not bad as B; B not bad as C	56	40	28	56	73	21	56	57	24	62	67	31
	b	B not bad as C; A not bad as B	78	73	39	56	80	36	67	77	38			
II'	a	C not good as B; B not good as A	33	67	14	63	47	32	48	57	23	53	66	26
	b	B not good as A; C not good as B	52	87	26	63	60	31	58	74	28			
III'	a	A not bad as B; C not good as B	45	67	34	33	60	45	39	64	40	51	69	40
	b	C not good as B; A not bad as B	67	80	34	56	67	45	62	74	40			
IV'	a	B not good as A; B not bad as C	48	60	26	37	73	30	43	67	28	53	69	28
	b	B not bad as C; B not good as A	67	67	23	56	73	35	62	70	29			

*Data for 14 "adjusted" Ss.

Table 7

Orders of Difficulty for Three-Term Series Problems;

Ordered by Percentages of Solution Errors

	Groups										
	Normals				Adjusted				Clark (1969b)		
	Imagery		No Imagery		Imagery		No Imagery				
	Problem Type	% Errors	Problem Type	% Errors	Problem Type	% Errors	Problem Type	% Errors	Problem Type	% Errors	
Easy											Easy
	III	23	III	24	III	33	I	52	III	10	
	I	32	I	32	II	49	III	56	I	17	
	IV'	37	IV'	33	I	50	II	64	II'	26	
	I'	40	II'	39	III'	51	II'	66	IV'	28	
	II'	40	I'	40	II'	53	I'	67	I'	31	
	IV	42	II	40	IV'	53	IV'	69	IV	32	
	II	44	III'	41	I'	62	III'	69	II	33	
	III	47	IV	43	IV	73	IV	74	III'	40	
Difficult											Difficult

more total errors than college undergraduates, and adjusted Ss committed more total errors than normal Ss, the relative difficulties of the problem-types are remarkably alike for each group. Problems that were difficult or easy for college undergraduates were usually similar in difficulty for normal and adjusted junior high students. Kendall's coefficient of concordance (W) for the ranks of Table 7 was significant beyond the .001 level (X^2 = 25.28).

Instructions to Use Spatial Imagery

Twenty-eight (10 males and 18 females) Imagery Ss reported afterwards that they consistently tried using spatial imagery to solve the problems.

Imagery instructions appeared to have little, if any, effect upon problem solution for normal Ss. There was no main effect found for the variable, instructional set (F = 0.22), and no interaction between instructional set and problem-type (F = 0.83). Inspection of normal group data from Tables 5 and 7 confirms that similarity of both absolute and relative error rates between normal Ss in the Imagery and No Imagery conditions.

Results for adjusted Ss must be tentative considering the small samples that were observed (5 Ss in the Imagery condition and 9 Ss in the No Imagery group). However, these data seem to suggest the presence of possible effects on both absolute and relative errors. There is a small but consistent reduction in absolute errors for Imagery Ss. They committed fewer errors than No Imagery Ss on 21 of 32 problem-types. Relative errors for both groups of adjusted Ss were quite similar to each other but differed from the pattern observed for normal Ss (Table 7) and college undergraduates (Clark, 1969b; Table 7) in at least one respect.

Problem-type II, consistently difficult for college and normal junior high Ss, was easy-to-intermediate in difficulty for adjusted Ss. Most investigators (see Table 3) consistently observed that problem-type IIb was easy or intermediate and type IIa was difficult. The same order was reported here for normal Ss. But for adjusted Ss in both conditions this situation is consistently reversed. Adjusted Ss found problem-type IIa easier than its alternate form, IIb. While this shift in problem difficulty appears for both Imagery and No Imagery Ss, at the same time Imagery Ss are making consistently fewer errors than No Imagery Ss, again suggesting that imagery instructions systematically facilitated problem solution for the adjusted group.

Classification Variables

Tables 8-14 contain percentages of solution errors and relative orders of problem difficulty for 92 normal Ss. In each case, the original data for this group (Table 5) was grouped into two or three levels of the classification variables verbal IQ, non-verbal IQ, sex, and age.

Table 8 presents percentages of solution errors grouped by three levels of Lorge-Thorndike verbal IQ. With few exceptions, absolute errors are greater for Ss who have lower verbal IQ scores. This association is observed for both Imagery and No Imagery groups. Table 10 presents the orders of difficulty for problem-types when the data are grouped into high, medium, and low levels of verbal IQ. Regardless of the imagery condition or level of verbal IQ, the same general pattern of errors emerges. Rankings for the six verbal IQ groups in Table 10 do not differ from each other or from the order reported by Clark for college undergraduates. Kendall's coefficient of concordance (W) among these seven sets of ranks (six verbal IQ ranks and Clark, 1969b) was significant beyond the .001 level ($X^2 = 36.75$).

Table 8

Percentage of Errors in Solving Three-Term Series Problems;

Presented for Three Levels of Verbal IQ*

Problem Type		Form of Question												Average						Overall Average					
		Best?						Worst?																	
		Imagery			No Imagery			Imagery			No Imagery			Imagery			No Imagery			Imagery			No Imagery		
		Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo
I	a	14	33	38	25	24	44	17	33	38	28	33	24	15	33	38	26	28	41	17	37	39	21	31	40
	b	11	19	44	8	19	30	28	62	36	22	48	45	19	40	40	15	33	38						
II	a	28	28	57	19	38	48	30	52	65	33	52	56	29	40	61	26	45	52	25	42	54	24	42	47
	b	19	52	57	19	38	42	22	33	36	22	38	41	21	43	47	21	38	42						
III	a	8	19	24	5	19	17	11	19	29	11	19	36	10	19	26	8	19	26	11	24	28	13	19	29
	b	8	28	33	14	19	32	14	28	26	19	19	33	11	28	29	17	19	32						
IV	a	28	57	51	11	33	54	17	48	54	17	48	51	22	52	53	14	40	53	25	55	48	24	42	54
	b	19	48	39	30	43	47	36	67	47	36	43	61	28	57	43	33	43	54						
I'	a	33	52	44	19	38	45	5	28	38	17	24	35	19	40	41	18	31	40	26	42	48	25	35	48
	b	42	52	59	28	43	56	25	33	48	36	33	54	33	43	54	32	38	55						
II'	a	17	38	41	22	33	44	25	43	54	33	19	50	21	40	48	28	26	47	27	38	47	23	35	48
	b	17	33	42	17	43	42	50	38	47	19	43	53	33	36	45	18	43	48						
III'	a	28	67	53	28	52	44	36	48	48	17	19	47	32	57	51	22	36	45	31	60	52	26	41	51
	b	30	67	48	28	48	56	30	57	57	33	43	57	30	62	53	30	45	57						
IV'	a	25	62	54	11	24	38	2	48	44	8	43	35	14	57	49	9	33	36	18	48	45	11	37	40
	b	17	38	39	11	33	38	28	38	42	14	48	48	22	38	41	12	40	43						

*Lorge-Thorndike

Table 9

Percentage of Errors in Solving Three-Term Series Problems;

Presented for Three Levels of Non-Verbal IQ*

Problem Type		Form of Question												Average						Overall Average					
		Best?						Worst?																	
		Imagery			No Imagery			Imagery			No Imagery			Imagery			No Imagery			Imagery			No Imagery		
		Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo
I	a	21	27	44	22	33	53	24	33	36	22	31	28	23	30	40	22	32	41	26	35	38	18	35	42
	b	24	33	33	6	31	30	33	44	36	22	43	55	29	39	35	14	37	43						
II	a	33	44	55	31	36	50	33	60	67	40	52	55	33	52	61	36	44	53	31	44	59	28	42	50
	b	38	35	67	22	40	44	17	35	44	18	40	50	28	35	56	20	40	47						
III	a	14	15	28	11	14	17	21	22	22	15	26	39	18	19	25	13	20	28	17	21	30	14	25	32
	b	14	22	42	11	31	33	17	24	28	18	26	39	16	23	35	15	29	36						
IV	a	33	58	44	20	43	55	28	51	47	20	50	55	31	55	46	20	47	55	32	50	47	29	47	56
	b	24	38	44	31	48	47	40	51	50	42	45	67	32	45	47	37	47	57						
I'	a	31	58	36	15	50	47	14	18	53	15	19	53	23	38	45	15	35	50	27	46	50	23	43	55
	b	43	55	61	29	59	50	19	51	47	31	43	67	31	53	54	30	51	59						
II'	a	21	29	53	29	31	50	26	53	53	27	36	61	24	41	53	28	34	56	33	40	46	22	44	53
	b	33	29	39	13	50	44	50	49	39	18	55	55	42	39	39	16	53	50						
III'	a	43	49	53	29	48	47	38	42	55	20	36	47	41	46	54	25	42	47	41	46	57	30	49	51
	b	40	38	64	33	59	47	40	53	55	35	50	61	40	46	60	34	55	54						
IV'	a	40	44	58	8	28	50	28	27	44	8	38	42	34	36	51	8	33	46	29	36	49	15	35	46
	b	19	33	47	20	28	42	28	38	47	22	45	50	24	36	47	21	37	46						

*Lorge-Thorndike

Table 10

Orders of Difficulty for Three-Term Series Problems;

Presented for Three Levels of Verbal and Non-Verbal IQ

Variable of Classification

Verbal IQ												Non-Verbal IQ											
Imagery						No Imagery						Imagery						No Imagery					
Problem Type			% Errors			Problem Type			% Errors			Problem Type			% Errors			Problem Type			% Errors		
Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo	Hi	Med	Lo
III	III	I	11	24	28	IV'	III	III	11	19	29	III	III	I	17	21	30	III	III	III	14	25	32
I	I	III	17	37	39	III	I	I	13	31	40	I	I	III	26	35	38	IV'	I	I	15	35	42
IV'	II'	IV'	18	38	45	I	I'	IV'	21	35	40	I'	IV'	II'	27	36	46	I	IV'	IV'	18	35	46
II	I'	II'	25	42	47	II'	II'	II	23	35	47	IV'	II'	IV	29	40	47	II'	II	II	22	42	50
IV	II	I'	25	42	48	II	IV'	I'	24	37	48	II	II	IV'	31	44	49	I'	I'	III'	23	43	51
I'	IV'	IV	26	48	48	IV	III'	II'	24	41	48	IV	I'	I'	32	46	50	II	II'	II'	28	44	53
II'	IV	III'	27	55	52	I'	II	III'	25	42	51	II'	III'	III'	33	46	57	IV	IV	I'	29	47	55
III'	III'	II	31	60	54	III'	IV	IV	26	42	54	III'	IV	II	41	50	59	III'	III'	IV	30	49	56

Easy

Difficult

Table 11

Percentage of Errors in Solving Three-Term Series Problems;

Presented for Males and Females

Problem Type		Form of Problem								Average				Overall Average			
		Best?				Worst?											
		Imagery		No Imagery		Imagery		No Imagery		Imagery		No Imagery		Imagery		No Imagery	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
I	a	37	20	35	33	38	28	33	24	37	24	34	29	39	27	32	31
	b	38	20	25	21	43	40	35	42	41	30	30	32				
II	a	54	36	43	38	65	45	42	57	59	41	42	48	52	40	40	40
	b	55	39	36	35	34	36	37	29	44	38	37	32				
III	a	20	15	10	20	22	22	26	27	21	19	18	23	25	20	24	23
	b	30	22	26	23	25	20	35	21	28	21	30	22				
IV	a	54	39	43	35	44	44	36	44	48	41	39	39	46	42	40	45
	b	35	40	32	50	52	45	50	50	43	43	41	50				
I'	a	47	36	46	27	35	20	35	21	41	28	41	24	46	35	47	32
	b	55	50	53	42	47	32	54	36	51	41	53	39				
II'	a	40	24	36	36	50	37	44	36	45	30	40	36	46	35	39	38
	b	45	31	35	38	47	48	40	42	46	40	37	40				
III'	a	57	42	33	44	50	43	33	30	54	42	33	37	53	44	39	44
	b	50	48	42	50	53	44	46	51	52	46	44	51				
IV'	a	48	44	36	24	35	39	32	27	41	41	34	26	44	33	35	30
	b	45	21	26	35	47	29	44	33	46	25	35	34				

Table 12

Percentage of Errors in Solving Three-Term Series Problems;

Imagery Totals Presented for Sex and Use of Imagery

Problem Type		Form of Question												Average						Overall Average					
		Best?						Worst?																	
		M Yes	M No	F Yes	F No	All Yes	All No	M Yes	M No	F Yes	F No	All Yes	All No	M Yes	M No	F Yes	F No	All Yes	All No	M Yes	M No	F Yes	F No	All Yes	All No
I	a	37	37	22	17	30	27	40	37	26	29	31	33	38	37	24	23	31	30	38	40	25	28	32	34
	b	53	23	22	17	38	20	23	63	30	50	27	57	38	43	26	33	32	38						
II	a	67	40	35	37	51	39	73	57	44	46	59	52	70	48	40	42	55	45	58	46	34	45	46	46
	b	53	57	28	50	41	54	37	30	26	46	32	38	45	43	27	48	36	46						
III	a	23	17	18	12	21	15	27	17	18	25	23	21	25	17	18	19	22	18	32	17	22	18	27	18
	b	43	17	22	21	28	19	33	17	28	12	31	15	38	17	25	17	32	17						
IV	a	47	60	31	46	39	53	40	47	30	58	35	53	43	53	30	52	37	53	41	51	35	49	38	50
	b	30	40	30	50	30	45	47	57	48	42	48	50	38	48	39	46	39	47						
I'	a	37	57	39	33	38	45	40	30	18	21	29	26	38	43	29	27	34	35	48	43	37	32	42	38
	b	67	43	57	42	62	43	50	43	31	33	41	48	58	43	44	37	51	40						
II'	a	50	30	30	17	40	24	43	57	41	33	42	45	47	43	35	25	41	34	45	47	35	35	40	41
	b	40	50	24	37	32	44	43	50	46	50	45	50	42	50	35	44	39	47						
III'	a	53	60	37	46	45	53	50	50	31	54	41	52	52	55	34	50	43	53	52	54	40	48	46	51
	b	50	50	41	54	46	52	53	53	50	37	52	45	52	52	45	46	49	49						
IV'	a	50	47	41	46	46	47	47	23	28	50	38	37	48	35	34	48	41	42	48	40	28	38	39	39
	b	50	40	20	21	35	31	43	50	24	33	34	42	47	45	22	27	35	36						

Table 13

Orders of Difficulty for Three-Term Series Problems;

Presented for Two Levels of Sex and Age

Easy

Variable of Classification															
Sex								Age							
Imagery				No Imagery				Imagery				No Imagery			
Problem Type		% Errors		Problem Type		% Errors		Problem Type		% Errors		Problem Type		% Errors	
M	F	M	F	M	F	M	F	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo
III	III	25	20	III	III	24	23	III	III	18	27	III	III	25	21
I	I	39	27	I	IV'	32	30	I	I	33	32	IV'	I	31	30
IV'	IV'	44	33	IV'	I	35	31	II'	IV'	36	38	I	IV'	32	31
I'	I'	46	35	II'	I'	39	32	IV'	I'	37	42	II	I'	38	34
II'	II'	46	35	III'	II'	39	38	II	II'	38	42	II'	II'	40	35
IV	II	46	40	II	II	40	40	I'	IV	39	45	III'	II	41	40
II	IV	52	42	IV	III'	40	44	IV	II	40	50	I'	IV	43	41
III'	III'	53	44	I'	IV	47	45	III'	III'	43	51	IV	III'	44	44

Difficult

Table 14

Percentage of Errors in Solving Three-Term Series Problems;

Presented for Two Levels of Age

Problem Type		Form of Question								Average				Overall Average			
		Best?				Worst?											
		Imagery		No Imagery		Imagery		No Imagery		Imagery		No Imagery		Imagery		No Imagery	
		Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo
I	a	37	24	38	31	28	33	22	33	32	28	30	32	33	32	32	30
	b	30	30	27	15	37	40	39	39	33	35	33	27				
II	a	40	48	38	39	43	62	45	54	42	55	41	46	38	50	38	40
	b	43	48	35	35	23	40	36	33	33	44	35	34				
III	a	15	22	14	13	13	30	29	22	14	26	22	17	18	27	25	21
	b	25	25	26	22	17	28	27	26	21	27	27	24				
IV	a	40	51	33	44	45	40	46	33	42	45	40	39	40	45	44	41
	b	30	40	49	31	45	49	46	55	37	44	48	43				
I'	a	45	40	39	33	22	32	36	17	33	36	38	25	39	42	43	34
	b	50	55	51	39	38	40	43	48	44	48	47	43				
II'	a	33	33	33	39	42	46	46	31	37	40	40	35	36	42	40	35
	b	33	33	36	33	37	55	45	37	35	44	40	35				
III'	a	45	51	43	37	35	54	36	30	40	52	40	33	43	51	41	44
	b	40	52	36	59	52	48	48	48	46	50	42	54				
IV	a	45	49	26	30	37	28	29	28	41	39	27	29	37	38	31	31
	b	33	32	27	31	33	40	42	33	33	36	35	32				

Percentages of solution errors are grouped into high, medium and low levels of Lorge-Thorndike non-verbal IQ in Table 9. As before, more overall errors are made by Ss who have lower non-verbal IQ scores. This seems to hold for both the Imagery and No Imagery conditions. While there do not appear to be any substantial differences in absolute errors between the two imagery conditions, a slight but consistent advantage (i.e., fewer errors) for High-No Imagery Ss over High-Imagery Ss suggests that imagery instructions may actually have been dysfunctional. Persons high in non-verbal IQ may have powerful non-verbal problem-solving strategies already at their disposal. The experimental imagery instructions may have interfered with or been less successful than strategies the Ss had already. Relative difficulties of the problem-types are shown in Table 10 for each of the three non-verbal IQ levels within both Imagery and No Imagery conditions. Differences in non-verbal IQ do not seem to influence the relative difficulties of problem-types. The same problem-types were usually either easy or difficult for all six non-verbal IQ groupings, as well as being similar to the problem-type difficulties reported by Clark (1969b). Kendall's concordance coefficient (W) among seven sets of difficulty ranks (six non-verbal IQ ranks and Clark, 1969b) was significant beyond the .001 level (X^2 = 37.40).

Percentages of solution errors are grouped separately for males and females in Table 11. If there are any sex differences at all, it may be that males in the imagery condition commit slightly more total errors than females in either group. In Table 12, these data are further broken down according to which Ss in the Imagery condition reported that they consistently used the experimental strategy in solving the problems.

Both males who did (Male-Yes) and males who did not (Male-No) report using imagery made more errors than females in any group, but the increase in errors over females seems larger for those males who said they used imagery to solve the problems. As far as relative errors are concerned, however, the usual pattern of problem-type difficulty emerged for males and females in both imagery conditions (Table 13). Again, this pattern was quite similar to that reported by Clark (1969b), and a concordance coefficient (W) among the four male-female rankings and Clark (1969b) was significant beyond the .001 level ($X^2 = 29.3$).

Table 14 re-groups percentages of solution errors into high and low levels of age within each imagery condition. No consistent differences in absolute or relative errors seem to result when age is used to reorganize the data. As before, the relative errors are in the expected pattern (Table 13) and a concordance coefficient among the four age rankings and the ranking reported by Clark (1969b) is significant ($X^2 = 30.52$; $p < .001$).

Method Experiment 2

Subjects

Ss were 54 junior high students enrolled in special education classes for the educable mentally retarded. They ranged in age from 12 to 14 years; their IQ's were estimated to range between 55 and 80 and most exhibited a variety of emotional and learning disabilities.

Experimental Task

Variations of two tasks were required of all Ss--directionality tests and solving a small number of three-term series problems. First, Ss indicated their spatial assignments for the elements of six premises which contained the relation words "better," "worse," "earlier," "later," "faster," and "slower." Then they solved 12 three-term series problems that contained these same relation words.

Procedure

The general procedures for obtaining spatial assignments were identical for all Ss although the premise form varied from group to group. The procedure was the same as that described by Handel et al. (1968) except that E read each premise aloud to S. After each premise was read, S told E in which of four boxes drawn at the ends of two perpendicular vertical and horizontal axes to place each person mentioned in the premise. E wrote these names in the boxes indicated by S and continued by reading the next premise until spatial assignments were obtained for all six premise statements.

Three-term series problems were also read aloud by E, who recorded S's verbal response. As before, each S was tested individually and given as much time as necessary to solve a problem.

Experimental Groups

The 54 Ss were divided into four groups. Each of the four groups performed a spatial assignment task and then solved three-term series problems; however, the precise forms of directionality statements and series problems were different for each group (Tables 15, 16, and 17).

Group 1 consisted of 27 Ss who made spatial assignments to six premises and solved 12 series problems, as shown in Table 15. Both directionality statements and series problems were presented in positive comparative form. To help them solve the series problems, Ss were given

Table 15

Experimental Treatments for Groups 1 and 2

Group	Experimental Treatment		
	Directionality Premises	Three-Term Series Problems	Type
1	A is better than B A is worse than B A is earlier than B A is later than B A is faster than B A is slower than B	A is (better/earlier/faster) than B B is (better/earlier/faster) than C	Ia
		C is (worse/later/slower) than B B is (worse/later/slower) than A	IIa
		A is (better/earlier/faster) than B C is (worse/later/slower) than B	IIIa
		B is (worse/later/slower) than A B is (better/earlier/faster) than C	IVa
2a	Same as Group 1	Same as Group 1*	
2b	A is not as good as B A is not as bad as B A is not as early as B A is not as late as B A is not as fast as B A is not as slow as B	Same as Group 1	

*Group 2a were not given paper cutouts to help solve three-term series problems.

Table 16

Experimental Treatments for Groups 3a and 3b

Group	Experimental Treatment		
	Directionality Premises	Three-Term Series Problems	Type
3a	A is better than B A is worse than B A is earlier than B A is later than B A is faster than B A is slower than B	A is (better/earlier/faster) than B B is (better/earlier/faster) than C Who is (best/earliest/fastest)?	Ia
		C is (worse/later/slower) than B B is (worse/later/slower) than A Who is (best/earliest/fastest)?	IIa
		A is not as (bad/late/slow) as B B is not as (bad/late/slow) as C Who is (best/earliest/fastest)?	I'a
		C is not as (good/early/fast) as B B is not as (good/early/fast) as A Who is (best/earliest/fastest)?	II'a
3b	A is not as good as B A is not as bad as B A is not as early as B A is not as late as B A is not as fast as B A is not as slow as B	Same as Group 3a	

Table 17

Experimental Treatments for Groups 4a and 4b

Group	Experimental Treatment		
	Directionality Premises	Three-Term Series Problems	Type
4a	A is better than B A is worse than B A is earlier than B A is later than B A is faster than B A is slower than B	A is (better/earlier/faster) than B B is (better/earlier/faster) than C Who is (worst/latest/slowest)?	Ia
		C is (worse/later/slower) than B B is (worse/later/slower) than A Who is (worst/latest/slowest)?	IIa
		A is not as (bad/late/slow) as B B is not as (bad/late/slow) as C Who is (worst/latest/slowest)?	I'a
		C is not as (good/early/fast) as B B is not as (good/early/fast) as A Who is (worst/latest/slowest)?	II'a
4b	A is not as good as B A is not as bad as B A is not as early as B A is not as late as B A is not as fast as B A is not as slow as B	Same as Group 4a	

three paper-men cutouts at the beginning of each problem. Each cutout was of the same height (3 1/2 inches) and shape and bore a name across its chest appropriate to the present problem. Ss were free to use the paper cutouts in whatever manner they wanted or not at all if they weren't helpful in solving the problems.

Group 2 (Table 15) contained seven Ss of which three (Group 2a) made spatial assignments to premises stated in positive comparative form and four Ss (Group 2b) made spatial assignments to negative equative premises. Group 2 Ss solved the same series problems that were used with Group 1 but they were given no paper cutouts to help solve them.

Groups 3 (n = 10; Table 16) and 4 (n = 10; Table 17) were similar in that one half the Ss in each group made spatial assignments to positive comparative premises and the other half made spatial assignments to negative equative premises. Both groups solved both positive comparative and negative equative series problems and used paper cutouts as adjunct aids. Group 3, however, received series problems whose questions were unmarked according to deep structure theory. Group 3 Ss were asked, "Who is better? (earlier?, faster?)" On the other hand, Group 4 received series problems with marked questions. Group 4 Ss were asked, "Who is worse? (later?, slower?)"

Results Experiment 2

Spatial Assignments

Percentages of types of spatial assignments made to six premise statements are presented in Table 18 for 54 retarded Ss in Groups 1, 2, 3 and 4. Forty Ss made their spatial assignments to six positive

Table 18

Percentages of Types of Spatial Assignments; Presented for Groups 1, 2, 3 and 4*

Spatial Assignment	Type of Relation Word					
	Better-worse		Earlier-later		Faster-slower	
	PC	NE	PC	NE	PC	NE
Consistent:	42	32	44	25	42	54
Top to bottom	18	11	14	3	11	18
Left to right	10	10	10	4	9	4
Bottom to top	7	0	14	11	14	14
Right to left	7	11	6	7	9	18
Inconsistent:	57	68	56	75	57	46
Top to left	10	4	8	18	10	11
Left to top	5	0	2	7	8	0
Top to right	20	14	17	14	25	3
Right to top	6	4	8	14	4	11
Bottom to right	4	11	5	7	2	7
Right to bottom	4	14	6	4	2	0
Bottom to left	2	14	4	7	5	3
Left to bottom	6	7	6	4	1	11

*Spatial assignments were made to premises that were stated in positive comparative (PC) or negative equative (NE) form.

comparative (PC) premises and the remaining 14 Ss to six premises stated in negative equative (NE) form. Perhaps the most striking feature of these data is the lack of consistent directional preferences. For each of the six premise pairs, Ss spread their assignments across nearly every one of the 12 directional categories. Spatial assignments for each of four premise pairs were spread across all 12 categories, while no fewer than 10 and 11 categories, respectively, were needed for the remaining two premise pairs. Preferences for single categories were quite small. No category received more than 25% of the assignments for a given premise pair and in only two instances was there more than 18%. Overall, Ss placed the first name of the premise in the top position more often than any other. They assigned the first name to the top position 41% of the time, with the remaining first name preferences nearly equally divided among bottom, left and right positions. Once the top position was chosen for the first name, however, they placed the second name to the right (18%) more often than to the bottom (13%), as Handel et al. (1968) observed, or to the left (9%). Overall, Ss made more inconsistent assignments (i.e., placing the names of a premise on different axes) than consistent ones. They placed one name on a horizontal and the other on a vertical axis 59% of the time. For only one premise pair, "A is not as fast/slow as B," were more than half of the spatial assignments made along a single axis.

While Table 18 illustrates the inconsistencies in preferences between directional categories and between different premise pairs, it does not convey the within-S inconsistencies which were also observed. One reason for not grouping subjects according to their consistent directional preferences

Table 19

Rank-Order Correlations;

Presented for the Spatial Assignments of Premises Which Were Positive Comparative (PC) or Negative Equatives (NE) and Contained Three Pairs of Relation Words

Positive Comparatives

	Better-worse	Earlier-later	Faster-slower
Better-worse		.86[1]	.79[1]
Earlier-later			.72[2]

Negative Equatives

	Better-worse	Earlier-later	Faster-slower
Better-worse		- .24	- .24
Earlier-later			.05

	Better-worse (NE)	Earlier-later (NE)	Faster-slower (NE)
Better-worse (PC)	- .05		
Earlier-later (PC)		.19	
Faster-slower (PC)			.30

[1] $P < .01$

[2] $P < .05$

across all the premises was that so few Ss were consistent. For example, regardless of which directional category is considered, only two Ss selected the same category for all six premises. On the average, each of the 54 Ss used four categories for spatial assignments of the names contained in their six premises. Most Ss failed to demonstrate a preference for a single directional category, so the prediction of specific series problem errors from a person's spatial assignments was severely handicapped.

Despite the lack of consistent directionality within subjects, there were some similarities in the patterns of spatial assignments to positive comparative premises (Table 19). Forty Ss made similar spatial assignments for all of the positive comparative premises. Rank-order correlations (rkc's of .86, .79, .72) between these three premise pairs were significant at the .05 level or beyond. Spatial assignments for negative equative premises (n = 14) seemed quite different, however. Ranks for the spatial assignments of negative equative premises did not correlate significantly with positive comparatives or with each other.

Three-Term Series Problems

Percentages of errors in solving 12 series problems are presented in Table 20 for Groups 1 and 2. Relative difficulties of the four problem-types are essentially the same across both groups and the three pairs of relational words--problems Ia and IIIa were easy, while IIa and IVa were difficult. Although the total errors committed by retarded Ss were usually greater, they found the same problem-types either easy or difficult as so often observed with normal Ss. And, although removing the paper cutouts from Group 2 Ss did result in more errors, the same general pattern of relative errors was observed.

Table 20

Percentage of Errors in Solving Three-Term Series Problems;

Presented for Groups 1 and 2

Problem Type	Form of Problem*	Type of Relation Word						Average	
		Better-worse		Earlier-later		Faster-slower			
		Group		Group		Group		Group	
		1	2	1	2	1	2	1	2
I a	A better than B; B better than C	18	71	41	28	18	43	26	48
II a	C worse than B; B worse than A	48	57	55	57	44	57	49	57
III a	A better than B; C worse than B	18	14	11	43	7	14	12	24
IV a	B worse than A; B better than C	44	71	52	71	52	86	49	76

*Problems alternately contained relation words better-worse, earlier-later and faster-slower.

Table 21

Percentage of Errors in Solving Three-Term Series Problems;

Presented for Groups 3 and 4

Problem Type	Form of Problem*	Type of Relation Word									Average		
		Better-worse			Earlier-later			Faster-slower					
		Group			Group			Group			Group		
		3	4	3&4	3	4	3&4	3	4	3&4	3	4	3&4
I a	A better than B; B better than C	30	60	45	20	20	20	70	20	45	40	33	37
II a	C worse than B; B worse than A	60	50	55	50	80	65	50	60	55	53	63	58
I' a	A not bad as B; B not bad as C	50	40	45	40	40	40	30	40	35	40	40	40
II' a	C not good as B; B not good as A	70	60	65	50	60	55	30	40	35	50	53	52

*Problems alternately contained relation words better-worse, earlier-later, and faster-slower.

Percentages of solution errors for Groups 3 and 4 are shown in Table 21. All Ss (n = 10 in each group) solved problem-types Ia, IIa, I'a and II'a. Group 3 Ss received unmarked questions, i.e., "Who is better? (earlier?, faster?)" while Group 4 received questions that were marked, i.e., "Who is worse? (later?, slower?)." Overall solution errors for both groups were reasonably close to expectation. Type Ia was easy, IIa was difficult and types I'a and II'a were intermediate. Predictions based on question form, however, were not borne out in the differences between the groups. According to deep structure theory, Ia and II'a should have been easier when questions were unmarked (Group 3) and I'a and IIa easier when questions were marked (Group 4) but the data did not support either prediction.

It was already shown that relation words that had similar directionality patterns also had similar patterns of series problem difficulty. Positive comparative premises containing the relation words "better-worse," "earlier-later" and "faster-slower" shared similar patterns of spatial assignments (Table 18) and problem-type difficulty (Table 20). One goal of this study was to see if an individual subject's spatial assignments could be used to predict his specific series problem errors. Perhaps Ss who make similar spatial assignments also commit the same types of reasoning errors. Table 22 presents percentages of solution errors for Ss who were either consistent (n = 19) or inconsistent (n = 21) in their spatial assignments. Because Ss differed so much in their directionality preferences, a broader criterion of "consistency" was adopted than was used earlier (Table 18). For the present situation, an S was regarded as consistent if his spatial assignments met one of two criteria--50% or more of his assignments were to

Table 22

Percentage of Errors in Solving Three-Term Series Problems; Presented for Group 1 Ss Who Were Consistent or Inconsistent in Their Spatial Assignments*

Problem Type	Form of the Problem	Spatial Assignment	
		Consistent	Inconsistent
Ia	A better than B B better than C	26	25
IIa	C worse than B B worse than A	42	58
IIIa	A better than B C worse than B	13	11
IVa	B worse than A B better than C	51	47

*Consistent Ss made spatial assignments that fell into only two of the four categories--top, bottom, right and left--while spatial assignments of inconsistent Ss were placed into more than two categories.

directional categories along the same horizontal or vertical axis, or 50% or more involved use of the same two categories even if they belonged to different axes. However, the usual pattern of errors emerged--types Ia and IIIa were easy, while IIa and IVa were difficult.

Discussion

Several theories have been advanced to suggest how people go about solving three-term series problems. At the same time, several investigators have reported empirical findings that tend to support certain of these reasoning theories more so than others. The purpose of the comments that follow is two fold--first, to examine the most popular reasoning theories in light of the findings reported by the present and other investigators of three-term series problems and, second, to attempt to describe a conceptual framework within which all these theories might be compatible. The first part of the discussion will consider each of the reasoning theories in turn, treating each as alternate "general" explanations of linear, deductive reasoning. Each theory is considered a "general" explanation of reasoning in the sense that differential predictions are not made for S̲s who differ along one or more physical or psychological dimensions. Apparently, each of these theories predicts that certain reasoning principles apply whether S̲s are young or old, male or female, of normal intelligence or retarded, etc. The reasoning theories to be considered include isotropic reorganization (Hunter, 1957b), spatial paralogic (DeSoto, 1965), spatial imagery (Huttenlocher, 1968), and deep structure theory (Clark, 1969a). At this point in the discussion, these theories will be treated as if they were rival explanations. However, in the second part of the discussion it will be assumed that each theory accounts for some aspect of a person's reasoning and rather than being rivals, each explanation is compatible with the others. A conceptual framework will be offered which describes the circumstances that determine which reasoning principles are influential at a given stage in a person's development.

Evaluation of Several Reasoning Theories

Isotropic Theory

Hunter (1957b) suggested that there were two forms, both isotropic, which Ss found easiest to solve. Problem-types Ia and IIa are isotropic and, therefore, very easy. The remaining problem-types are heterotropic, according to Hunter, and must be covertly reorganized by S into either isotropic form before solving. Problem reorganization involves the psychological operations of converting, reordering, or both, and problem difficulty increases the more reorganization a problem-type requires to make it isotropic. Hunter chose to study only the positive comparative three-term series problems. He did not report on negative equatives. Of the positive comparatives, he pointed out that eight pairs of problem-types were mirror images of each other and were psychologically equivalent (e.g., IaB: A>B; B>C. "Who is best?" laW: C<B; B<A. "Who is worst?")--that is, problem-types IaB, IaW, IIbB, IIbW, IIIaB, IIIaW, IVaB, and IVaW were the psychological equivalents of types IIaW, IIaB, IbW, IbB, IIIbW, IIIbB, IVbW, and IVbB, respectively. Therefore, he studied just the former set of eight problem-types since the latter eight were thought to parallel their structures.

The data which Hunter reports appear at first to support isotropic theory, as do the findings of several other investigators. On closer inspection, however, isotropic theory does not fare so well.

Problem-type IIIa, which must be converted, should be more difficult than Ia which is already in isotropic form. However, type IIIa is usually easier than Ia (Clark, 1969a, b; present study, Table 5). In fact, Hunter reported that this same reversal of problem-types Ia and IIIa occurred for his 16-year-old Ss.

Isotropic problems Ia and IIa should be easier than all others but they are not. Types IIIa and IIIb are often found easier than Ia and IIa (Clark, 1969a, b; present study, Table 5). In addition type IIa, despite its isotropic advantage, is consistently very difficult for Ss to solve correctly (DeSoto, et al., 1965; Handel, et al., 1968; Huttenlocher, 1968; Clark, 1969a, b; present study, Tables 5, 20 and 21).

Both converting and reordering are necessary to reorganize types IVa and IVb, so they should be harder than any other problems, but both Clark (1969a, b) and the present study (Table 5) demonstrate that type IIa is at least as difficult as IVa and IVb.

Finally, it is clear that problem-types IaB through IVaW are not psychologically equivalent to problems IIaW through IVbB (Clark, 1969a, b; present study, Table 5). This point is made most dramatically for the isotropic pair, Ia and IIa, which are very easy and very difficult, respectively.

Although Burt (1919) reports that Ss said they reorganized problem-type IVbW to type IIaW by converting the first premise, there is little empirical evidence that isotropic reorganization adequately predicts problem-type difficulty, at least for three-term series problems that are presented within a verbal context.

Spatial Paralogic

DeSoto pointed out that a problem is easy if it proceeds from top to bottom, that is, if the top two elements, A and B, are presented before the bottom pair, B and C. It is also easy if within each premise the top element, A or B, is mentioned before the lower element, B or C. Presumably, people construct spatial images as representations which help them solve the problems and it is easier to construct these images in a top-to-bottom (or left-to-right) direction. In addition, since persons tend to learn the end items of a series before the middle items, premises will be easier when they present end items, A or C, before the middle item, B.

Spatial paralogic is fairly successful at predicting the relative difficulties of positive comparative problems. Types Ia and IIIa are reported by most investigators to be easy while IIa and IVb are difficult (Table 3). It was pointed out earlier, however, that types IIIa and IIIb are often easier than Ia. Spatial paralogic predicts that Ia, IIIa, and IIIb should all be easy to solve but provides no basis for suggesting that the III's are easier than Ia.

Clark (1969a) has demonstrated that a weakness of spatial paralogic appears to be an inability to predict correctly the relative difficulties of negative equative problems. Where spatial paralogic predicts that I' and III' are easy, Ss consistently find them difficult and, instead of II' and IV' being difficult, they are easy.

It was suggested earlier (Table 4) that a complete analysis of problem-types in terms of the various influences of directionality and end-anchoring on problem-difficulty resulted in at least four levels of difficulty, while DeSoto seems to describe but three. A related criticism is that the effects of end-anchoring are supposed to offset each other in problem-types Ia, Ib, IIa, and IIb since in each problem one premise is end-anchored and the other is not. This suggests that the effect of end-anchoring is the same regardless of the premise in which it occurs and is difficult to resolve with Huttenlocher's (1968) observation that it is the end-anchoring in the second premise which is of most importance.

As Clark (1969a) put it, it's not that people don't use spatial imagery to help solve the problems--they do. It's just that spatial imagery does not seem to have differential effects on problem difficulty. In fact, the present data (Tables 5 and 6) suggest that there are few differences in absolute errors as well. Ss who were instructed to employ one form of spatial imagery made just about the same overall number and types of errors as Ss who did not receive imagery instructions. Spatial imagery instructions have been extremely influential recently in studies dealing with several facets of verbal learning. As a general explanation of linear reasoning, however, spatial paralogic falls short, at least when dealing with three-term series problems that are verbal in form.

Spatial Images

Huttenlocher (1968) agrees with DeSoto that Ss construct spatial representations of the elements A, B, and C which help them solve the problems. The theory of spatial images as first described (1968) seems to resemble spatial paralogic quite closely. Later (Huttenlocher, 1970), by dealing with negative equative series problems, it is apparent that spatial images theory is more broadly conceived.

Spatial images theory predicts that problems are easy when the second premise is end-anchored, that is, when the first element mentioned in the second premise is an end element in the series. When this condition is met for an active sentence, the first element of the second premise is the grammatical subject and can easily be "moved" by S into its position in his spatial representation of the series.

Huttenlocher (1968) describes at least two other mental operations that seem to influence problem difficulty, although these may exert less influence individually than the second premise end-anchoring just described. If the problem contains a relation word which suggests a particular spatial axis to S (e.g., "better" and "worse" usually suggest a vertical axis), he begins the problem by selecting the top element in the first premise and placing it at the top of his spatial image. Problems are easier when the first element of the first premise is also the top member of that premise. If the top element is mentioned second in the premise, S must search for it with the result that problem difficulty increases. Another operation influencing the difficulty of a problem involves whether the movable element (i.e., the third element to be mentioned in the problem) must be placed at the top (or left) or the bottom (or right) of S's spatial image. Spatial images theory adopts the notion from spatial paralogic that it is easier for S to construct his representation in a top-down or left-to-right direction than the reverse. In effect, this is similar to what DeSoto described as between premises directionality, the top pair A-B being presented before the bottom pair B-C. If a problem has between premises directionality, the movable third element becomes C, the bottom element, and so construction of S's spatial image proceeds top-down and is easy.

Table 23

An Analysis of Three-Term Series Problems

According to the Theory of Spatial Images

Problem Type	Desirable Properties		
	Movable element is subject?	Is first item the top element?	Between-premises anchoring?
IIIa	+	+	+
Ib	+	+	0
IIb	+	0	+
Ia	0	+	+
IIIb	+	0	0
IVb	0	+	0
IVa	0	0	+
IIa	0	0	0

Note: A "+" indicates that a desirable property is present and a "0" that it is absent.

Assuming that these three effects are real ones, that they are separate effects, and that their combined effects are at least additive, eight positive comparative problems (Ia through IVb) might be analyzed as shown in Table 23. In each case, A "+" indicates the presence of a desirable property and "0" indicates its absence. Table 23 yields several predictions, some of which may not coincide with Huttenlocher's original formulation of spatial images theory. For example, problem-type IIIa has all three properties and should be easier than all others, which it is. Type IIIa was found easiest by Hunter (1957b; 11-year-olds), DeSoto, et al. (1965), Handel, et al. (1968; for father-son problems), Clark (1969b) and in the present study (Table 5, normals and Table 21, retarded Ss in Groups 1 and 2). Problem-type IIa has none of these properties and should be the most difficult; Clark (1969a,b) and the present data for normals (Table 5) indicate it is. Several other predictions receive at least some support. Type IIb has one more desirable property than IVa and is often found easier than IVa. Type Ia has one more desirable property than IVa or IVb and is easier than either one. Similarly, Ib is easier than IVb. Problem-type IIIb, however, should be more difficult than Ib or IIb according to Table 23 but most investigators find that this is not the case.

The most popular prediction of spatial images theory is that problems are easier whose movable third elements are grammatical subjects (types Ib, IIb, IIIa and IIIb) rather than objects (types Ia, IIa, IVa and IVb). All the aforementioned studies and the present one support this prediction. More general support for spatial images theory has not been demonstrated, however, beyond the set of positive comparatives. Clark (1969a) pointed out that spatial images theory was unable to predict the relative difficulties of the negative equatives. As with spatial paralogic, the theory of spatial images does a pretty good job in explaining how Ss solve positive comparative problems but not negative equatives. A satisfactory theory of linear reasoning is expected to explain both sets of problems.

Deep Structure Theory

Clark (1969a) presented one of the most interesting explanations to date of how persons solve three-term series problems. His three principles of functional relations, lexical marking, and congruence provide several predictions about the relative difficulties of series problems, both positive comparatives and negative equatives. These predictions were supported in his original (1969a) and again in a later investigation (1969b).

Table 5 presents data from Clark (1969b) alongside the data for Imagery and No Imagery normals. Even a casual inspection reveals that relative percentages of solution errors for all three groups were quite similar. When the No Imagery group data are subjected to an analysis of variance, Clark's predictions generally are supported. For example, the principle of lexical marking predicts that problems whose base strings contain unmarked relational terms (types I and II') will be easier than those with marked terms (II and I'). This was the case for the No Imagery Ss (F = 7.13; df = 1,45). Congruence predicts that III and IV' have base strings which agree with either question and so they should be easier than IV and III' whose base strings are incongruent. The data for No Imagery Ss also agree with this prediction (F = 29.52; df = 1,45). Less support was found, however, for other predictions based on congruence. According to this principle, problems I and II' should be easier when the question is unmarked (e.g., "Who is best?") and II and I' easier when it is marked (e.g., "Who is worst?"). For only one comparison, IbB vs. IbW, was the difference significant and in the predicted direction (F = 6.04; df = 1,45). Clark's finding that negative equatives were always more difficult than positive comparatives was also observed with No Imagery Ss (F = 7.13; df = 1,45).

To explain why the order of the premises seems to influence the difficulties of certain problems (i.e., I, II, I' and II'), Clark borrowed an additional principle referred to as "compression." According to this principle, S reads the first premise of a problem (e.g., B is better than C). Rather than trying to remember the two base strings, B is good, C is good, and the semantic feature that B possesses more goodness than C, S compresses this information into the single base string and semantic feature, B is good (+). In other words, he drops the base string, C is good, and simply remembers that B is the better element in the first premise. If the remembered element, B, is also mentioned in the second premise (e.g., A is better than B), solution is easy since S combines the remembered base string, B is good (+), with the base strings in the second premise, A is good (+) and B is good, to yield an ordering in which A is best, B is in the middle, and the other element (C) is worst. Reversing the order of these premises should result in a more difficult problem, according to this principle. S compresses the first premise, A is better than B, into A is good (+). But the second premise, B is better than C, does not contain A, the remembered element from the first premise, so S does not have enough information to arrive at a complete ordering. To solve the problem, he must refer to premise I a second time and so the problem is difficult.

Compression predicts that Ib and IIb are easier than Ia and IIa and that I'a and II'a are easier than I'b and II'b, respectively. The present data (Table 5) tend to support predictions from the principle of compression as they affect problems I, II, I' and II'. Presumably, the remaining problem-types are not differentially influenced by a compression strategy, since in each case altering the order of the premises results in the same effect.

It was pointed out earlier in this paper that some of the reasoning theories were incomplete in one or more respects. Some of these criticisms may also apply to deep structure theory. Remembering that a powerful reasoning theory should predict equivalences as well as differences among problem-types, one would regard a theory incomplete if significant differences consistently were observed among problems which the theory predicted as equivalent.

To illustrate this point with deep structure theory, consider problems III, IV, III' and IV'. Each is an equivalence group according to deep structure since the theory contains no principles at this time which differentiate their levels of difficulty. For example, type III problems (IIIaB, IIIaW, IIIbB and IIIbW) should all be influenced in the same manner by lexical marking, congruence, and compression. Since the premises in each problem-type contain one marked (worse) and one unmarked (better) relation word, lexical marking would not make differential predictions. Each of the four type III problems is favored by congruence since the base strings for elements A and C agree with either question and, according to the compression principle, all type III problems have a structure that makes a compression strategy a difficult one. Similar analyses of types IV, III' and IV' indicate that equivalence should exist within each group of four problem-types. The present data (No Imagery _S_s) indicate that the equivalence predictions are met in only half of the groups. Groups IV and IV' do not differ within themselves ($\underline{F}$ = 1.39; $\underline{df}$ = 3,135 and $\underline{F}$ = 1.42; $\underline{df}$ = 3,135, respectively) but III and III' do ($\underline{F}$ = 3.45; $\underline{df}$ = 3,135 and $\underline{F}$ = 3.55; $\underline{df}$ = 3,135).

Next, consider that the principles of functional relations and lexical marking predict that types I and II' will be easy, while II and I' are difficult. Functional relations and congruence make III and IV' easy and IV and III' difficult. These principles render I, II', III, and IV' easy and II, I', IV, and III' difficult. Again, however, significant differences (Table 5; No Imagery) are found which remain unexplained by deep structure theory. Types I, II', III, and IV' are not equal in difficulty--III is easier than I ($\underline{F}$ = 7.72; $\underline{df}$ = 1,45) and IV' is easier than II' ($\underline{F}$ = 4.27; $\underline{df}$ = 1,45).

Irregularities in certain of these equivalence groups also appear in Clark (1969a, b). Should subsequent investigations of three-term series problems demonstrate consistently that differences within any of these groups occur, deep structure theory may need to be revised to include appropriate explanations.

A Conceptual Framework for Linear Reasoning

No single reasoning theory seems to account for all the differences in relative difficulty that are observed when _S_s solve three-term series problems. Maybe investigators of linear reasoning have been asking the wrong questions. Perhaps it isn't a matter of which theory is "correct" or which are "wrong," but rather _what are the conditions for which each theory makes correct predictions_? Looking at the problem in this way, one reasoning theory is not pitted against another. For each theory, we try to identify a constellation of variables for which that theory correctly predicts solution errors. A conceptual framework is needed which integrates several or all of these reasoning theories. Results from some recent investigations suggest what such a framework may be like.

Smedslund (1968) reported a study that was very nearly the same as others previously described in this paper. Ss were timed as they solved three blocks of eight three-term series problems. But these were problems which differed in at least two respects from popular series problems. In the first place, the problem elements were random letter pairs (e.g., HN, PD, UV) rather than men's names. But more importantly, inequality signs ">" and "<" replaced relation words such as "better-worse" or "faster-slower." In the Smedslund study problem-type Ia, for example, looked like the problem illustrated below.

HN PD

PD UV

Although Smedslund reports latencies only for eight positive comparatives (Ia through IVb), his results are extremely interesting. Table 24 presents orders of difficulty for Smedslund (1968), Clark (1969b) and the present study (normals, No Imagery). Problem-type Ia is also easy in the Smedslund study, but here the similarity ends. Type IIa is now very easy, not difficult as usually observed. Type IIIa instead of being the easiest problem is now the most difficult. Type IVa and IVb are only intermediate rather than very difficult, and so on. Clearly, Smedslund has uncovered a difficulty pattern unlike any other. His explanation of the phenomena has much in common with isotropic reorganization. Types Ia and IIa are "normal" forms to which each problen is reorganized before solution occurs.

Table 24

Orders of Difficulty for Three-Term Series Problems;

Ordered by Percentages of Solution Errors or Latencies

Groups					
Normal; No Imagery (Table 5)		Smedslund (1968)		Clark (1969b)	
Problem Type	% Errors	Problem Type	Latency (Seconds)	Problem Type	% Errors
IIIa	20	Ia	3.0	IIIa	9
IIIb	27	IIa	3.8	IIIb	11
Ib	31	Ib	4.3	Ib	12
Ia	32	IIIb	4.5	IIb	21
IIb	34	IVb	4.6	Ia	22
IVa	40	IVa	5.1	IVa	28
IVb	45	IIb	5.2	IVb	38
IIa	45	IIIa	5.5	IIa	46

*Latencies were recorded from the moment S began to read a problem until he responded.

Sitter and Ranken (in press) presented 16 positive comparative series problems to four groups of college undergraduates. The construction of problems was varied in a 2 x 2 design in which elements were either men's names or random letter-pairs and relation was expressed as words (bigger-smaller) or inequality symbols (> and <). Among their results were tests for each of three reasoning principles--normalization (after Smedslund, 1968), congruence, and lexical marking (both after Clark, 1969a,b). For the normalization hypothesis, they found that the normal problem-types, Ia and IIa, were easier than the others only when their relations were expressed in inequality symbols. Normal forms were not easier when relations were expressed in words. Clark's congruence hypothesis was supported for relation words but not inequality symbols, and the lexical marking hypothesis was supported for neither words nor symbols.

The Representation Hypothesis

Bruner and his associates (1966) have suggested that persons represent their experiences primarily through their actions (enactive), through pictures and images (iconic), through symbols such as language (symbolic), or some combination of these three modes. As it concerns the present task, linear reasoning in three-term series problems, the representation hypothesis states that relative difficulty hinges on how S represents the problems.

Ss who represent series problems enactively, through their actions, may encounter difficulties which parallel the difficulty of arranging physical objects into serial orders. This is precisely what spatial images theory claims. In a recent article Huttenlocher (1970) points out that the essence of the theory of spatial images is not whether Ss actually employ spatial imagery in solving the problems. The hypothesis is just that the difficulties in solving three-term series problems parallel the difficulties Ss encounter when arranging real, physical objects such as colored blocks, trucks etc.

Persons who represent series problems iconically through pictures or images may experience difficulties of an entirely different sort. Ss who reorganize (Hunter, 1957b) or normalize (Smedslund, 1968) problems into standard forms prior to solution may be representing them iconically. Perhaps the new pattern of series problem difficulty reported by Smedslund (1968) for problems whose relations were expressed as inequalities resulted because a majority of Ss represented them non-verbally.

And, finally, many Ss presumably deal with the problems in symbolic terms exclusively. Their primary mode of representation is symbolic so that they follow linguistic conventions when attempting to solve them. A striking feature of this and other studies of three-term series problems is the similarity between patterns of relative difficulty across many studies which have little in common except that the problems are presented in linguistic terms. Despite differences in administration, relation words, elements, and dependent measures, there is a strong resemblance of difficulty patterns so long as problems are written or read aloud to S. This seems to hold despite differences in Ss' age, sex, and intelligence. Linguistic reasoning principles seem to apply when relations are expressed as words but not when expressed using non-verbal symbols (e.g., ,).

The representation hypothesis suggests that there is a pattern of series problem difficulty that accompanies each mode of representation. It is not necessary, however, that a different pattern exist for each mode; only that Ss who consistently represent enactively, for example, encounter the same relative difficulties in solving the problems as others who represent these problems in the same way.

Bruner points out that a person represents his experience using some one or another, or a combination of each representational mode. In fact, it is exactly this multiplicity of representational schemata that leads to situations in which a given experience is represented in opposing ways with the result that an imbalance is created fostering cognitive growth. The representational hypothesis applied to three-term series problems suggests that problem difficulties depend on how S happens to represent the problems at that particular moment. There may then be as many patterns of problem-type difficulty as there are ways of combining action, imagery, and symbolism to represent the problems. Consider the following example where relation is expressed by inequality signs (after Smedslund, 1968). Inequality signs might be represented in one of two separate modes, imagery or symbolism, or both. The imaginal representation of inequalities does not require recourse to language. It is possible for S to solve the problems without knowing that the language equivalents for inequalities are the words "greater than" and "less than". By the same token, S may represent them entirely symbolically--that is, he uses the language equivalents "greater than" and "less than" exclusively and ignores the imaginal component. It is also possible that the inequalities will be represented in both forms--images and language equivalents.

How a person represents his experience seems to be a very potent factor in his ability to solve a wide range of problems. The representation hypothesis merely extends this observation to the solving of three-term series problems in an attempt to integrate what at first appears to be quite different theories of linear reasoning.

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