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Intelligence as an Information Processing Concept

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This paper examines the relationship between general cognitive competence and several aspects of information processing. Three sources of individual differences in information processing are proposed: structure, strategy, and general attentional resources. Structural factors set limits on the effectiveness of specific information processing steps. These factors appear to be important when we contrast the cognitive capacities of extreme groups, such as normal and mentally retarded persons

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but they account for only a small amount of the variability in homogeneous groups such as college students. The reason may be that within such groups, strategy of attacking problems is a more important source of variation, and moderates the relationship between simple information processing steps and complex reasoning. Finally, the fact that scores on almost all measures of cognitive competence are positively correlated may be related to the fact that all mental processes seem to compete for general attentional resources, and that individuals differ in the attentional resources they can bring to bear on any cognitive task.

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Intelligence as an Information Processing Concept[*]

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My son's high school biology text begins with a chapter entitled
"The meaning of life." After he and his fellow teen-agers have mastered
this, they move on to Chapter 2, "The diversity of life." Is there a
message here for those who would explain intelligence? How can we speak
about who thinks, or who thinks well, until we have a clear picture of
what thinking means to us? Viewed another way, if we think that we have a
good theory of thought, then we should be able to use that theory to de-
scribe individual differences. This point has been made before (Underwood,
1975). Rather than repeat the argument, I shall try to develop it further.
What progress has been made by using information processing theories to
understand individual differences in cognition? More interestingly, where
is our progress stymied, why, and what can we do about it?

A naive, but common, way of studying individual differences in cognition
is to establish a statistical relationship between performance on psychomet-
rically defined intelligence tests and performance on more theoretically
defined laboratory tasks. Investigators who do this are usually not inter-
ested in the intelligence test itself. The test serves as a surrogate for
some general cognitive performance that has been shown, empirically, to corre-
late with test score. The experimental task, however, is supposed to have
been derived from a theory of cognition. Hence linking the test and the
task should provide evidence that our theories of cognition have something
to do with natural world thinking.

A prominent subspecies of this approach is the attempt to link perform-
ance on tests designed to evaluate verbal aptitude with tasks that are sup-
posed to tap some pure aspect of memory (Hunt, 1978a). This is an attrac-
tive endeavor because of the central role of verbal processes in our culture
and because of the prominence of memory in our theories of cognition. While
the purpose of this paper is to raise questions about intelligence and infor-
mation processing in general, most of the examples will be based on the study
of memory and verbal intelligence, simply because we know more about this
point on the interface between psychometrics and experimental psychology.

The Current Status of the Effort

Saying that the approach just described is naive is perhaps too harsh.
The experimental paradigms used typically yield parameters that estimate
some theoretically basic information processing function, e.g. the speed of
access to information in either short or long term memory. It is certainly
of interest to determine whether or not those people who are facile with
linguistic reasoning differ from less facile persons along such dimensions
of information processing. Indeed one of Underwood's (1975) points was
that the failure to find that there are differences between more and less
competent individuals on any of our information processing parameters should
be cause for serious rethinking of our theories.

How much progress has been made in establishing links between theories
of memory and individual verbal aptitude measures? The answer to this ques-
tion is "Some, but surprisingly little." A common problem keeps resurfacing;
very small differences are found between "high verbal" and "low verbal" sub-
jects within the normal range of intelligence, but substantial differences

are found if we move to the study of extreme groups, such as mental retar-

dates. To see this, let us examine the findings in three areas; access to

well learned material, access to recently presented material, and learning.

Asymptotic memory access refers to the speed with which we can re-

trieve highly overlearned associations. A useful technique for testing

the speed of an asymptotically learned lingusitic association is the stimu-

lus identification paradigm developed by Posner and Mitchell (1967), and

since used by many others. Figure 1 illustrates the procedure. Two letters

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Figure 1 about here
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are presented, and the task is to indicate whetehr or not they have the same

name. Concentrating our attention on "yes" trials, letters may be either

physically identical (PI), as in the pair A-A, or name identical (NI), as

in the pair A-a. The reaction time (RT) for identification of NI pairs is

greater than the reaction time for identification of PI pairs. The difference

between RTs for NI and PI pairs, which will be called the NI-PI measure, can

be regarded as a measure of the efficiency of retrieval of a highly over-

learned linguistic association.[1] Note that using the NI-PI measure does

not commit one to the assumption that physical identification inevitably

precedes name identification, but simply to the assumption that name

identification is more dependent on linguistic associations than is physical

identification. (Posner, 1978).

Since reading is the process of associating verbal codes with arbitrary

symbols, one can reasonably hypothesize that the naming process should be

related to the ability to use written language, which is what a verbal apti-
tude test tests. The hypothesis fares moderately well when we examine
studies using subjects within the normal range of intelligence. Table 1
shows the results from two correlational studies in our laboratory, one in-
volving college students and one involving grade school children. In both
cases the correlation between the NI-PI measure and the intelligence or apti-
tude test score was on the order of -.30.[2] Such results are consistent with
results from studies that contrast the NI-PI measures obtained from groups
of "high" and "low" test scorers, when both groups are within the normal
range (Goldberg and Schwartz, 1977; Hunt, Lunneborg, and Lewis, 1975; Keating
and Bobbitt, 1978).

We can make a much more dramatic case for an association between "ver-
bal intelligence" and access to long term memory for verbal codes if we con-
trast the results obtained from studies of groups that span the whole range
of mental competence. Figure 2 summarizes several such studies, covering
populations ranging from exceptionally bright college students to educable
mental retardates. A point of some interest is that there is a considerable

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Table 1 about here
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non-linearity between the NI-PI measure and estimates of "general intelli-
gence". There is roughly a thirty point IQ spread between bright university
students and average young adults, and a similar IQ spread between young
adults and educable mental retardates. The results shown in Figure 2 show
that the equal difference in "IQ points", which is basically a statistical

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Figure 2 about here
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concept, is not paralleled by an equal difference in our estimates of the efficiency of memory... an information processing concept. There seems to be little prior reason for preferring one or the other of these scales as a measure of mental competence, so it would be hard to argue that the non-linear relation indicates that either scale is wrong.

When we move from speed of access of material in long term memory to speed of access in short term memory, much the same picture applies. Short term memory access speed is usually measured by memory scanning experiments, (S. Sternberg, 1966), as illustrated in Figure 3. The observer is shown from 1 to 6 letters or digits, called the memory set, and then shown a probe stimulus. The task is to indicate whether or not the probe was a member of the memory set. RT to make this decision is found to be a linear

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Figure 3 about here
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function of the number of items in the memory set, and the slope of this function is considered a measure of speed of access to information in short term memory.

Equivocal results have been obtained in studies examining individual differences in memory scanning in normal subjects. While there are some reports of correlations between memory scanning rate and verbal intelligence, the relations are neither large nor consistent. Chang and Atkinson (1976) even reported sex differences in the direction of the relationship! Our present knowledge supports S. Sternberg's (1975) earlier conclusion that there are individual differences in memory scan rates, but that their relation to other characteristics of the person is not clear. Once again, though, the picture changes when we examine results from extreme groups. Figure 4

Figure 4 about here
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shows results from a number of such studies. There is more than a 10 to 1 difference between the fastest memory scanning reported (by Hunt and Love (1972), for an expert mnemonist) and the slowest reported (by Harris and Fleer (1974), for mental retardates with suspected brain damage).

A similar pattern appears if we change from studies that examine the speed of access of short term memory to studies that examine its size, using conventional memory span procedures. There are reliable individual differences in memory span that are not associated with differential use of mnemonic strategies (Lyon, 1977), but this again appears to be an example of a statistically reliable effect that is not practically significant. Normal adult memory span runs from five to nine items, depending on the material to be memorized (Miller, 1956). Matarazzo (1972) has observed that this is not a wide enough range to be of clinical significance.[3] On the other hand, Matarazzo also advises that memory spans below this range may be indicants of brain damage. Ellis (1978) has observed that mental retardates show a deficit on practically any task that taps primary memory capacity, and argues strongly that this is not due to a failure of the retardates to use powerful mnemonic strategies. Huttenlocher and Burke (1976) have made the same argument with respect to the fairly large changes in memory span that occur as children mature. As in the case of long term memory measures, the efficiency of short term memory is at best a moderate predictor of intelligence test scores within the normal adult range, but if we move to the full spectrum of mental competence, marked differences in short term memory efficiency are observed.

Over the years there have been a number of studies that attempt to relate "ability to learn" to intelligence test score. Indeed, some authors have even maintained that intelligence should be defined as the ability to learn. To the extent that there is truth in this proposition, performance in learning experiments should relate to tested intelligence. One of the most comprehensive attempts to show this relationship, almost as a by-product of an effort to understand the components of learning itself, is an experiment by Underwood, Boruch, and Malmi (1978), in which some 200 university students participated in 33 (!) different learning experiments, and also made available their scores of the Scholastic Aptitude Test. Underwood et al. were primarily interested in the factorial composition of performance on the learning tasks, and simply observed that the different subtests of the SAT appeared to represent a cluster of abilities different from those required for learning under various conditions. I have reanalyzed the Underwood et al. results, including in the analysis the aptitude test measures. A factor analysis recovered the original learning factors and, as Underwood et al. suggested, identified a "test factor" that was independent of the learning factors. Table 2 shows the loading of the SAT verbal aptitude test on all six factors. Clearly test performance in normal subjects is related to learning performance, but the relation is not a close one. On the other hand, though, learning is notoriously deficient in the mentally

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Table 2 about here
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retarded. It has also been found that injuries to various brain structures render it difficult, if not impossible, to learn new associations between well recognized items.

These results are typical of many other results relating information processing to general measures of (verbal) cognitive competence. Given reasonable attention to statistical power considerations, reliable associations are easy to find. Practically significant associations, within the normal range of intellectual competence, are seldom found. Keele (Note 1) has summarized the situation nicely by referring to the ".3 barrier", no single information processing task seems to able to account for more than 10 per cent of the variance in a general intelligence test. Of course, one might hope that a set of, say, ten such tasks would provide us with a complete account of intelligence. Unfortunately, this does not work either. Most measures of memory functioning are positively correlated with each other, so the multiple correlations between verbal aptitude tests and batteries of information processing measures are seldom higher than .6 (see, for instance, Lunneborg, 1977). On the other hand, as soon as we move to the study of differences between groups whose mental competence varies widely, we find that practically every information processing measure will singly differentiate between groups. What we do not find is any appreciable number of "in between" studies, in which the correlations are in the .5 to .7 range.

I do not believe that this problem is a statistical one, produced solely by a tendency to study populations who differ either very little or very much in their cognitive competence. Rather, I believe that we are seeing evidence of a qualitative difference. Changes in basic information processing parameters probably do account for a great deal of the differences in individual cognitive power when we compare, say, mental retardates to high school students. When we examine the very real differences in cognitive

power between dull and bright university students, or even dull and bright "normal people", we may find that these differences are produced by other factors. To consider what these other factors are, and how they fit into cognitive theory, a return to a more theoretical perspective is in order.

Cognition and Information Processing

Following the lead of Newell and Simon (1972), I believe that it is appropriate to think of human reasoning as being the product of a program's being executed on a peculiar information processing device, our brains. The "computer analogy" is frequently misunderstood to mean that our brains must follow the style of processing of physical computers; binary operation, passive memory systems, and serial computation. This is in error. The analogy only maintains that it is useful to think about thought by applying the same concepts to human reasoning that we would apply to any physical information processing system.

Every problem solving machine must possess some mechanistic capacities for storing, retrieving, and transforming information. This is the structural aspect of thought. Most of the information processing paradigms of experimental psychology have been designed to deal with structural considerations. In order to solve a problem the mechanistic capacities must be applied in a particular, and possibly highly flexible, order. This is the program, or process, aspect of thought. Finally, virtually every activity that we would call intelligent presumes some co-ordination between the present situation and the problem solver's store of previously acquired information. This is the knowledge aspect of thought. You cannot say how, or how successfully, a particular information processing system...be it man or computer...will attack a particular problem unless you understand its structure, process, and

knowledge.

To drive this point home, let us consider an analogy to basketball playing rather than computing. If you try to predict a basketball player's scoring potential from isolated physical characteristics you would have only limited success. Extreme weaknesses or lack of stature would be associated with very poor performance, but once the person moved into the "above normal" field correlations with physiological measures break down. The reason is that there are two quite different ways of scoring points in basketball. Some players score by muscling their way underneath the basket, then jumping up and slamming the ball down into the goal. For players who use this strategy, height and weight are good predictors of success, while hand-eye co-ordination and depth perception are not. The other strategy for scoring is to move quickly backwards, away from your opponent, and toss a high, arcing shot up into the goal, over the heads and hands of the opposition. Players who use this strategy need not be particularly large or strong, but must be quick and have excellent depth perception.

With both the computer and athletic analogies in mind, let us look again at intelligence as defined by psychometric theory. Intelligence tests fall into two broad categories. Tests used for clinical, educational, and industrial prediction are typically (intentionally and properly) designed to be work samples for the endeavors to be predicted. They owe their success to the fact that they test so many behaviors that they are almost bound to produce a good sample of a person's general cognitive capacities (Wechsler, 1975). Given the pragmatic, behavior sampling approach taken in the development of such instruments as the Wechsler and Stanford-Binet tests, it is unreasonable to expect that any one information processing procedure would provide "the answer" to our questions about the nature of intelligence.

A far more interesting group of intelligence tests are those that are derived from an explicit psychometric theory, such as the various tests used to measure "general intelligence" or, even more explicitly, its crystallized and fluid components (Horn, 1979). It is much more reasonable to expect to find that there is a close link between information processing measures and psychometrically pure tests of intellectual functioning than to find such a link between information processing and the behavior-sample type of test. Indeed, such research is currently being conducted in our own laboratory and in others, and we await its outcome with interest.

In spite of the theoretical importance of research linking specific information processing theories to specific psychometric theories. I must admit to having little hope that these studies are going to make a great breach in the .3 barrier. (They may push it back to .4.) The reason for my pessimism is that when psychometric tests are carefully orchestrated so that they are psychometrically pure, they too, bump up against the .3 barrier. This has been illustrated in a convincing way by the research of Snow (in press). By considering the correlation between two tests as an ordinal measure of their similarity, Snow applied multidimensional scaling methods to construct a space of psychometric tests. Figure 5 shows the results. The "good, robust" intelligence tests, i.e. those that are useful in predicting behavior in a variety of situations, all lie in the center of the space. Scattered around the periphery are various tests of specific abilities. These peripheral tests

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Figure 5 about here

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are the ones that would be most likely to show high relations to performance in specific information processing paradigms.

I suggest that this picture would be obtained if the peripheral clusters

of tests present people with very restricted problem solving situations, in which there is only one reasonable way to attack the task. Performance in such a situation will be more determined by mechanistic information processing capacities than by strategy choice, simply because of the limited range of strategies possible. By contrast, performance in the central cluster of tests may be much more dependent on a person's having available a store of strategies to deal with the varied problems presented by the items within each test. In this respect, it is of interest to note that the Raven Matrix test (Raven, 1965) appears in the central cluster. Logical analysis of this test has shown that it is amenable to attack by at least two psychologically distinct strategies, one based on perceptual reasoning and one based on propositional reasoning (Hunt, 1976). Statistical analyses of very large samples of persons taking the Raven test have also shown that there are clusters of performance that are, presumably, associated with different strategies. The assumption that the test is some sort of yardstick for a uni-variate, normally distributed ability cannot explain the pattern of clusters obtained (Hunt, 1978b).

The conclusion that the tests in Snow's central cluster are characterized by their having a number of different solutions, depending on the program the person chooses to use, is reinforced by studies of the individual items in tests that are considered "good indicators of intelligence." Carroll (1976) performed a "Gedanken" experiment, somewhat similar to the analysis of the Raven Matrices, in which he analyzed the information processing requirements of various test items in the Educational Testing Service's reference battery Harman, Ekstrom, & French, 1976. The more complex subtests appeared to Carroll to require more different information processing steps. Still more direct evi-

dence has been obtained by R. Sternberg's (1977, 1977) careful analysis of the time spent in each information processing step during the solution of individual intelligence test items. Consider, for example, the frequently used "analogy problem" item. An example is

DOG is to CAT as WOLF is to (HYENA, LION, SKUNK, FOX).

Sternberg has shown that the solution of such problems can be broken down into several steps; encoding the information associated with each term, comparing the first two terms (DOG, CAT) to each other, inducing the relationship from this comparison, and applying the relationship to map from the third term (WOLF) into one of the possible response terms (HYENA, LION, SKUNK, FOX). Each of these steps calls upon different mechanistic information processing actions. Each step will introduce its own variance into performance on the problem as a whole. Sternberg has also shown that the separate steps can be combined in different orders, and that the importance of an isolated step to total problem solving performance cannot be evaluated without knowing what the combination rule is. If this is true of individual test items, how can we expect to establish correlations between very specific aspects of information processing and total test performance unless we can identify strategies and the people using them?

Strategies as Mediators of Structure: An Illustration

The observation that strategies must be considered in evaluating individual differences in cognitive performance is hardly original. Newell and Simon, surely the leading proponents of the view that thinking can be modeled by computer simulations, have warned that

"A few, and only a few, gross characteristics of the human information

processing system are invariant over tasks and problem solvers."
                                    Newell and Simon, 1972, p. 788.

This is undoubtedly correct. Summarizing the relationship between cognitive performance on two different tasks by a linear equation may give us a picture of population performance that fails to capture the essence of individual problem solving. But what is the alternative to the correlation coefficient? Presenting simulation programs for each person and each task is clearly an inadequate summarization. Having provided an excellent argument for rejecting correlational studies of thinking, the computer simulation approach as yet has not developed an alternative method of stating results. How are we to summarize if each person is unique?

One approach that we can take is to identify groups of people who use similar strategies, and apply correlational analysis within each group. Problem solving strategies can be grouped into large classes, based upon the problem representation that each strategy uses. Psychologists, computer scientists, and educators have long argued that the way in which a problem solver initially represents the problem is one of, if not the, major determinants of performance (Bloom and Broder, 1950; Polya, 1954, 1957; Simon and Hayes, 1976). We can divide representations themselves into two broad classes; linguistic representations or spatial-imaginal representations. The sorts of skills that a problem solver uses to solve a particular problem will depend very much upon which of these two classes of representations are chosen. Furthermore, the argument does not apply only to the very complex problems studied in mathematics or education, we have found that it applies to ostensibly very simple cognitive tasks. When allowance is made for the type of problem representation chosen, and the concomitant choice of strategy, we find

that some puzzling observations about the relationship between information

processing and psychometric performance become quite regular.

The task that we have chosen to study is the sentence verification

paradigm (Clark and Chase, 1972), a miniature linguistic situation in which

verbal statements must be co-ordinated with non-verbal stimuli. In a sen-

tence verification paradigm the participant first sees a sentence describing

a simple picture, and then sees the picture. The task is to determine whether

or not the sentence accurately describes the picture. Some examples are shown

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Figure 6 about here
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in Figure 6. A logical analysis of each sentence is also shown in the figure.

This demonstrates that the sentences vary in the extent to which they con-

tain embedded propositions. A number of experiments have shown that the time

required to verify a sentence as a description of a picture depends upon the

extent of the propositional embedding. (For a review of this literature,

see Carpenter and Just, 1975). Furthermore, speed of sentence verification

has been shown to correlate moderately well with measures of general verbal

comprehension (Baddeley, 1968; Lansman, 1978). On its face, and from a

theoretical analysis of the task as an exercise in psycholinguistics, the

task appears to be a reliable, rapid way to measure one's competence in

dealing with linguistic materials. This is particularly interesting because

the test itself is virtually knowledge free, while many conventional tests

of language comprehension have been criticized for their dependence upon

specific semantic knowledge.

One of the major strengths of the sentence verification task as a mea-

sure of language performance is its close tie to theories of psycholinguistic

information processing. As noted, a psycholinguistic approach assumes that sentence verification requires the resolution of various embeddings. The basic ideas of the psycholinguistic approach are that

(a) the picture is represented by the simplest possible propositional representation. Thus the picture ($\overset{*}{+}$) would be represented as STAR ABOVE PLUS.

(b) The process of verification involves successive transformations of the sentence representation until it either matches the picture representation or no further transformations are possible. Thus to resolve STAR NOT BELOW PLUS the marked form BELOW must be converted to NOT ABOVE and the negations must be resolved.

All psycholinguistic information processing models assume that each transformation takes time. They differ only in the way they regard the transformations. Clark and Chase (and Trabasso, Rollins, and Shaugnessey, 1972, in a related paper) estimate parameters for resolving marking, negation, and the affirmative-negative decision separately, whereas Carpenter and Just regard each of these as the same process, requiring estimation of a single parameter. Both models can be shown to account for better than 90% of the variance in the times required to verify different types of sentences. In general, negatively worded sentences require more time to verify, sentences with marked forms take longer to verify, and negative decisions are slower than affirmative decisions. There are also interactions between these effects, which are predicted by the psycholinguistic model. By any account, the fit of the data to the models is impressive.

Most studies of sentence verification have used relatively few subjects, and hence have not studied individual differences. In the course of our

explorations of this task as a measure of linguistic competence, however, we

acquired data from some seventy subjects. Averaged over subjects, the data

showed a close fit to the expectations of the psycholinguistic models, as is

shown in Figure 7. John Palmer and Marcy Lansman realized that the individual

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Figure 7 about here
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difference data could be used to discriminate between the two main psycho-

linguistic models. The "one parameter" model requires that there be a very

high correlation between estimates of individual times required to resolve

different types of embedding, since each resolution is assumed to be accom-

plished by the same process. The results are shown in Table 3. The expected

high correlations did not appear, so the single parameter model can clearly

be rejected. But the multiple parameter model is also in trouble. The

reason for this has to do with our estimate of falsification. Two estimates

are possible, one for affirmatively worded and one for negatively worded

sentences. The two estimates of the same parameter are not correlated.

Clearly the models that do so well in handling response times averaged over

individuals are doing very poorly when applied to individual differences data.

Table 3 about here

These paradoxical observations have been resolved by a series of experi-

ments conducted by Colin MacLeod, Nancy Mathews, and myself (MacLeod, Hunt,

and Mathews, 1978; Mathews, Hunt, and MacLeod, Note 2). To foreshadow, we

have shown that the type of information processing underlying sentence verifi-

cation depends upon how the subject approaches the task. Our procedure,

which differs slightly from that used in some other studies, is shown in

Figure 8. The sentence is presented, and left on display until the subject

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Figure 8 about here
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indicates that it has been comprehended. The time required for this will

be called comprehension time. The picture is then presented, and the sub-

ject decides whether or not the picture was correctly described by the sen-

tence. The time required for this decision will be called underline(verification

time). It is important to remember that verification time is the dependent

variable that has been used in other sentence verification tasks.

In our first experiment (MacLeod et al., 1978), we applied Carpenter

and Just's one parameter model to both group and individual data. Averaged

over subjects, the differences in verification times for the various sen-

tence-picture combinations agreed well with the predictions of the one-param-

eter model. On an individual basis, however, the fit ranged from very good

to very poor. (The same thing was true for Palmer and Lansman's data.) We

identified three groups of subjects, subjects whose data conformed closely

to the model, subjects whose data appeared to bear no resemblance whatso-

ever to any data predicted by a psycholinguistic model, and a group of "in

between" persons. The first two groups will be referred to as the "well

fit" and "poorly fit" groups. As is the historic fate of compromisers, the

third group will not be further discussed.

Figure 9 shows the relationship between the predictions of Carpenter

and Just's model and the data from the well-fit and poorly-fit groups. The

discrepancy is striking. But why? We hypothesized that the two groups were

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Figure 9 about here

Figure 10 about here
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using qualitatively different strategies. The strategies we believed to

be involved are depicted in Figure 10. In the linguistic strategy the

subject reads the sentence, remembers it in some form tied to the proposi-

tional structure of the sentence, then observes the picture, derives a

sentence (or propositional structure) from this observation, and compares

the two representations. In the spatial-imaginal strategy the subject reads

the sentence, forms a mental image of the picture that is expected, then

observes the picture and compares the internal visual representations of

the observed and expected display.

Two independent analyses were conducted to test this hypothesis. The

linguistic strategy places the burden of translation from one representation

to another on the verification stage, while the spatial-imaginal strategy

places the burden on the comprehension stage. Accordingly, users of the

linguistic strategy should spend more time in verification and less in com-

prehension, while the reverse should be true of the users of the spatial-

imaginal strategy. Table 4 shows the relevant data. This prediction was

confirmed. The second analysis, which was especially relevant to individual

differences, examined the relationship between verification time and psycho-

metric scores of verbal and spatial aptitude within groups of strategy users.

There should be an interaction between predictability and strategy use.

Verbal comprehension scores should be closely related to verification for

linguistic strategy users, while spatial aptitude scores should be closely

related to verification for spatial-imaginal strategy users. The appropriate

correlations are shown in Table 5, and are as predicted.

Table 4 about here

Table 5 about here

While the MacLeod et al. study produced a consistent pattern of results,

a <u>post</u> <u>hoc</u> analysis of data is always suspect. The Mathews et al. study

extended our reasoning by reproducing the data for the two strategies ex-

perimentally. The experiment consisted of three sessions, on successive

days. On the first day the MacLeod et al. sentence verification procedure

was replicated. This will be called the "free" condition. The criteria

developed from the MacLeod et al. experiment were used to divide the new

sample of subjects into groups, and the anlaysis from the first study was

repeated. The same phenomena were observed, as is shown in Figure 11. The

second and third days were replications except that the subjects were instructed
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Figure 11 about here
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to use one strategy or the other. (As there was no evidence of an effect of

order of instructions, this variable will be disregarded.) Figure 12 shows

the results. It is clear that our university student subjects were able to

perform either in accord with the spatial or linguistic strategies. Thus

the MacLeod et al. results should not be interpreted as establishing a type

of reasoning, in the sense that such typologies as introvert-extrovert or field

dependent-field independent have been proposed. Rather, our results show

that above average young adults can shift from one strategy to another

relatively easily, and that the underlying abilities that they use to solve

an ostensibly linguistic task depend upon strategy choice.

Figure 12 about here

Whether or not less talented subjects could display the same flexibility

in strategy choice is an open question. We need further studies to determine the conditions under which particular types of individuals will use particular strategies. The general point remains valid. The relationship between task performance and information processing capabilities depends upon the individual's choice of how the task is to be done. Most complex problems, including those problems that are typical of general intelligence test items permit considerable flexibility in making this choice.

The Problem of General Intelligence

By stressing the importance of strategy choice in intellectual performance, we implicitly develop an argument for a view of intelligence as a combination of special abilities; i.e. the "ability" to make good strategy choices. The extreme statement of this view is that there is no such thing as general intellectual capacity. Cognitive behavior is instead seen as a compendium of structural capacities and strategies to hold them together. This viewpoint is consistent with much of the thinking in both experimental and psychometric psychology. The quotation from Newell and Simon (see above) is a good summary of its logic. Psychometricians will recognize the specialized viewpoint as being a restatement of Guilford's (1967) view that there are a variety of highly specialized abilities, each defined by stating the type of stimulus material being processes, the type of operation required on it, and the type of answer required. Indeed, Guilford has used this cross-classification scheme to generate a table of over 100 hypothetical abilities!

An opposing view, which dates back to Spearman (1927), and is represented today by Horn (1979) and Jensen (1979) is that there are one or two broadly relevant "general intelligence" capabilities, which permeate virtually all intellectual endeavors. The principal evidence for the general intelligence

viewpoint is the observation that superficially disparate intellectual tasks
are almost always positively correlated.

The argument between the generalist and the specialist view does, at
times, take some of the aspects of an argument over whether a glass is half
full or half empty. The generalist points to the undeniable fact that many
cognitive tasks are positively correlated, with r's in the .3 to .4 range.
The specialist observes that the r^2 values are only .1 to .2! Granted that
this is true, the phenomena of widespread positive correlations between
different tests (technically, the phenomenon of positive manifold) is too
robust a fact to be ignored. Explaining it within an information processing
concept requires that we locate some information processing concept that
applies to an equally wide range of behaviors and show that this concept
is related to test performance.

There is such a concept, but it does not fit easily into the computer
analogy. This is the concept of attentional resources. Probably the most
comprehensive recent statement of this concept has been given by Kahneman
(1973), although a number of other names are also associated with the idea.
(Posner (1978) has cited references to the concept in the late 19th Century
and, interestingly, Spearman (1927) made it a prominent part of his theory
of general intelligence.)

The basic assumption of "attention theory", for want of a better name,
is that every human information processing task requires the allocation of
some (rather poorly defined) "attentional resources" for its execution. If
less than enough resources have been supplied to a particular mechanistic
process, then that process may be able to function but it will do so at a

reduced level of efficiency. Whether or not this will have a catastrophic effect upon thinking depends upon the extent to which the affected process is central in the problem solving strategy being executed. The attentional resource concept is even broader than the concept of general intelligence, for attentional resource demands are assumed to be made by non-intellectual information processing tasks, such as signal detection, as well as by such things as paragraph comprehension and arithmetic problem solving.

Marcy Lansman and I have been exploring the possibility that differential demands for attentional resources can be used to explain individual differences in a wide range of tasks, all of which involve information processing, but not all of which would conventionally be called "thinking". In order to study attention resource demands we have used the "dual task" methodology, in which a person is asked to do two information processing tasks at once. We examine inter-task interference as an indication that the two tasks draw on a common mental resource. Such paradigms have been subjected to extensive theoretical analysis (Posner, 1978; Kerr, 1973; Norman and Bobrow, 1975). Customarily one of the tasks is designated to be the primary task, and the other the secondary task. (For brevity, we shall refer to tasks A and B.) An assumption of the strict secondary task interpretation is that task B is done with whatever spare capacity remains after task A has been executed. This implies that task B should not interfere with task A. We, and others, have found that this assumption can seldom be justified, so we offer a slightly different analysis of the dual task paradigm that does not depend on the primary task-secondary task distinction.

Tasks A and B must be chosen so that it is not reasonable to expect them

compete for the same information processing structures ("structural

interference").   For instance, one would certainly not use tasks that

required incompatible responses, such as moving a lever in task A and

and pressing a button with the same hand in task B. Such gross examples

are easy to deal with. In practice,though, the situation may be much more

subtle, and whether or not structural interference has been avoided is often

a matter of judgement. When it can be, we are justified in saying that any

interference between the two tasks must be due to competition for attentional

resources. The resource competition itself can be illustrated by an unusually

simple "electrical", rather than electronic, analogy. Figure 13 shows a

schematic of two machines, one for task A and one for task B, that are

attached to the same power source. They compete for resources in the same

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Figure 13 about here
----

sense that an electric light and an electric washing machine compete for

resources in residential electric systems.

In fact, the washing machine analogy can be used to show how

the dual task technique can be applied to the study of individual differences.

Suppose that Figure 13 was a diagram of a washing machine - light circuit,

and that the washing machine was inefficient, and thus exerted a heavy load

on the system just before it broke down. In a very simple circuit (i.e.

one without safety fuses) the first indication that you would have of a mal-

function of the washing machine would be a dimming of the lights, as the

appliance began to make excessive demands on the circuit. Lansman and I have

used a similar logic in our studies. We have sought tasks A and B that have

the following characteristics:

(a) The tasks are sufficiently different so that structural inter-
ference is unlikely.

(b) The difficulty, and, in theory, the demand for attentional resources,
of task A can be varied in a continuous manner.

(c) The level of performance of task B varies in response to the attentional
resources supplied to it.

One series of experiments (Lansman, 1978; Hunt, Lansman, and Wright, Note 4)
applied the paradigm to study attentional demands in easy and hard memory
tasks. Task A was the continuous paired-associates task developed by
Atkinson and Shiffrin (1968). In this task the subject must keep track of
the continuously changing state of several variables. This is done by pair-
ing numbers with letters, aperiodically requiring the subject to report the
number currently paired with a letter, and then changing the letter-number
pairing. The exact procedure is shown in Figure 14. The task can be made
arbitrarily difficult by varying the number of letter-number pairs that
must be kept in mind. Task B was a simple probe reaction task that was inserted
during the memory task. Figure 14 shows the procedure for a visual probe;
auditory probes were also used.

Figure 14   about here

Our interest centers on probe performance under memory load conditions
(keeping track of two variables) as a predictor of individual performance under
hard memory load (seven variables). Recalling the washing machine analogy,
probe reaction time under the easy memory condition is analogous to the light's
intensity when the washing machine has a small load, and should thus predict,
across individuals, those persons who would have the most difficulty in the

memory load were to be increased. The relevant correlations are shown
in Table 6. There was a reliable, moderately high correlation between
probe reaction time in the easy memory condition and memory performance in

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Table 6 about here
----

the hard memory condition.

One can object that while this does show that probe reaction and memory
do draw upon a common attentional resource, after all, short term memory is
not the same as thinking. We have applied the same design to an analysis
of two tasks that differed even more radically in their surface characteristics
(Hunt et al, Note 4). In this experiment task A was a subset of 18 of the
36 Raven Progressive Matrix problems (Raven, 1965). Raven problems require
that the subject detect a relationship between the elements of complex visual
pattern, and then apply that relationship to complete a missing part of the
pattern. Two samples are shown in Figure 15. As can be seen, the problems
vary widely in difficulty. The Raven Matrix problems are particularly

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Figure 15 about here
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interesting as a sample Task A because this test is frequently cited as one
of the best measures of the general intelligence factor (Jensen, 1979).[4]

Task B was a psychomotor task designed so that it would not normally
be considered a test of intelligence. The task, which we call a "Gizmo",
requires that the subject hold a lever between two posts, using the thumb
and index finger of the left hand. By itself, this is quite easy to do. The
task becomes difficult when the subject is distracted, in this case by
attempting to solve Raven Matrix problems that were projected onto a screen
immediately in front of the subject. Procedurally, the subject first

practiced with the Gizmo alone, then solved 18 Raven problems alone, and then solved 18 Raven problems while trying to hold the Gizmo in place. The Raven problems were presented in ascending order of difficulty, as defined by the extensive norms available for the test (Forbes, 1964.)

If both the Raven Matrices and the Gizmo are drawing on the same attentional resources, then performance on the Gizmo task should deteriorate as Raven problems become harder, as, indeed, it does. It is difficult to interpret this, however, as we do not have a clear model for attention allocations as the subject begins to "break down", by making errors on more difficult problems. A more sensitive test is to observe Gizmo performance before the subject makes an error on the Raven items. As a person approaches the first Raven problem that represents, for that individual, a non-trivial problem, the person's Gizmo performance should deteriorate. Just where this happens in the sequence of Raven items, however, will vary from individual to individual.

There are two ways that this prediction can be tested. By the same logic that applied in the memory experiment, there should be a correlation between individual psychomotor performance on the first five problems (on which virtually no errors are made) and the point at which a person makes his or her first error. The correlation was -.30, which was statistically significant at the .02 level. Note that this cannot be explained by assuming differential concentration on one task or the other, because people who are doing well on the psychomotor task also do well on the Raven problems. Also, the correlation was calculated after partialling performance on the psychomotor task alone,

and hence cannot be explained by assuming that people who do well on the psychomotor task also *do well on the intelligence test.*

The effect can be shown somewhat more graphically by plotting psycho-motor performance on the three problems just prior to problem N, as a function of N. Figure 16 shows this for two groups of subjects; those who make their first error on problem N and those who make their first error on some problem

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Figure 16 about here
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beyond problem N. Clearly the subjects who are about to make an error show worse performance on the psychomotor task while solving problems just prior to their first error.

The data from both the memory and the Raven tasks are clearly compatible with the assumption that intellectual and psychomotor information processing tasks draw on a common source of attentional resources. This, of course, does not mean that there is a single pool of such resources. There may very well be several, and "intellectual" tasks may draw on only some of them. Further, the very simple model in which the tasks compete equally for resources is un-likely to be correct. We need to investigate more closely different models for allocation of resources during reasoning. In spite of these reservations, Spearman's notion of "mental energy" seems to be a surprisingly good first approximation for explaining the general intelligence phenomenon.

Concluding Comments

People differ widely in how, and how well, they think. One of the biggest sources of individual variance in thought is simply knowledge, different people *know different things. Psychological research on intelligence has tended to*
disregard this, regarding it more properly as part of the realm of education or

sociology. The role of knowledge must be included in any comprehensive account of individual cognition. On the other hand, there are situations in which wide ranges of cognitive ability are displayed when it seems unlikely that knowledge is a determinant of differential performance. The experiments reported here are examples.

Three sources of individual differences in information processing have been proposed; structure, process, and attentional resource allocation. These factors should affect cognitive competence in different ways. Structural resources set limits on the effectiveness of specific information processing steps. Such processes appear to be important when we contrast the cognitive capacities of quite different individuals, such as the contrast between normally and mentally retarded persons. As we learn more about subpopulations within such extreme groups we may very well find that there are specific structural changes that apply to each normal-"unusual group" contrast. For example, there is already evidence that specific types of mental retardation will lead to specific information processing deficits (Money, 1964; Warren, 1978).

Attentional and process differences exert powerful but more transient effects on cognition. Not only do we think differently between ourselves, each of us varies in our own thought processes from time to time. Structural influences on thought will be mediated by strategy choice, so which of our basic capacities influences our thinking may often depend on how we are thinking at the time. While there is undoubtedly some truth in the notion of general cognitive styles, it would be a mistake to think that a given individual has a fixed style of thought. More studies are needed of the interaction between personal and situational characteristics and an individual's choice of

problem representation and problem solving strategy. Our results indicate that these variables can operate in what would appear to be, superficially, very simple problem solving situations. More complex situations than sentence verification undoubtedly offer an opportunity for a much greater choice of strategy!

It has been argued that the phenomenon of positive manifold, the tendency for intellectual tasks to be positively correlated (in spite of the effect of strategy choice just described), can be derived from the concept of attentional resources, applied to complex problem solving situations. For the same reason, we expect correlations between intellectual performance and perceptual-psychomotor performance under stressful conditions. We also expect to find mutual interference between/tasks and demanding psychomotor activity.
intellectual
(Indeed, such interference was found in the dual task studies described above.) Airplane pilots should not compose poetry during landings.

Psychologists and sociologists have frequently discussed the causal correlates of cognition. Studies have been performed relating cognitive performance to variables such as education, nutrition, socioeconomic status, genetic constitution, and nutrition. The information processing view of cognition suggests that some thought be given to how these variables are supposed to mediate our ability to think. Variables that represent relatively permanent characteristics of an individual, such as sex, genetics structure, and chronic injury, can presumably affect structure. Attentional resource changes may also be subject to such influences, but they will also reflect transient changes in an individual's physical state, responding to such things as the acute effects of drugs or illness, fatigue, and diurnal variation. Process differences are subject to a still wider range of influences. The problem solving strategies a person

could use will be determined by attentional and structural resources. The strategies that he or she actually will use will, within limits, be determined by education in its broadest sense. How has the person learned to solve problems? Who can learn to apply what strategies? It is my belief that more will be learned about the nature of cognition and its antecedents if we study the role of such causal agents directly upon measures of information processing structure, attention, and strategy choice than will be learned from studies in which the dependent variables are extremely complex "intelligence tests".

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Footnotes

[1] It is important that some method of controlling for motor reaction time be introduced into experiments of this sort. Most of the variance in reaction times in stimulus identification studies is, in fact, associated with simple choice reaction times, including the time required to move the fingers. Negative results are quite likely in studies that fail to control for this effect (e.g. Hogaboam and Pellegrino, 1978).

[2] In general, correlations between reaction time studies and test scores should be negative, as long RTs reflect poor performance.

[3] This raises the interesting question "What is clinically significant?" Language is a product of the interaction between social and biological evolution, and may very well have developed in such a way that "proper speaking" means that the speaker produces language in such a way as not to overtax the information processing capacities of all but a very few members of the population. Put another way, human language must adjust to the lowest information processing capacity that would be considered "normal", not to the average. If Mnemonists constituted 95 per cent of the population we might have developed

a very different communication system.

[4]Referring back to Figure 5, we see that the Raven test is located near tests that Horn and Cattell categorize as fluid intelligence (Gf) tests. Hunt (1976) has shown that the test can be attacked using a number of different strategies. Interestingly, Spearman (1927) agreed with the conclusion that the test measures g.

GROUP	TEST	r
Warren- Grade School Children	WISC	-.34
Lansman- College Students	WPCT-V	-.29

Table 1. Correlations of stimulus identification (NI-PI)
performance with verbal intelligence

FACTOR	1	2	3	4	5	6
	PAIRED ASSOC.	SIMULT. LEARN.	SERIAL LIST	VERBAL DISCRIM.	FREE RECALL	SAT
SAT-V LOADING	.23	.15	-.28	.02	.20	.51

Communality of SAT-V = .46

Table 2: Loading of verbal comprehension test on various memory factors

	Fals.I	Fals.II	Below Time rel.=.52
NEGATION TIME (TN+FN)-(TA+FA) rel. = .91	.28**	.32**	.22*
FALSIFICATION I (FA-TA) rel.=.74		.10	.44**
FALSIFICATION II (TN-FN) rel.=.77			.17

Table 3: Correlations between parameters, all subjects.

Group	Comprehension	Verification
WELL FIT	1652	1210
($\underline{n}$ = 43)		
POORLY FIT	2579	651
($\underline{n}$ = 16)		

Table 4: Mean overall Comprehension RT and Verification RT
for Well Fit and Poorly Fit Groups.

Group	Nelson-Denny Comprehension	WPC Verbal	WPC Spatial
WELL FIT	-.47*	-.52*	-.32
POORLY FIT	-.03	-.33	-.68*

Note: Those correlations marked with an asterisk are significant

beyond p < .01.

Table 5. Correlations of Psychometric scores with Mean
Verification RT.

PROPORTION CORRECT

		Easy Recall	Hard Recall
	Control Condition	-.09	-.05
PROBE RT	Easy Recall Condition	-.27*	-.40**
	Hard Recall Condition	.01	.07

Table 6: Correlations between Probe RT and Recall Scores

Figure Captions

Figure 1. The stimulus identification paradigm. The first pair exemplifies the physical identity condition (PI), the second pair the name identity (NI) condition, and the third pair the different condition.

Figure 2. Mean difference between name identity and physical identity RTs for groups varying in intellectual ability.

Figure 3. The memory scanning paradigm. In the example at the top of the figure, the subject is first presented with the memory set "1, 3, 5, 7." The probe item "6" is then presented and the subject is to respond as to whether "6" was a member of the memory set. The graph below illustrates the typical finding that RT is a linear function of the size of the memory set.

Figure 4. Functions relating RT to memory set size in the memory scanning paradigm for groups varying in intellectual ability.

Figure 5. Multidimensional scaling of between-test correlations in a battery administered to high school students (N = 241). W identifies subjects of the Wechsler Adult Intelligence Scale. (Taken from Snow, in press.)

Figure 6. Sample sentence verification items.

Figure 7. Comparison of observed group means and values predicted from the Clark and Chase model of the sentence verification task.

Figure 8. The sentence verification paradigm with sequential presentation of sentence and picture.

Figure 9. Mean verification RTs of the well fit and poorly fit groups as a function of the number of constituent comparisons hypothesized by Carpenter and Just's model. Also included are the 95% confidence intervals, and the best fitting straight line for the well fit group only.

Figure 10. Flow chart representations of the strategies believed to be used by the well fit and poorly fit groups.

Figure 11. Mean verification RTs of the well fit and poorly fit groups as a function of the number of constituent comparisons hypothesized by Carpenter and Just's model. Results are for the first day of the study, during which subjects received no instructions concerning strategy.

Figure 12. Mean RTs for all subjects in the three instructional conditions.

Figure 13. The battery model of attentional resources.

Figure 14. The dual task paradigm used by Lansman (1978), which involved recalling a series of letter-digit pairs and responding to a simple visual stimulus.

Figure 15. An easy and hard item from the Raven Matrices Test (1965).

Figure 16. Deviation rate on the Gizmo during the three Raven problems preceding the problem plotted on the abcissa. The dotted line represents the performance of those subjects who made their first error on that problem, and the solid line represents the performance of those subjects who made their first error on a later problem in the sequence.
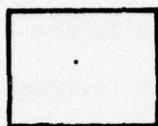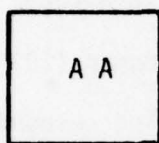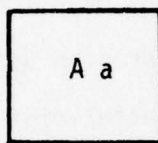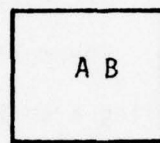
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                    ┌─────────┐
                    │    .    │  Fixation Point
                    └─────────┘
                         │
                         ▼

   ┌─────────┐       ┌─────────┐       ┌─────────┐
   │  A A    │  or   │  A a    │  or   │  A B    │
   └─────────┘       └─────────┘       └─────────┘
                         │
                         ▼

                  Subject Responds
                 "Same" if letters have
                    the same name
                         or
               "Different" if letters have
                   different names
```

y-axis label: NI - minus - PI Measures in milliseconds

400 — Mild Mental Retardates

300 —

200 — Fifth-grade Children
Elderly Adults
← Poorer Adult Readers

Young Adults
100 — ← Better Adult Readers
Univ. Students, Low
Verbal Aptitude
Univ. Students, High
Verbal Aptitude
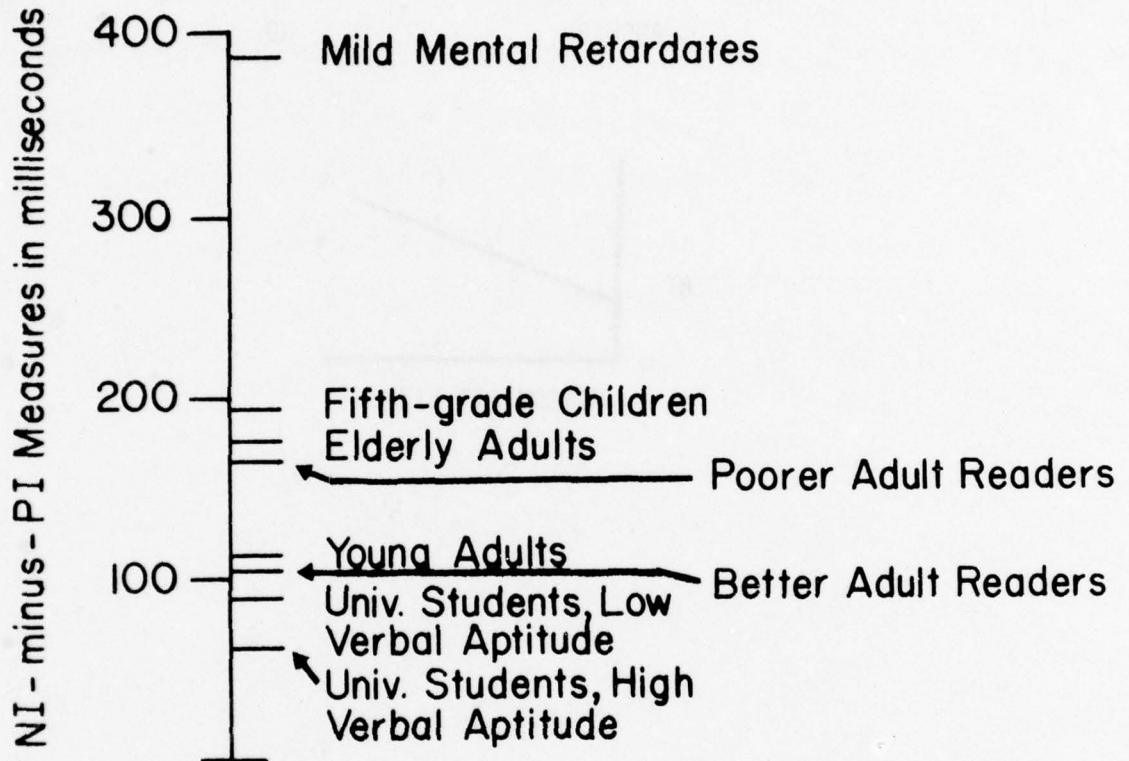
MEMORY SET   1,3,5,7

PROBE   ?6?

ANSWER   NO
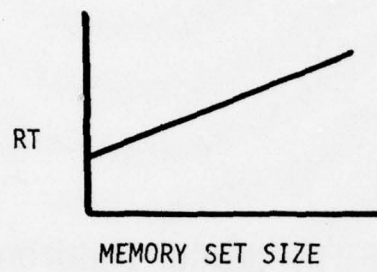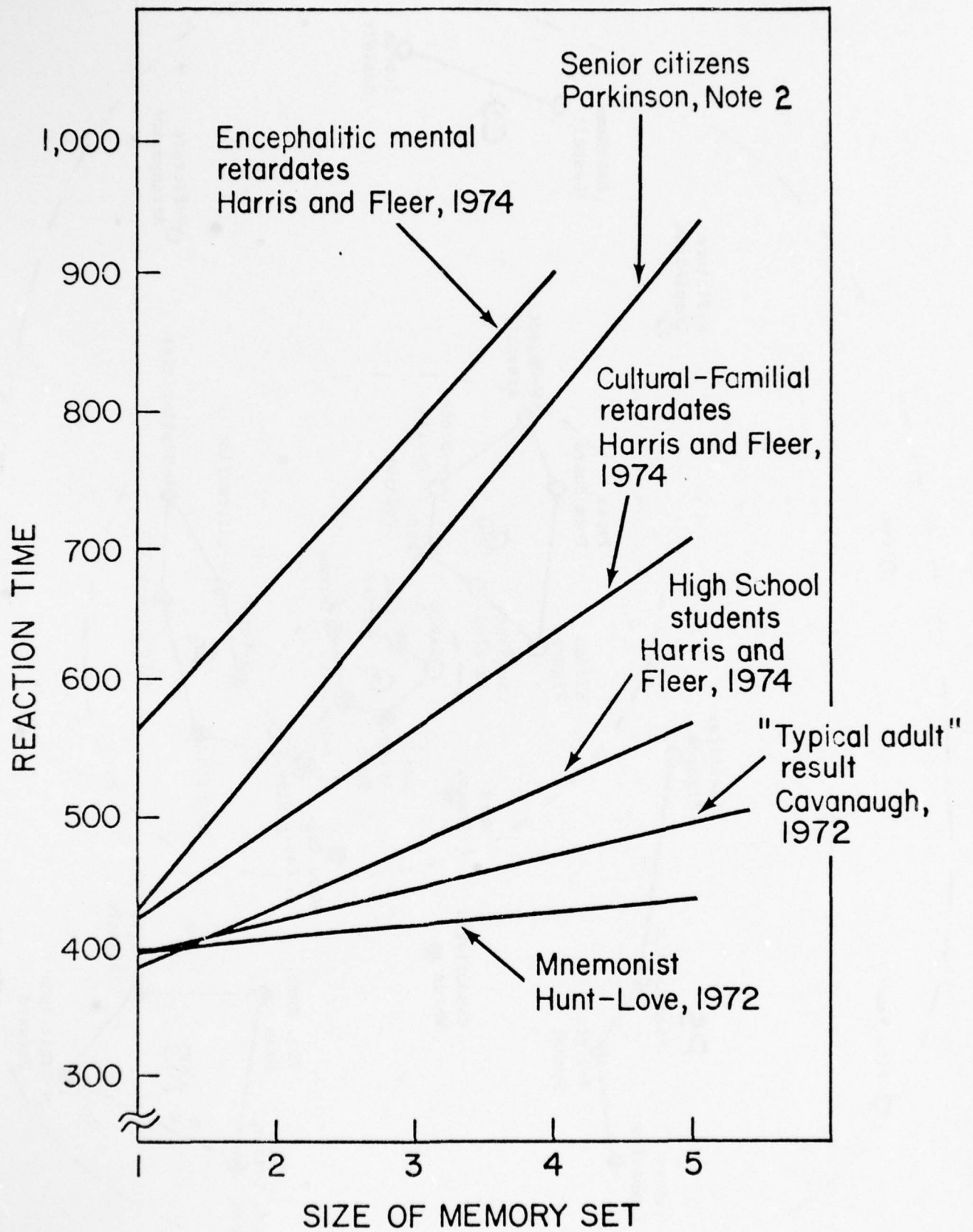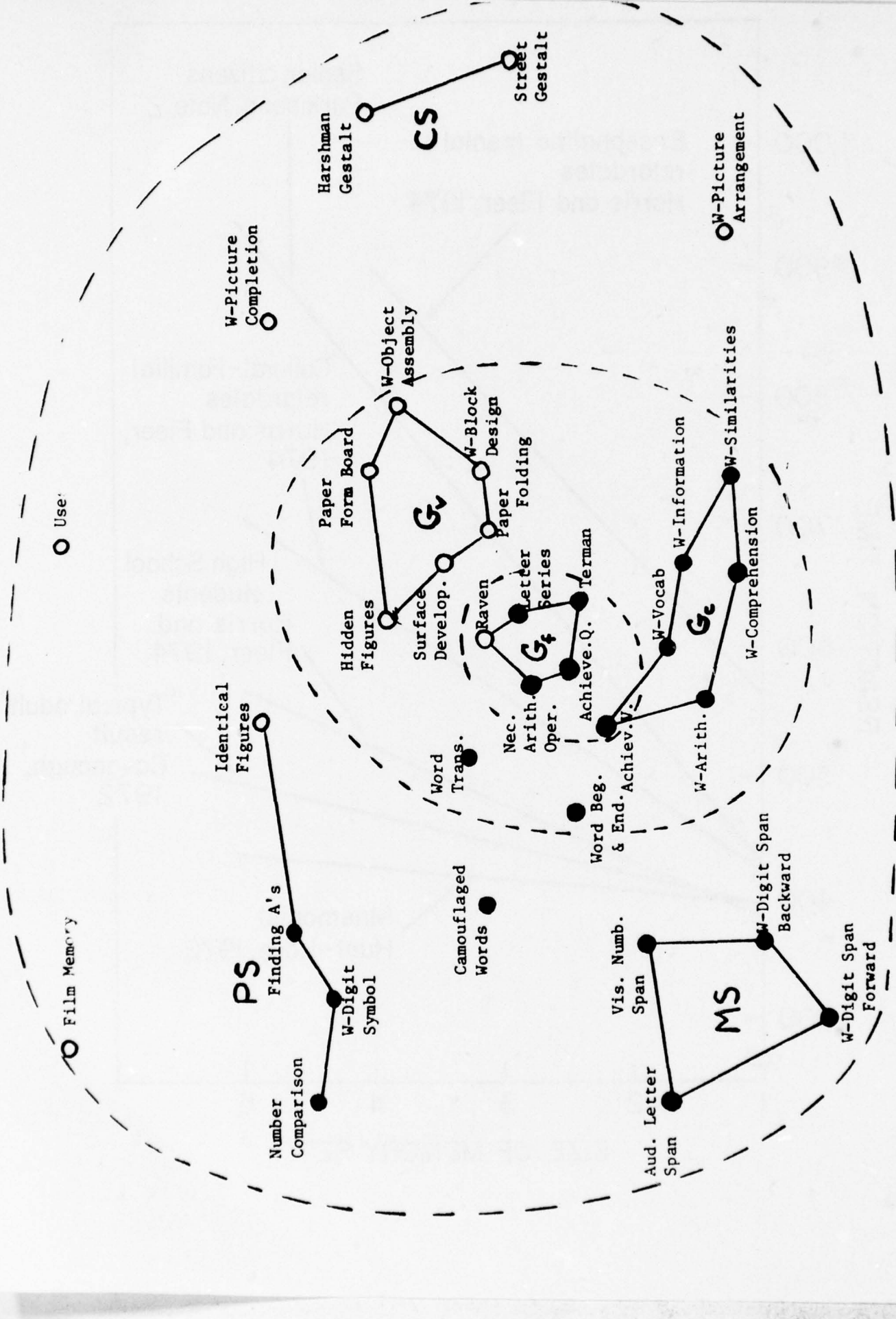
RT

MEMORY SET SIZE

TRIAL TYPE	SENTENCE	PICTURE	SENTENCE REPRESENTATION	PICTURE REPRESENTATION
True Affirmative (TA)	STAR IS ABOVE PLUS PLUS IS BELOW STAR	* +	$[AFF,(STAR,TOP)]$	(STAR, TOP)
False Affirmative (FA)	PLUS IS ABOVE STAR STAR IS BELOW PLUS	* +	$[AFF,(PLUS,TOP)]$	(STAR, TOP)
True Negative (TN)	PLUS IS NOT ABOVE STAR STAR IS NOT BELOW PLUS	* +	$\{NEG,[AFF,(PLUS,TOP)]\}$	(STAR, TOP)
False Negative (FN)	STAR IS NOT ABOVE PLUS PLUS IS NOT BELOW STAR	* +	$\{NEG,[AFF,(STAR,TOP)]\}$	(STAR, TOP)
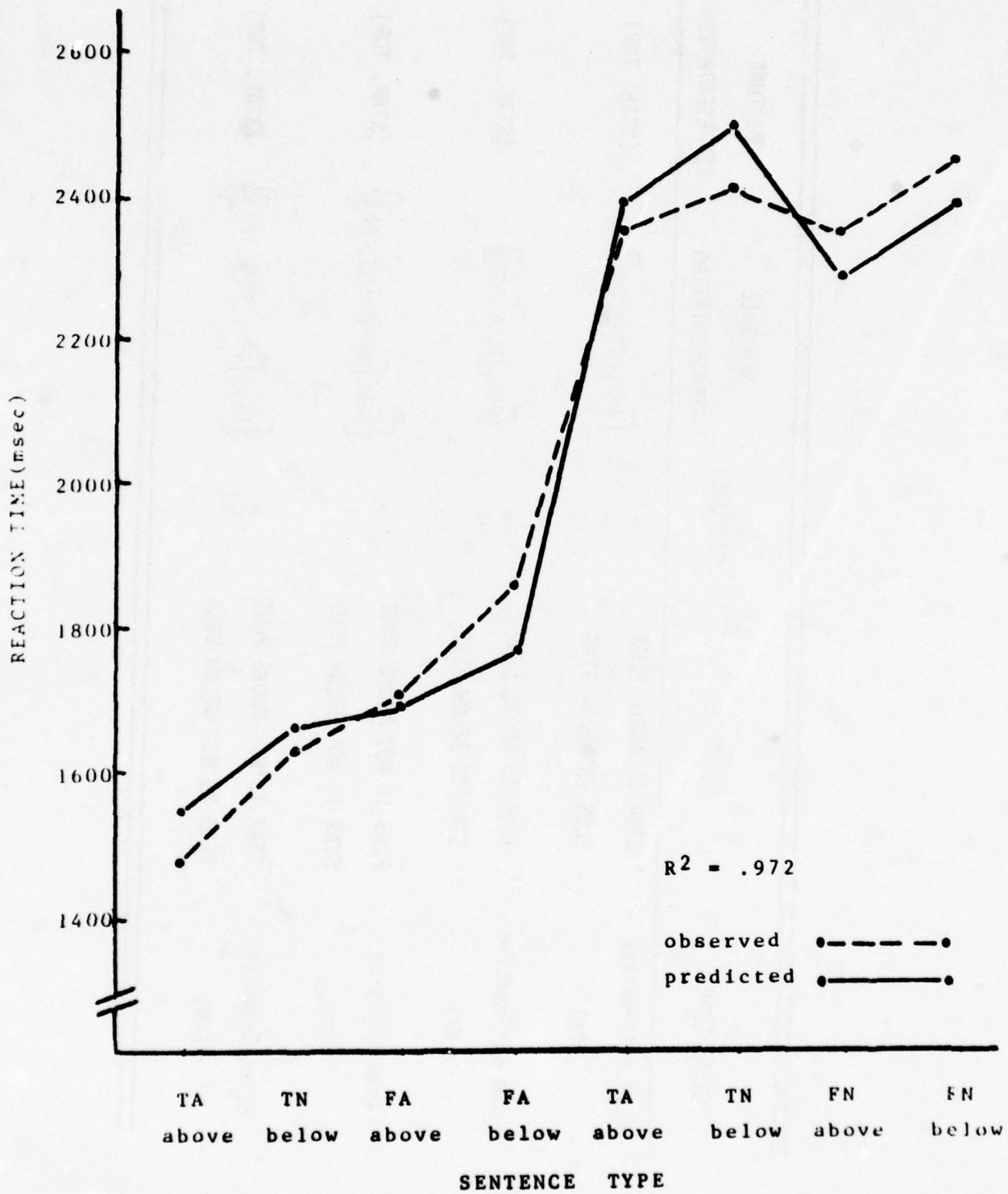
```
┌─────────────────────────┐
│                         │
│   PLUS IS ABOVE STAR    │
│                         │
└─────────────────────────┘
             │
             ▼

OBSERVER PRESSES A
KEY WHEN READY FOR
PICTURE.

             │
             ▼
┌─────────────────────────┐
│                         │
│           +             │
│           *             │
│                         │
└─────────────────────────┘
             │
             ▼

      OBSERVER PRESSES
   "TRUE" OR "FALSE" KEY.
```

MEAN VERIFICATION RT (msec)

WELL FIT

POORLY FIT

K
(TA)

K+1
(FA)

K+4
(FN)

K+5
(TN)

HYPOTHESIZED NUMBER OF
CONSTITUENT COMPARISONS
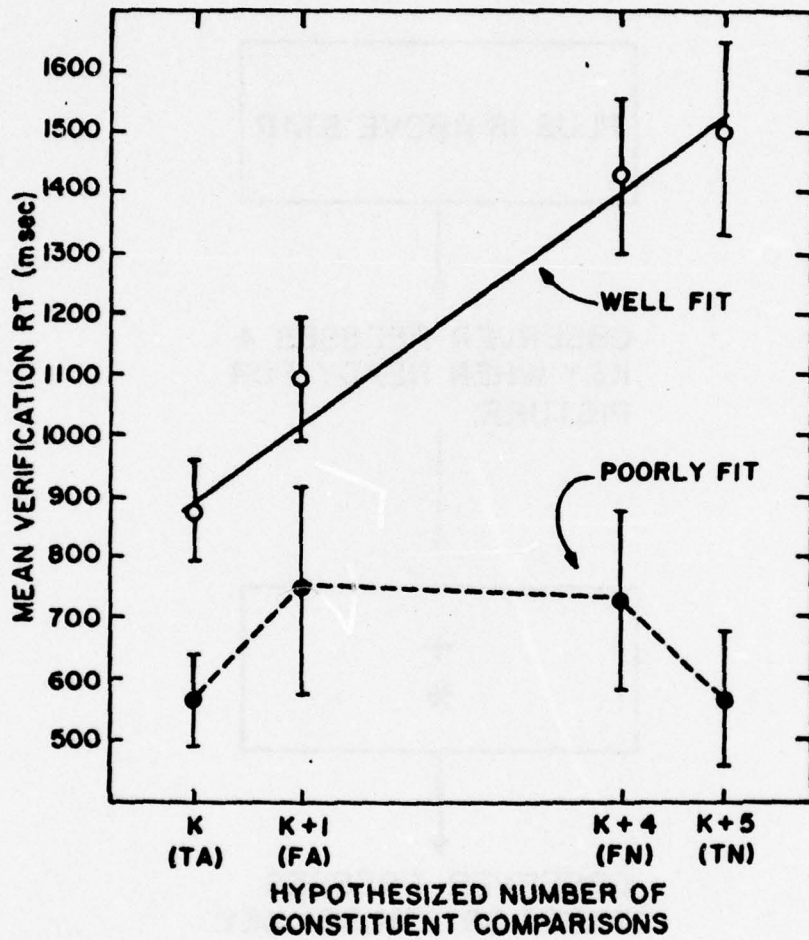
LINGUISTIC MODEL
(WELL FIT GROUP)
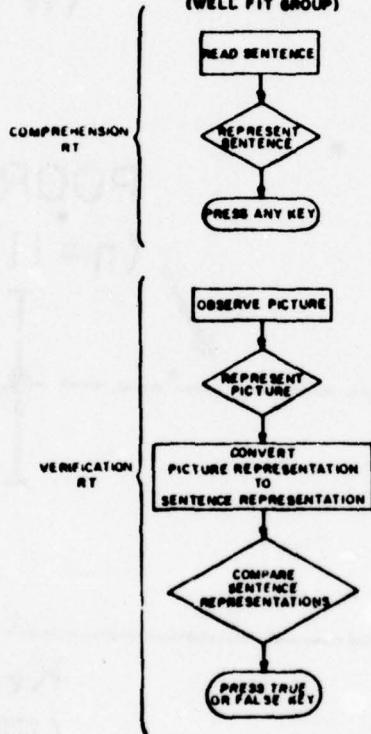
PICTORIAL MODEL
(POORLY FIT GROUP)

COMPREHENSION RT

READ SENTENCE

REPRESENT SENTENCE

PRESS ANY KEY

OBSERVE PICTURE

VERIFICATION RT

REPRESENT PICTURE

CONVERT PICTURE REPRESENTATION TO SENTENCE REPRESENTATION

COMPARE SENTENCE REPRESENTATIONS

PRESS TRUE OR FALSE KEY

READ SENTENCE

REPRESENT SENTENCE

CONVERT SENTENCE REPRESENTATION TO PICTURE REPRESENTATION

PRESS ANY KEY

COMPREHENSION RT

OBSERVE PICTURE

REPRESENT PICTURE

VERIFICATION RT

COMPARE PICTURE REPRESENTATIONS

PRESS TRUE OR FALSE KEY

MEAN VERIFICATION RT (msec)

1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400

LINGUISTIC

FREE

SPATIAL

TA
(k)

FA
(k+1)

FN
(k+4)

TN
(k+5)

HYPOTHESIZED NUMBER OF CONSTITUENT COMPARISONS

A SHOCKINGLY SIMPLE MODEL OF THINKING

Event	Display	Duration
Sequential presentation of	A = 7	3 sec
initial pairs.	B = 3	3 sec
Query. The correct answer is 3.	B = ?	Subject-paced
Letter just queried is paired with a new number.	B = 4	3 sec
(Visual probe: On 3/4 of the trials in the probe condition, asterisks appear 500, 1000, or 1500 msec after the presentation of the new pair. The subject presses any key as quickly as possible.	(****) B = 4	(If subject fails to respond to probe within 1.5 sec, the probe disappears.)
Query. The correct answer is 7.	A = ?	Subject-paced
Letter just queried is paired with a new number.	A = 5	3 sec

A   B   C   D

A   B   C   D
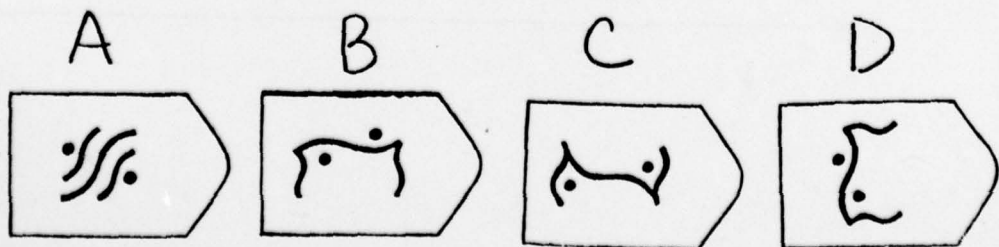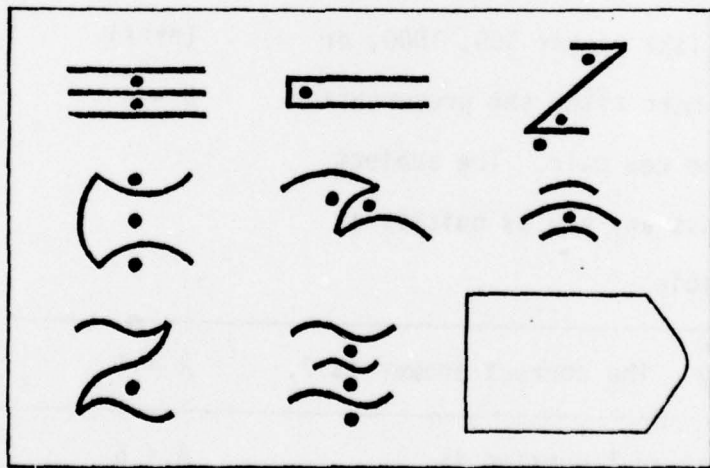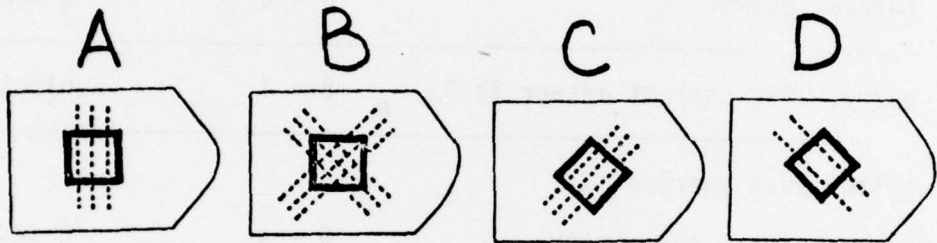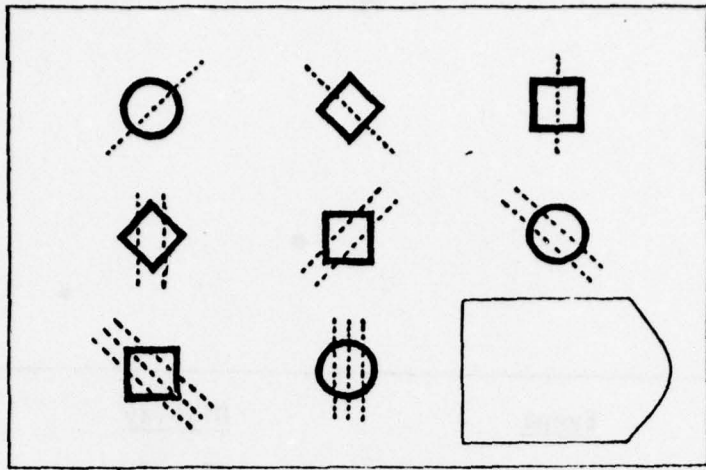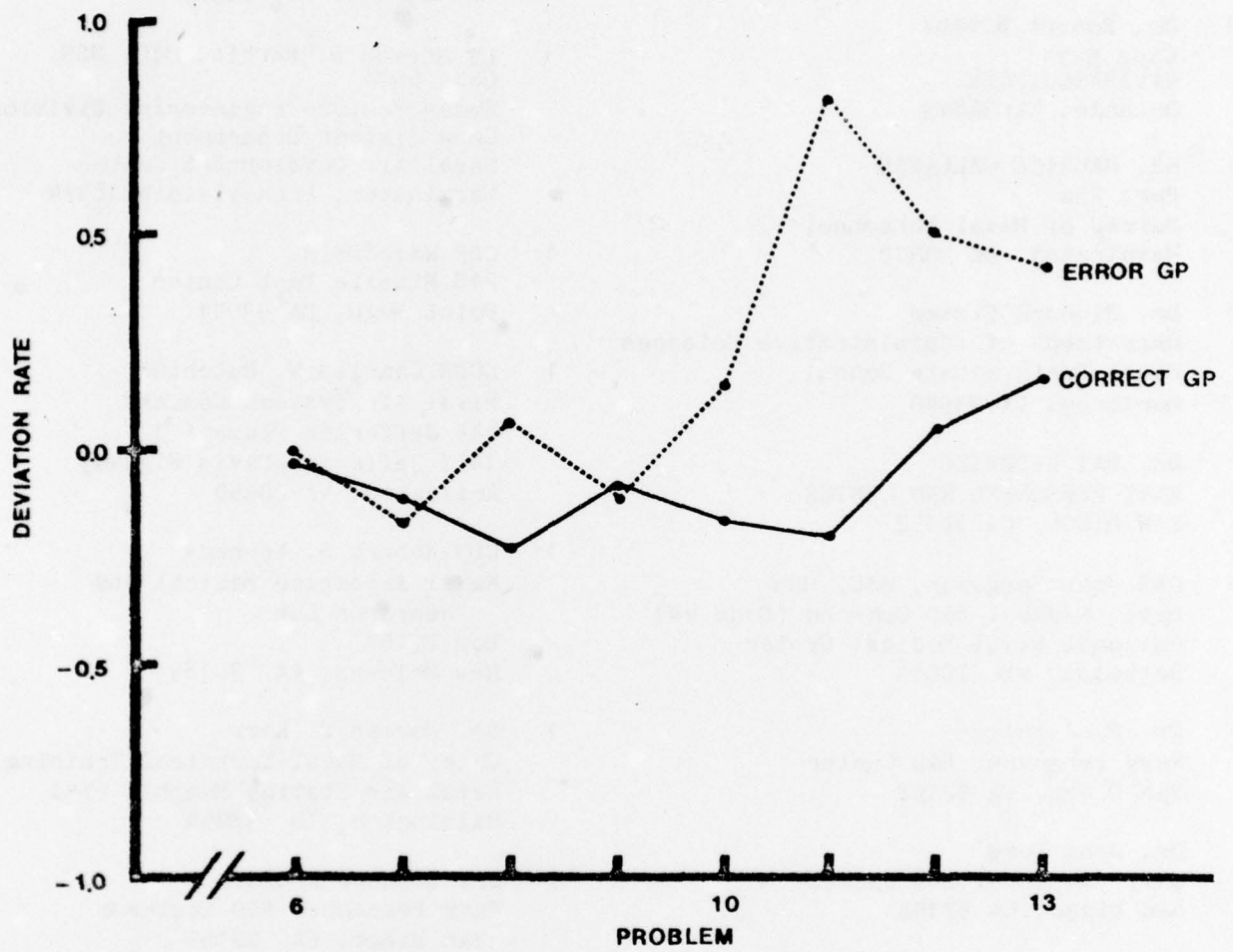
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