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THE FUNCTION OF IMAGERY AS A MEDIATOR IN RELATIONAL LEARNING

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THE FUNCTION OF IMAGERY
AS A MEDIATOR IN RELATIONAL LEARNING

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAI'I IN PARTIAL FULFILLMENT
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May 1983

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ABSTRACT

Two general hypotheses were tested in a transposition experiment. One hypothesis was that individuals differ in the structure of their internal representations of stimulus information. The differences in internal representational structure were thought to have a function in determining whether or not a relationship among the stimuli would be the outcome of learning. The other hypothesis was that relational information would be stored in memory in an imagery format.

On each of twenty-five or more trials, subjects were presented with three squares differing in size by a constant ratio. They were consistently reinforced for choosing the medium sized one. On the test trials following training, the stimulus configuration was shifted toward the larger end of the size dimension. Continuing to select the medium sized square indicated that the relationship had been learned. Three variables were manipulated in the experiment. The salience of the relational information was manipulated by exposing subjects to one or two sets of stimuli in training. Only relational responses were reinforced in the two problem condition; but, relational and absolute responses were reinforced simultaneously in the one problem condition. The other two variables were the size ratio of the squares and whether or not squares were displayed or named on the test trials. Names had been learned for each square prior to the experiment. A battery of tests that measured verbal and imagery processes was administered.

Half of the subjects consistently selected the medium sized square. Choice reaction times were faster to stimuli with large size ratios than to stimuli with small size ratios when squares were displayed on test trials, but there was no difference when stimuli were named. The salience of the relational information following two problems in training affected the percentage of relational responses only in the stimulus display condition on the test trials. The inference to be
drawn from these outcomes is that relational information can be encoded concurrently in an image and a verbal format.

Differences in cognitive structure were interpreted as indicating that transposers were capable of forming abstract images but non-transposers were capable of only concrete images.
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I. INTRODUCTION

Most psychologists would agree that a slow but steady change has been taking place in experimental psychology, over the last twenty years. For almost fifty years, psychologists in the mainstream of experimental psychology have rallied around the premises of behaviorism proclaimed by John B. Watson in the early years of the twentieth century. Watson's behaviorism represented an American revolution in psychology and like most revolutions it went to extremes. Imagery, attention, states of consciousness, and other concepts that were important to pre-twentieth century psychology were branded as "mentalistic" and cast into darkness. Now a new revolution is getting under way. The first revolution banished thought, imagery, volition, attention, and other cognitive concepts. But, these concepts are vital to the understanding of man, and it is the task of the second revolution to bring them back. This second revolution is what Paivio (1975b) has labeled "neomentalism"; "Neomentalism is the objective study of the structure, function, and development of mental representation" (p. 264).

The most obvious example of the new mentalism is the research on mental imagery. Imagery is the most enduring and prototypical mentalistic concept. It appears as a unit of analysis and an explanatory principle in all ages and all approaches in psychology. It was found in ancient mnemonic systems and is currently found in computer simulations of the mind. The mental image was one of the elements of Titchener's structural psychology. It was thought by Galton to be an important variable on which individuals differed. Nevertheless, mental imagery along with other mentalistic concepts has been categorically rejected by J. B. Watson (1913) and the early behaviorists.

There were two reasons why mental imagery was rejected. First, there was the conviction that mental images could not be examined objectively. Second
there was the notion that mental images had no functional role in behavior. The first objection was decidedly more important.

To understand Watson's objections to mental imagery and mentalism in general, it is necessary to remember that the experimental psychology that was flourishing at or around the turn of the twentieth century was a direct outgrowth of British empirical philosophy. Wilhelm Wundt systematized the work of the British empiricists, particularly John Locke and David Hume, and developed it into German experimental psychology.

In Wundtian psychology, sensations and feelings are the basic states of consciousness. However, they do not exist in a non-compounded state. Instead, they must be abstracted from the compounds by careful introspection. When sensations and feelings are combined, they form images and perceptions. The task of the introspective observer is to separate the basic elements. If this is done properly, the experimenter can make inferences about the relation between the objects of either perception or memory. The emphasis placed by Wundt upon sensations and images was the result of the method of introspection. The introspective scientist using himself as his own laboratory is limited to the study of conscious processes. The consequence of this is that the scientist often misses the regulative aspects of thought, the sets or motivations which often fail to penetrate the conscious mind. Wundt's division of psychology was soon challenged by the Wurzburg school (Buhler, 1907; Marbe, 1901; Mayer & Orth, 1901; Messer, 1906). The Wurzburgers used the method of introspection promulgated by Wundt to examine the thought processes intervening between a stimulus word and the subject's reaction. They found a new set of conscious events which they were unable to describe or define. It seems that the Wurzburgers had stumbled upon the processes of thought in contrast to the contents of thought. The processes, however, were incomprehensible since introspection could deal only with
conscious elements. They referred to these incomprehensible phenomena as imageless thought.

The research of the Wurzburg school resulted in a deep division in psychology. Wundt would not tolerate an experimental psychology of the type he had declared impossible, and he bitterly attacked the Wurzburg school. Titchener (1909) provided a more dispassionate analysis of the work of the Wurzburg school. He concluded that there are no such things as imageless thoughts, that what the Wurzburgers had seen, but had failed to recognize due to faulty methods, were really highly complex combinations of sensory elements.

The whole controversy, however, revolved around the nature of introspection and basically the failure of introspection as a method of science. The failure of introspection is a consequence of its vulnerability to whatever theoretical language is in vogue. Mandler and Mandler (1964) give examples from Messer's protocols showing the extent to which "imageless thought"—a phrase that was invented as a theoretical term for an inexpressible experience—came to be used by subjects to describe their thought processes.

The controversy over imageless thoughts produced in American psychology a conviction that the introspective method was inherently incapable of providing common objective data for studying mental processes. Therefore, the study of mental processes as the business of psychology was abandoned in favor of the objective measurement of behavior. Not only were mental processes unacceptable but the very words to describe them were to be redefined in terms of behavior or else excluded from scientific discussion. Watson (1914) took it upon himself to define the domain of psychology.

Psychology as the behaviorist views it is a purely objective experimental branch of natural science which needs introspection as
little as do the sciences of chemistry and physics. It is granted that
the behavior of animals can be investigated without appeal to
consciousness. The position is taken here that the behavior of man and
the behavior of animals must be considered on the same plane...
It is possible to define (psychology) as 'the science of behavior' and
never to go back upon the definition, never to use the terms
consciousness, mental states, mind, content, will, imagery, and the
like...(pp. 9, 27).

Mental imagery which had been a central concept of the previous era was
thenceforth excluded from psychology. Watson described mental images as mere
ghosts of sensations and declared they had no functional significance whatever. In
Roger Brown's colorful words "He mercifully closed the bloodshot inner eye of
American psychology" (1958).

In contrast, psychology as the new mentalists see it, does have a place for
mentalistic concepts such as imagery and mental representation. New mentalists
have rediscovered many of the functions of imagery and have developed new
objective ways of studying the phenomenon. Many of the traditional problems in
psychology may now be re-examined in light of the new mentalistic approach and
with the objective methods devised by the new mentalists. One such research
problem is transposition.

The term transposition refers to both an experimental method and a
psychological phenomenon, stimulus generalization. In a transposition
experiment, the experimenter transposes or shifts a stimulus along some physical
dimension. The object of the experiment is to determine whether or not the
subject's response will transfer to the transposed stimuli. Beyond that, any
transfer of a response based on the relative position of a stimulus on any
dimension can be called transposition. Examples of transposition are the ability to recognize a melody when it is played in a different key and the recognition of a shape or form after it has been changed to a different size, color, or orientation.

Gestalt psychologists performed most of the early transposition experiments. They spoke of the transposition of forms and used transposability as a criterion of form perception. In Gestalt theory, transposition meant a kind of transfer that appears to result from responses to relations among stimuli or to patterns of stimulus qualities rather than to absolute qualities of the stimuli. Later, Kenneth Spence sparked an interest in transposition among learning theorists when he argued that transposition did not necessarily mean that animals or people had learned the relations between stimuli. He developed a theory of how learning absolute stimulus qualities would yield transposition. The result was a large body of research on which there was very little consensus about what it all meant.

The problem that will be examined in this dissertation is the problem of transposition and the reinterpretation of transposition research in terms of new mentalistic constructs. Specifically, it is argued that imagery has a functional role in the learning of stimulus relations.
II. FUNCTION OF IMAGERY

Historically, one function attributed to mental imagery is that of mediating associations. This function is found in an ancient memory technique used by orators in the classical world, the method of *loci* (Yates, 1966; Wittrock, 1977). The same function appears in the conceptual peg hypothesis of paired associate learning and in another memory technique utilizing the conceptual peg, the one-bun mnemonic. In the method of *loci* an orderly series of places is imprinted in memory and an image of each item to be remembered is located at each place. By recalling the places in order the objects can be remembered in order. According to the conceptual peg hypothesis, a mnemonic peg word or a concrete imagery-provoking stimulus serves to facilitate recall just as the places in the method of *loci*.

---

1 In the one-bun mnemonic an individual first memorizes a simple rhyme that goes like this: One-bun; two-shoe; three-tree; four-door; five-hive; and so on, in which a series of concrete objects called peg words (bun, shoe) are remembered in a particular order from one to ten or twenty depending on how the rhyme goes. Then, whenever a list of things needs to be remembered, each item is associated with one of the peg words. So, for example, if the list of things to be remembered included a bicycle, a radio, an egg, or whatever, the subject would construct an image in which each item interacted with a peg word (i.e., bicycle inside a bun, a shoe on top of a radio, or an egg in a tree). Then when it was necessary to recall the items, the individual would simply remember the images associated with each of the items in the rhyme and thus be able to recall ten or twenty things in the order in which they were memorized.
In using the method of loci and related techniques employing mnemonic peg words, a compound image is formed in which the item to be remembered is related to the peg in some fashion. In the case of the method of loci, this relationship is implicit in the procedure of placing images on loci. The relationship that is established is that of item-context or figure-ground. The mnemonic techniques based on rhyming peg words and experiments to test the conceptual peg hypothesis are generally accompanied by explicit instructions to construct an image of the peg and the object of recall in some relation to one another. These relationships are necessarily ad hoc for each pair. Nevertheless, the mnemonic peg word technique is as effective as the method of loci in facilitating recall (Bower, 1970a).

Evidence that it is the relation between the objects being imaged, that is the effective variable, comes from experiments by Paivio (1971) and Bower (1970b).

Paivio manipulated the variable of stimulus concreteness in the one-bun mnemonic. One experimental group was instructed in the use of the mnemonic before learning a list of words. The other experimental group was instructed in the use of an abstract version of the mnemonic: one, fun; two, true; three, free, etc. Contrary to what was expected, there was no difference in recall between the group imaging concrete pegs and the group imaging abstract pegs. Both groups, however, did significantly better than two control groups that did not receive imagery instructions. The instructions to the subjects to use imagery also urged subjects to form an interaction between each word and its peg; that is, to relate the two in a compound image. For example, if the first word was "bicycle", subjects might construct an image of a bicycle sandwiched in a bun in the concrete condition, or children having fun on a bicycle in the abstract condition.
Bower examined the effectiveness of two different types of imagery instruction on recall. Each subject was presented with a list of concrete noun pairs, one pair at a time. One group of subjects received the standard instructions to imagine the two items in each pair interacting. Another group received instructions to construct images of the two items but to keep them separate in imagination such that one imaged object did not influence the other imaged object. Subjects had ten seconds to form images for each concrete noun pair. After the entire list was presented, recall of the second word of each pair was cued by the first word. The interactive imagery group recalled with 61% accuracy, whereas the separated imagery group recalled with 34% accuracy. A control group who merely repeated the word pairs for ten seconds recalled with 36% accuracy.

The effective variable, therefore, appears to be the instruction to relate the images of the objects. Imageability or concreteness of an item itself may offer no advantage in storage or recall. Instead, the faculty of imagery which processes information in a holistic fashion thus preserving the relational organization between the separate elements, facilitates recall by reconstructing an entire image from one of the elements. This is the essence of the method of loci: First, a compound image made up of a separate item at each locus is constructed and stored; then, at recall each locus is cued and the compound image is reconstructed. Mental imagery appears to be particularly well suited for storing concrete information about an object. Objects that are high in concreteness have generally been found to be more imageable than more abstract objects (Paivio, Yuille, & Madigan, 1968).

Knowledge, however, is in the form of abstractions. How then does imagery fit into a theory of knowledge? The answer is in the ability of individuals to construct compound images in which the separate elements are somehow related
or interact with one another. The compound image then contains concrete information about the relationships between the items. This is basically the scholastic theory of knowledge in which knowledge is acquired as commonalities across particulars. In this case the commonalities are found in the connections between the separate elements of the image.

The relation or connection between elements can be of several types (Reese, 1968). First, the relation could be a physical dimension such as is found with two or more objects differing in size or brightness. Second, the relationship could be a conceptual association such as whole-part, cause-effect, synonymity-antonymity. A third relation arises from special contexts such as the connection between clown and bicycle in the sentence "The clown is riding the bicycle."

Mnemonic techniques employing imagery exploit these relationships either implicitly or explicitly in the construction of images to facilitate efficient storage or recall. Just as storage and retrieval can be facilitated by manipulating the relationships between images, so the manipulation of images can yield new insights, new understanding, or heretofore undiscovered relationships.

This was the rationale underlying Renaissance memory techniques which were based on earlier mnemonic techniques incorporating the method of loci. The Renaissance saw the development of new mnemonic techniques which were designed not so much to facilitate memory as to yield new universal secular knowledge. Renaissance man believed that through the faculty of imagination and through the aid of organized memory systems he could understand the entire universe (Yates, 1966; Wittrock, 1977). The Renaissance memory techniques were based on the scholastic theory of knowledge which holds that understanding is derived inductively from images and the relations between the imaged objects.
III. OBJECTIVE METHODS IN THE STUDY OF IMAGERY

Neomentalism is characterized by the development of a corpus of objective methodology for studying mental imagery and related processes. Two paradigms for studying mental imagery are particularly relevant here. These are the paradigm of second order isomorphism and the paradigm of internal psychophysics. The objective study of mental imagery requires that certain assumptions be made about the nature of the mental image. The first assumption is that the image is a spatial representation like that underlying the experience of seeing an object. The second assumption is that images may serve as templates for the processing of percepts.

A tremendous volume of research on mental imagery has emerged from the laboratories of Roger Shepard and his colleagues. This research, more than any other body of work, has advanced neomentalism with new methods and exciting findings. Exhaustive summaries of the experimental procedures and extensive catalogs of findings are available in several sources (Cooper & Shepard, 1973; Shepard, 1975, 1978; Shepard & Podgorney, 1978). The basic theory put forth in all of this research may be stated simply: the equivalence between perception and imagination takes the form of a second order isomorphism.

The concept of second order isomorphism means that perception and imagination mirror each other to the extent that the functional relations among the objects of imagination mirror the functional relations among the objects of perception. According to Shepard and Chipman, "The crucial step consists in accepting that the isomorphism should be sought—not in the first order relation between (a) an individual object, and (b) its corresponding internal representation—but in the second order relation between (a) the relations among alternative external objects, and (b) the relations among their corresponding internal representations" (Shepard & Chipman, 1970, p. 2).
Since the concern is with functional relations, the isomorphism can be said to be found in behavior. That is, the isomorphism appears as a similarity between the response to an image and the response to a percept. Thus, subjects should be able to answer questions about objects with equal facility regardless of whether the objects are perceived or imagined.

The question of interest to Shepard and Chipman (1970) concerned the perceived similarities between objects. Subjects were given a deck of cards containing the names of fifteen states paired in all possible combinations, one pair per card. They were asked to arrange the cards in order according to the degree of similarity in shape of the states in each pair. Following that, subjects were given another deck containing two dimensional outlines of each of the states named in the first deck. These were paired in the same manner as the name deck, and the subjects were instructed to do the same task. The first task it is assumed could only be performed by invoking some image of the states named in the first pair. The ratings for the perceptual and imagery conditions were indistinguishable. Subjects were most likely performing similar processes in both conditions and the processes operated on the relevant properties of objects even when the objects were not there.

More interesting results were obtained from reaction time experiments on the mental rotation of internal representations (Shepard & Metzler, 1971; Cooper & Shepard, 1973). In the typical experiment subjects had to decide whether a test figure was the same as the standard or different from it. Prior to presentation the test figure was rotated to one of several orientations.

The principal claim made for the mental rotation experiments is that in the course of comparing the shapes of two similar appearing objects that differ appreciably in orientation, the subject passes through a series of internal states that bear a one-to-one relation to the physical states that the object would pass
through if it were physically rotated from one orientation to the other. Evidence in support of the claim comes from the additivity of times taken to compare objects separated by different angles of orientation. First, reaction time (RT) was observed to increase linearly with the angular departure of the test stimulus from the reference. Second, and more convincingly, the sum of the RTs to go from orientation A to B and B to C equaled the RT to go from A to C directly. This would be expected if the subject cannot get to C without passing through B.

Third, Metzler (1973) arranged for alternative ways of getting from A to C. For example, if the prevailing direction of rotation is clockwise, a test stimulus could be presented with the departure of 235° in the clockwise direction. This would also be a departure of 125° in the counterclockwise direction. With these alternative physical paths there was a bimodal distribution of RT's indicating that subjects sometimes went the long way around and other times took the shortcut.

In other experiments subjects were told the identity of a figure and its orientation before presentation. Presumably, this allowed subjects to form a preparatory image. Subjects then informed the experimenter when they were ready for the stimulus. Two measures are appropriate in these experiments: preparation time and decision time. Preparation time was found to increase with increasing amounts of rotation. The effect on decision time depended upon whether or not the preparatory image was appropriate. If the image was appropriate, the speed and precision of the discrimination response improved. If the image was inappropriate, reaction time increased. An increase in reaction time could be obtained if the stimulus was rotated 20° or 30° from the preparatory stimulus.

The results are consistent with the first assumption that an image is a spatial representation like that underlying the perception of an image. The observation that decision times vary with the degree of rotation of the test object
from the standard suggests that subjects are performing an operation like that of moving an object through space. Shepard and Metzler proposed that the internal process described in the experiments was a mental analog of an external process. That is, it is similar to the perceptual process that would take place if the subject were actually to watch the corresponding physical rotation. The experiments involving a preparatory image are consistent with the second assumption that the image functions as a template. The preparatory image is highly concrete. Cooper and Shepard (1973) demonstrated a functional equivalence between a preparatory image and a template-like perceptual stimulus in an experiment in which subjects prepared for the test stimulus by (a) imagining the appropriate stimulus, or (b) viewing an outline of the appropriate stimulus. Reaction times and accuracy were nearly the same in both cases. In general the use of the paradigm of second order isomorphism demonstrates the similarities between perceptual behavior when a stimulus is present and when it is absent.

The other method of investigating mental imagery is the paradigm of internal psychophysics. Moyer (1973) had subjects compare the sizes of animals from memory. In a pre-experimental task subjects ranked animal names according to their judgments of the relative sizes of the animals themselves. In the experimental task the names of the animals were presented visually in pairs and subjects were required to throw a switch under the name of the larger animal. The dependent measure, RT, was found to increase as the difference in animal size decreased. In fact, it was found to vary as an inverse linear function of the logarithm of the estimated differences in the animal size. This linear function is similar to the functions obtained when subjects make direct perceptual comparisons of stimuli differing in size. Moyer's interpretation was that subjects compared the names by making an "internal psychophysical judgment."
Several rival hypotheses were offered to account for the data. First, a traditional verbal associative explanation could be invoked. The experimental task involved all pair-wise comparisons so that the largest animal was always largest, the smallest animal was never largest, and intermediate animals were sometimes larger and sometimes smaller. Over repeated trials probabilities associated with each animal could be built up to account for Moyer's data. A second hypothesis involves a theory of semantic features or propositional networks. According to this type of theory percepts are encoded with discrete semantic attributes (Banks et al., 1975). The word "bear", for example, might be encoded as mammal +, large +, wild +, etc. in which "+" indicates the possession of the particular attributional feature. Size relations might be difficult to code in a stack of semantic features, but the task would be possible if the size relations could be reduced to ordinal positions on the size dimensions. As it turns out, subjects in Moyer's experiment need to construct representations that preserve no more than ordinal information. So, a plausible semantic features model could easily be constructed to account for the data, especially since the item category (animal names) is restricted.

Paivio (1975b) and Moyer and Bayer (1976) replicated Moyer's essential findings but included controls that make the above hypotheses highly unlikely. First, Paivio exposed each subject to a particular item only once during the experiment. Thus, there were no opportunities for associated probabilities to accumulate. Second, Pavio expanded the list of stimulus names to include more animals as well as inanimate objects. Subjects were given animal-animal, animal-object, and object-object pairs of comparison. The larger set of stimuli and the fact that several conceptual categories were included present difficulties for a theory of discrete semantic features. The list of features necessary to account for the data would be so long as to be implausible. The same is true for a
propositional network; it would be too complex to be plausible. Third, Moyer and Bayer had subjects learn nonsense syllables as labels for circles of various size. Two sets of circles were used. In one set the size range was much larger than in the other set. The size difference between adjacent circles in the large range set was twice the corresponding difference found in the small range set. They hypothesized that if subjects were making use of only ordinal information, RTs to both sets of stimuli should be the same since the same ordinal information is retained in both sets. But, if subjects responded to more than ordinal information, RTs for the set with the larger size range ought to be faster than the RTs for the set with the smaller size range; discriminating among the large range circles would be easier. The results were that RTs were faster for the large range group; a finding that is not easily accounted for by semantic or propositional theory. Fourth, both Paivio and Moyer and Bayer included a perceptual control group. Thus, subjects made their judgments on either word pairs or picture pairs. RTs for the word pairs varied in a linear manner similar to the earlier experiment. The curve for RTs to picture pairs was nearly identical to the curve for word pairs. The only difference was that RTs for picture pairs were faster overall. This can be attributed to the more direct involvement of the visual system.

In these experiments subjects presumably construct analogue representations or images that undergo the same transformations as percepts. The paradigm of internal psychophysics leads to the strong conclusion that information is represented in memory in an analogue fashion. The representation preserves nearly all of the information that could be obtained in the act of perceiving. The mental image is not a mere epiphenomenon but instead is a real and reliable perceptual phenomenon that is capable of being transformed in a manner similar to the products of perception itself.
IV. INDIVIDUAL DIFFERENCES

Ever since the pioneering work of Galton, a large part of the psychological community has had the conviction that the laws of behavior are limited in their generality. Neomentalism points to individual differences in internal representations as one source of limits upon the generality of psychological laws and principles.

This should not be at all surprising considering that Galton began his study of individual differences by studying the problem of visual mental images which he thought would shed light on some essential cognitive differences. Galton constructed a questionnaire in which he asked respondents to elicit images for various situations and rate them on such things as clarity, definition, color, distance, and spatial extent among other things.

The results of Galton's survey lent support to his hypothesis that individuals did indeed differ in imagery ability. Galton's fellow scientists reported very little use of mental images and in fact some claimed they did not know what he was talking about. From a broader sample of people, however, he found a high prevalence of mental imagery of a clear and distinct sort. He found that it was more frequent and vivid among children, housewives, and laborers. He also concluded that it tended to be inherited because members of a family were usually alike in their reports of imagery; but there was considerable variability between families.

Galton had found that the vividness of images is highly variable across individuals. Naturally, it was hoped that such variation would be correlated with the ease with which information is retained in memory.

Galton's questionnaire technique has been utilized extensively by other researchers. The most prominent of the imagery tests was Betts' (1909) Questionnaire Upon Mental Imagery (QMI) derived from Galton's questionnaire.
The popularity of Betts' test seems to be due in part to the fact that it measured evoked imagery in seven modalities; visual, auditory, cutaneous, kinesthetic, gustatory, olfactory, and organic—in contrast to Galton's test which measured only visual imagery; and in part to its reliability which remained high. Sheehan (1967) constructed a shorter version which is the one with the most widespread usage (hereafter, QMI will refer to Sheehan's version, and Betts' QMI will refer to Betts' version).

The other imagery variable on which individual differences have been observed is the control of mental imagery. Fechner (see White, Sheehan & Ashton, 1977; J. T. E. Richardson, 1980) is reported to have been the first to observe that the extent of control over optical memory images varied considerably across individuals. Galton also reported on the phenomenon. He noted that most people cannot exercise control over their images but that there are a few who apparently are able to exert mastery. Gordon's (1949) Test of Visual Imagery Control (TVIC) is the most prominent instrument for measuring this variable. Both the QMI and the TVIC may be found in A. Richardson's (1969) book.

Two other tests, Marks' (1972) Vividness of Visual Imagery Questionnaire (VVIQ) and Paivio's (1971) Individual Differences Questionnaire (IDQ), complete the list of the most common introspective self-report measures of imagery.

Another type of measure that is frequently used to assess imagery ability is the spatial type of test. The usage of spatial tests stems from the early unsuccessful attempts to establish the functional significance of imagery from self-report ratings, and from a conviction (Barratt, 1953) that imagery is an important component of tasks involving manipulation of space relations. The tests that have been most frequently used are Flags (Thurstone & Jeffrey, 1956), Minnesota Paper Form Board (MPFB, Likert & Quasha, 1941), Space Relations
(Bennet, Seashore & Wesman, 1947), and Primary Mental Abilities Space Test (Thurstone, 1938).

The psychometric properties of these measures of imagery have been reviewed in detail in several sources (Ernest, 1977; White, Sheehan & Ashton, 1977; J. T. E. Richardson, 1980). In general the self-report questionnaires are highly reliable. The difficulty, however, is in determining whether or not they are valid. Since mental imagery is one phenomenon that is purely private and internal, there are no non-verbal criteria for its occurrence. Most validity discussions fall back on factor analysis to demonstrate a coherent internal structure or a high correlation with other similar tests.

Another approach to validity is to predict from scores on the tests to performance in learning and memory tasks. Studies of vividness, as rated on the QMI especially, have yielded consistent negative findings in predicting performance on these tasks. Vividness has not been found to affect the benefit gained from instructions to use imagery mnemonics; nor from the presentation of relevant pictures accompanying the verbal stimuli to be learned; nor from the effect of stimulus imageability on recall (J. T. E. Richardson, 1980). Following a review of the recent literature, Ernest (1977) concluded that "In no instance was the ability to use vivid imagery significantly related to learning nor did imagery vividness interact with other effects" (p. 187).

Regarding memory Neisser (1970) concluded that the vividness of mental imagery is unrelated to its usefulness or accuracy as a memory code. J. T. E. Richardson echoed Neisser's conclusion "...the most appropriate conclusion at present seems to be that the QMI has little predictive validity in the study of human memory" (p. 120).

Marks (1972) objected to the research that led to the above conclusions. He claimed that the construct of vividness is not at fault, rather it is the QMI and the
experimental tasks that are inappropriate. First, the problem with the QMI is that evoked imagery is measured in seven modalities and vividness is averaged across all seven. It would be more appropriate, according the Marks, to select subjects on the basis of scores on the modality most likely to function in the experiment. For most people and in most situations, this would be the visual modality. Accordingly, Marks devised the Vividness of Visual Imagery Questionnaire (VVIQ) with visual imagery as the single factor. Second, the learning and memory tasks that were commonly used had employed abstract geometrical patterns that held little interest for the subjects. Marks argued that vividness should be related to the interest and meaning evoked by a stimulus. Consequently, he used pictures and found that forced-choice recognition was higher for good visualizers on the VVIQ than for poor visualizers. Subsequent tests of the predictive validity of the VVIQ have not yielded similar positive results (McKelvie & Rohrberg, 1978). Instead, the pattern of negative findings observed on the QMI seems to have emerged on the VVIQ as well.

These results should not be surprising considering that they follow the same pattern that emerged from Galton's own research. Galton (1883) speculated at some length on the importance of imagery in various professions and on its functional role in thinking. However, in trying to predict cognitive differences from the results of his inquiries, he had to admit failure:

I cannot discover any closer relation between high visualizing power and the intellectual faculties than between verbal memory and those same faculties. That it must afford immense help in some professions stands to reason, but in ordinary social life, possession of a high visualizing power, as of a high verbal memory, may pass unobserved. I have to the last failed in anticipating the character of the answers
that my friends would give to my inquiries, judging from my previous knowledge of them; though I am bound to say that, having received their answers, I could usually persuade myself that they were justified by my recollection of their previous sayings and conduct generally. (pp. 77-78)

Betts (1909) arrived at a position similar to Galton's when he concluded that the role of mental images in cognitive tasks had been greatly overstated and that imagery may drop out altogether without in any way hampering the efficiency of unconscious processes. In light of such research Watson appears to have been amply justified in concluding that images may not play an important causal role in behavior.

In contrast to the self-report measures, studies employing spatial tests as measures of imagery have generally shown a larger relationship with paired associate learning and memory tasks (Ernest, 1977). As might be expected spatial tests are also good predictors of performance on mental rotation tasks. In an unpublished doctoral dissertation, Snyder (1972, discussed by Ernest, 1977; Posner, 1978) found the space relations test to be a significant predictor of mental rotation speed. The TVIC was also found to be a significant but less powerful predictor in this study whereas the QMI did not predict at all.

Do the self-report and spatial tests measure the same ability? Generally, moderate correlations have been found between spatial tests and self-reports; however, this needs to be qualified by the test. With a few exceptions no correlations have been found between the QMI and spatial tests; on the other hand, moderate correlations have been found between the TVIC and spatial tests (Ernest, 1977). A. Richardson (1977a) factor analyzed spatial tests, self-report
measures (QMI, TVIC, and IDQ) and several performance tests. He found the self-report and spatial tests loading on separate orthogonal factors.

What then are subjects reporting on the self-report tests? One possibility is that they are heavily influenced by pressures to respond in a socially favorable manner or in accord with the experimenter's expectations.

Angell (1910) was one of the first to point out that subjects may vary their performance according to task expectations. The same year Woodworth (1910) interpreted scores on the Betts QMI as indicating differences between subjects in their tendency to rank themselves high on imagery. The problem, of course, is the vulnerability of introspection to the demands of the experimenter: "The normal person's introspections are frequently neither very discriminating nor particularly valid, and they are easily influenced by loaded or leading questions" (Bower, 1970, p. 502).

In a study designed to examine the possibility of response bias on imagery questionnaires, Di Vesta et al. (1971) found that scores on the QMI and TVIC correlated positively with social desirability as measured on the Marlowe-Crowne scale. More recently A. Richardson (1977a) reported that the QMI was related to social desirability for males but not for females. He found the TVIC and the IDQ to be relatively free of bias. The results of these and other experiments (Ernest, 1977; J. T. E. Richardson, 1980) strongly suggest that self-report measures of imagery ability (at least vividness) may be contaminated by cues from the experimenter regarding the desired outcome. The introspective questionnaires involve tasks that are often ambiguous and ill-defined so that subjects are likely to respond in such a manner as to produce results they believe the experimenter wants.

That vividness of imagery should have so little predictive validity is in one sense disappointing. It seems on the face of it at least that the more vivid an
image the longer it would be retained in memory and the easier it would be to recall. This expectation, however, derives directly from the two metaphors which have characterized most of our thinking about mental imagery; Plato's wax imprint metaphor (Theaetetus, 191D) and the picture metaphor (Pylyshyn, 1973). We tend to expect from the wax imprint metaphor that vividness is like the depth of the imprint; the more vivid the image the deeper the impression. Similarly with pictures, one obvious dimension on which pictures differ when content is not considered is in vividness. Moreover, we expect vivid images to stand out among all other images in memory just as vivid pictures stand out in a gallery.

However, the evidence just provided suggests that the ability to construct vivid images offers little or no advantage in learning and recall tests. Perhaps we have been misled by the picture metaphor. Vividness may be related to imagery in an all-or-none fashion. In any given instance an image has been constructed or it has not. If it has been constructed we could say that some threshold of vividness has been crossed. Once constructed information could be read out from the image regardless of additional levels of vividness. Thus, it could be that the vividness on which people differ is functionally irrelevant. Put another way, vividness may not be a relevant attribute of pictures that are in the head.

Another consideration is that the great variability between individuals may be due not to any processing ability but to the lack of a commonly agreed on scale for measuring vividness. This could simply be a flaw in the use of introspective questionnaires which have subjects rate vividness on a subjective scale. Much is to be gained by operationalizing the concept of vividness and providing objective scales of measurement. Instead of dealing with the concept of visual imagery which is difficult to define and operationalize, it might be better to concern ourselves with the concept of visual memory which can be operationalized in terms of the amount of visual information stored and recalled and the amount
retained over time. Such an approach would free research from the constraints imposed by the wax imprint and picture metaphors.

A great deal of research in the pre-behaviorist flowering of scientific psychology was devoted to the study of imagery types. The concept of distinct imagery types has been variously attributed to Galton, Fechner and Charcot (Boring, 1950; Horowitz, 1970). Whoever the concept originated with, the period of 1880 to 1910 is one in which thinking was dominated by the notion of pure imagery types. Subjects were categorized as visualizers, audiles, kinesthetes, and so on.

Titchener (1910) was one proponent of imagery types. He distinguished four different modes of imagery with which to classify observers: visual, auditory-kinaesthetic, kinaesthetic, and mixed. A visual type of observer translates all sensations into visual images. A mixed type of observer constructs images in the same modality as the sensation. Titchener claims that there is no pure auditory type and no visual kinaesthetic type.

By the end of the first decade of this century, the research on imagery types was so confused that Angell (1910) took on the task of reviewing all the methods for determining mental imagery. The assumption underlying all of this research was that subjects could be classified according to the type of imagery habitually used in thought. One way of discovering an individual's habitual mode of representation was to observe him at a memory task under different modes of stimulus presentation. The subject's type was assumed to be the mode of presentation under which memory for the stimulus was found to be easiest. Thus, a person who did best on a visually presented list of stimuli was declared to be a visualizer. Another method was distraction. An auditory imager was expected to be more distractable by sound during visual memorization than by visual stimuli.
during auditory memorization. Literary works were also expected to yield clues about an author's type from the type of images most prevalent in metaphors.

Angell pointed out that subjects could make images in several different modalities and translate from one to another. He suggested that learning might accompany translation so that subjects would show better recall of the list they had translated than of one that was presented and recalled in the same modality. Having no way of knowing if and when subjects translated from one imagery mode to another, researchers could not claim that the preferred mode of imagery corresponded to the stimulus mode associated with ease of learning. Likewise, the distraction experiments rather than indicating preferred imagery modes might be better explained by an intensification of learning to overcome the distraction. Regarding modes requiring some introspection, Angell noted that subjects varied in performance according to what they thought the experimenter expected.

Angell concluded that there were no reliable methods of imagery analysis. He also concluded that clear imagery types did not exist. Instead he suspected that changes in conditions would cause shifts from one imagery mode to another.

Subsequent research on imagery types was more limited in scope. Griffitts (1927) asked subjects to report on their thought processes following a variety of problems. He decided on the basis of the results that the subjects were either concrete thinkers or verbal thinkers and these were related to visual or auditory types, respectively. Roe (1951) interviewed 64 scientists and elicited introspective reports from them about the types of imagery used in thinking about research problems. She found a preponderance of visual imagery among biologists and experimental physicists but very little among theoretical physicists, psychologists, and anthropologists. Among the latter two groups, verbal imagery or no imagery were the predominant modes of thought. She suggests that the preferred mode of thought influences the choice of profession and that scientists whose patterns of
thought differed from their colleagues also differed in their approaches to problems.

The research of Griffitts (1927) and Roe (1951) suggested that some people differ in the extent to which they favor verbal or visual strategies of processing information. Unlike the imagery typologies, verbal and visual modes do not refer to discreet categories of people or processes but instead refer to end points on a scale or dimension of processing strategies. It is likely that most people move from one point of the scale to another according to the demands of the task. Some, however, may be expected to be more heavily dependent upon one type of strategy or the other.

One intriguing hypothesis relating spatial ability, verbal ability, and imagery has been put forth by Jerison (1973, 1977). He examined nearly all of the available paleoneurological data and concluded (a) that the best biological indicator of intelligence is encephalization, (b) that encephalization evolves through pressure for increased sensory capacity, and (c) that human encephalization evolved as a result of pressure for improved visual organization in order to navigate large expanses of territory. Jerison's hypothesis is that the cognitive process that resulted was mental imagery which served our hominid ancestors by coordinating the distance senses and encoding space and time. He also hypothesized that language evolved as a supplement to other sensory systems for the construction of reality. What we refer to as a mental image can be thought of as a complex interaction of the language and spatial systems.

It follows from Jerison's hypothesis that the verbalizer-visualizer dimension would be an important one on which individuals may differ in their preferred mode of imagery. Verbalizer-visualizer is also a dimension of localization of cognitive function in the cerebral hemispheres. The idea that individuals differ in their cognitive style has focused on the verbalizer-visualizer dimension.
A. Richardson (1977b) constructed a shortened version of Paivio's (1971) Individual Differences Questionnaire (IDQ) and related it to gaze when responding to a question. Direction of gaze has been suggested by some (Kinsbourne, 1972; Kocel et al., 1972) to be an indicator of degree of hemispheric lateralization, cognitive processing mode or both. Richardson selected subjects with scores above the 85th percentile (visualizers) and below the 15th percentile (verbalizers) on the IDQ. For these subjects there was a significant positive correlation between IDQ scores and the number of left-lateral eye movements, left movements being indicative of visual processing. Habitual visualizers were found to give significantly higher ratings of vividness of voluntarily produced imagery than habitual verbalizers; and verbalizers were found to score significantly higher on a vocabulary test than visualizers.

However, even such a seemingly obvious dimension as verbalizer-visualizer does not always yield clear-cut experimental results. In attempting to replicate his own work with another sample of subjects, Richardson found a significant negative correlation between gaze direction and IDQ scores. That is, direction of gaze while responding to a question was in the opposite direction to that which was predicted. Richardson could not find an explanation in the experimental procedures. He suggests that other personality variables need to be considered including psychoticism and field dependency-independency.

An additional variable that needs to be considered is that of sex. Sex differences are somewhat problematic. On the one hand reported vividness of imagery tends to be greater in females than in males (Galton, 1883; White, Sheehan, & Ashton, 1977) and effects of imagery ability on other tasks has been found to be greater for females than for males (Ernest, 1977). On the other hand, a male superiority has been found on tests of spatial ability (McGee, 1978) and on mental transformation tasks (Metzler & Shepard, 1974). It would appear,
therefore, that females have greater imagery ability and males have greater spatial ability. The problem with this is that we tend to expect the two to be related if not identical abilities since visual processes are implicated heavily in both.

Why the differences then? Two explanations could be advanced to account for them. One explanation is related to sex differences in the lateralization of cerebral functions. The right hemisphere is typically viewed as being specialized for spatial processing and the left hemisphere for verbal processing. There is evidence that females are less lateralized than males such that in right-handed females the right hemisphere takes on more verbal functions and the left hemisphere takes on more spatial functions than in right-handed males (Levy & Reid, 1976). Ernest (1977) suggests, therefore, that females who are high in spatial ability may use imagery on spatial tasks differently from males; the spatial test performance may be more intimately tied to verbal processing in females than in males.

A second explanation is suggested by J. T. E. Richardson (1980) who notes that most reports of female superiority in imagery ability come from female experimenters. It may be that attitudes towards imagery are such that females are reluctant to disclose their use of imagery to males and males are reluctant to disclose their use of imagery to anyone. Given the vulnerability of introspective questionnaires to experimenter demand effects, reports of sex differences in imagery should not be accepted unless such reports are based upon the use of objective instruments.

It must be said that the evidence to date does not indicate that individual differences in the type of internal representation plays any important role in behavior. However, this area of research is fraught with difficulties, two of them being the failure of scientists to operationalize the concept of imagery and the
use of introspective self-report methods of investigation. It has been noted that one variable on which individuals differ is in the vividness of imagery. Vividness derives from the concept of the picture metaphor and it seems to imply that pictures that adhere longest in memory are the most vivid. Vividness, however, is difficult to measure because of the problems of scale and the inability to measure vividness without resorting to introspection. (An alternative is to change the focus of measurement from vividness of imagery to the accuracy and capacity of visual memory.) The other construct on which individuals differ is control of imagery. The moderate correlations between the TVIC and various spatial tests suggest that the control of imagery is measured by spatial tests. Most common spatial tests employ tasks that require the subject to manipulate two or three dimensional objects in imagination. Thus, instead of dealing with the concepts of vividness and control of imagery, the focus should be on visual memory and spatial ability as two of the components of mental representation. Objective tests are readily available for both of these constructs.
V. TRANSPOSITION

It was pointed out above that in current research and in the thinking of earlier ages mental images have been implicated in the acquisition of relations between objects. The learning of stimulus relations is commonly studied in the transposition paradigm. Transposition is itself a special case of generalization or transfer. Transfer simply means that previous experience influences current performance. Generalization refers to transfer along some stimulus continuum. Transposition refers to "transfer that apparently results from learning to respond to patterns or relations among stimuli rather than to stimulus elements" (Reese, 1968, p. 13).

The transposition paradigm refers to a class of experiments that are similar in design. Some number of stimuli that differ from each other on some physical dimension such as size or brightness are chosen. The distance separating any pair of adjacent stimuli is the same or proportional for all pairs of adjacent stimuli. The experiment has two phases: a training phase and a test phase. In the training phase a pair of stimuli S1 and S2 are presented and subjects receive regular reinforcement for selecting S2. In the test phase stimuli S2 and S3 are presented. If subjects choose S2, they are said to be responding to absolute properties of the stimuli; if they choose S3 they are said to be responding to relational properties of the stimuli. The latter case is sometimes called transposition behavior and the response is sometimes called the transposition response. Since S3 is adjacent to the reinforced stimulus S2, the test with S2 and S3 is referred to as a near transposition test. Stimulus S3 is said to be one step from the training stimulus. If S3 and S4 are used in the test, where S4 is the positive stimulus, the test is referred to as far transposition, or a two step test. The number of steps in transposition is the number of stimuli plus one that fall between the positive training stimulus and the positive test stimulus.
A common variation of the transposition procedure is the middle size problem in which three or more stimuli (usually 3 or 5) are presented in training and the subject is reinforced for picking the middle stimulus. The logic is similar to that discussed above for paired stimuli, but the middle size problem is generally considered to be more difficult.

Research on transposition has a long history beginning with experiments that seemed to show that animals could respond to relative stimulus proportions (Kinnaman, 1902; Bingham, 1913; Kohler, 1929). These experiments supported the Gestalt view that organisms respond to the relationships of one stimulus to another and not to simple structural elements of the stimuli.

Spence (1937b) developed a theory to account for transposition in purely absolute terms. His theory was important in bringing transposition to the attention of a large number of behaviorist psychologists and in stimulating research to test the predictions derived from his theory. Briefly, Spence's theory proposes that transposition results from a simple summation of individual response tendencies to individual stimulus characteristics. These response tendencies are under the control of gradients of excitation and inhibition which develop through the action of reinforcement.

One suggestion made by Spence (1937a) was that humans approach discrimination problems differently than animals because of their unique verbal ability. In other words, he suggested a verbal mediator for human transposition. A large body of developmental literature has grown up around the verbal mediation hypothesis (Stevenson, 1972).

Kuenne (1946) hypothesized that transposition is under verbal control in older children and adults but not in younger pre-verbal children. Spence's theory which was concerned with inarticulate organisms predicted only near transposition and not far transposition. Kuenne reasoned that a verbal mediator should yield
far transposition. She found that older children could indeed do far transposition while younger children could not. Both groups, however, were able to handle near transposition. Similar results were obtained in an experiment by Alberts and Ehrenfreund (1951).

In general numerous experiments on the age effect seem to show that implicit mediation reactions do control transposition behavior (Reese, 1968; Riley, 1968). However, it is not clear whether the mediator is a specific verbal process or some other correlated variable such as increased mental age. It is not always the case that older children who are capable of far transposition and young children who are not differ in their ability to express the relationship as would be expected if the behavior is under verbal control (Riley, 1968). Furthermore, other procedures such as the use of multiple training problems may be introduced into the experiment to overcome the verbal deficiency and yield far transposition (Johnson & Zara, 1960; Sherman & Strunk, 1964). Stevensen (1972) concluded that verbal mediation is not a necessary condition but may be a sufficient condition for transposition provided that a certain level of development has been attained, else the child is unable to benefit from his own verbalizations or those of others.

If there is a developmental level in which children's transposition comes under the control of a verbal mediator, it might be expected that adult transposition behavior would be under the same kind of control. However, an experiment by Zeiler (1964) yielded results that cannot be adequately explained by a verbal mediation hypothesis. Zeiler's experiment involved a five item middle size transposition problem with adult subjects. There were ten stimuli altogether so that up to five steps of transposition could be tested. An important variable in the experiment was the presentation of training stimuli; half of the subjects were presented with all five stimuli simultaneously and half were presented with each of the five successively.
If the subject responds independently to the positive and negative stimuli as Spence proposed, then transposition should occur regardless of whether the stimuli were presented successively or simultaneously. On the other hand, if the subject responds to the relationship of the stimuli, simultaneous presentation would be a necessary condition for the occurrence of transposition.

Zeiler found in his experiment that subjects responded to the absolute stimulus elements rather than stimulus relations on all five test steps following training with successively presented stimuli. But he found an interaction between the distance from training and the type of response among subjects who had been trained on simultaneously presented stimuli. Specifically, the percentage of relational responses increased and the percentage of absolute responses decreased with increasing distance of the test stimuli. Spence's theory predicts that the number of relational responses should make no difference. The verbal mediation hypothesis predicts that relational responses would follow training on simultaneously presented stimuli but not on successively presented stimuli; however, the distance of the test stimuli from the training stimuli should make no difference in the amount of relational responding. Thus, neither Spence's theory nor the verbal mediation hypothesis can provide an adequate explanation of Zeiler's results.

However, Zeiler's results can be explained if a mental image is hypothesized as the mediator. The image hypothesis assumes that both individual stimulus characteristics and relationships between stimuli may be encoded in the same visual image. As with a verbal mediator the relations would not be encoded during training on successively presented stimuli. The finding that transposition did not occur following successive presentation is in accord with predictions made by both verbal and imagery mediation hypotheses. The other finding, that of an interaction between the type of response and the number of steps from the test,
may be attributed to an imagery mediator if it is also assumed that the information extracted from the image is cued by the test stimuli.

Let us suppose that when presented with the test stimuli the subject matches it with his image of the training stimuli and responds on the basis of the number of cues present. If the test stimuli are one step away from the training stimuli, then four of the five items were present in training including the one that was positive. As the steps increase the number of items common to both training and test decreases. Absolute cues become less salient and relational cues become more salient. At step five there are no common items and only relational cues are present. Thus, both absolute and relational responses can be mediated by a mental image which encodes both absolute and relational information about the stimuli. The salience of the absolute or relational information that guides the subject's choice can be attributed to the congruence between the test stimuli and the image.

In contrast an explanation based on verbal mediation runs into difficulty in explaining the interaction. A verbal mediator can easily encode relational information; but if the mediator governs choice behavior, all of the choices ought to be relational. Physical stimuli can, of course, be described verbally, so a verbal mediator could encode absolute information; but, all of the choices ought to be absolute in that case. To encode both absolute and relational information plus some means of weighting each bit of information as a function of distance from training would probably require a verbal mediator so complex as to be implausible.
VI. THE PROBLEM

The general goal of experimental studies of learning has been to answer the question "What is learned?" In transposition experiments, for example, experimenters have addressed the question of whether a relational response is learned or whether an absolute response is learned. Another question that has been asked by experimenters is under what conditions is an absolute stimulus configuration learned.

A neomentalistic approach asks a slightly different question. The neomentalist asks the epistemological question "How do we know?" The epistemological question necessarily involves the question of representation as Attneave (1974) points out. Another way of stating the epistemological question is to ask how is information stored in memory? In the case of transposition the question that is asked is "How is relational information stored?"

In this experiment two general hypotheses were tested. The first hypothesis is that individuals differ in the structure of their internal representation, and that differences in internal structure are related to differences in learning an absolute stimulus configuration or in learning stimulus relations. The second hypothesis is that relational information is stored in memory in the form of a mental image.

In order to examine the internal representational structure of individuals, it was necessary to identify certain types of structures and to choose appropriate objective tests of them. One important cognitive structure is clearly that of verbal processes. The transposition literature which will be reviewed below points to the verbal mediator as being the most frequent explanation for the occurrence of transposition. The second cognitive structure is that of a visual mental image. The literature to be reviewed suggests a need to operationalize visual imagery to the fullest extent possible and to avoid the use of introspective measures. Two components of visual imagery can be identified in the literature, one of them
being visual memory and the other being spatial ability. In all, seven cognitive
tests were chosen to examine the individual differences in internal representation.
The specific tests will be discussed below.

To test the second hypothesis the logic required is that of second order
isomorphism. That is, it is necessary to look at the subject's behavior and to
determine whether the subject's response when stimuli are not present is similar
to the subject's response when the stimuli are present. If a visual image does
indeed mediate a relational response in the transposition experiment, then the
response pattern to the test stimuli in conditions which preserve the physical
characteristics of the stimulus elements will be similar to the response pattern in
conditions in which the test stimuli are retained only in memory. A mediator is
almost certainly required for the relational response to occur in the absence of
the stimuli. If the response is similar to that which occurs in the presence of the
stimuli, then we can say that the same mediator is being used in both cases.

In order to distinguish between a verbal mediator and an imagery mediator,
it is necessary to know not only the subject's choice of stimuli but also the time to
make the choice. In other words, the subject's reaction time is the discriminating
measure.

The logic of the experiment was similar to the logic of the one reported by
Moyer and Bayer (1976). The experimental design follows that of other
transposition experiments with the exception that the test phase of the
experiment was similar to Moyer and Bayer's experiment. It was expected that by
using that procedure with reaction time as the dependent variable an effect due
to an imagery mediator would be distinguishable from an effect due to a verbal
mediator. Several specific hypotheses were tested in this regard. The specific
hypotheses are:
1. The cognitive structure mediating a response to stimuli is the same regardless of whether the stimuli are actually presented or only named.

2. Assuming that the mediator is a mental image, the speed of response to the stimuli will vary inversely as a function of the size ratio between adjacent stimuli on the size continuum and the number of stimulus positions on the dimension separating elements of any stimulus configuration.

3. Assuming that the mediator is a mental image, the proportion of transposition responses will be greater following training with more than one stimulus configuration due to the increased salience of the relational information.
VII. METHODS

Subjects

Data were obtained from 110 subjects. All subjects were volunteers, most were graduates or undergraduates at the University of Hawaii. Undergraduates were recruited from several psychology courses offered in the Department of Psychology and they received partial course credit for their participation in the study. Females comprised 62 percent of the sample and males comprised 38 percent of the sample. The ethnicity of the subjects reflected the multiethnic population of Hawaii: 35 percent were of Caucasian ancestry; 29 percent were of Japanese ancestry; 20 percent were of Chinese ancestry; 4 percent were of Hawaiian ancestry; 3 percent were of Korean ancestry; 6 percent were of Filipino ancestry; and 2 percent claimed other ancestry. The determination of ethnicity was based on the reported ethnicity of the subject's father.

Materials

Tests. The following tests of cognitive ability were administered in the indicated order. Also listed are the test times allowed and the estimated reliabilities. The reliabilities were obtained from Wilson et al. (1975).

1. Visual Memory, 1 minute exposure and 1 minute recall, 0.58.
2. Primary Mental Abilities (PMA) Vocabulary, 4 minutes, 0.96.
3. Memory for Figures, 1 minute exposure and 1 minute recall, unknown reliability.
4. Things (a fluency test), two parts, 3 minutes each, 0.74.
5. Shepard-Metzler Mental Rotations, 10 minutes, 0.88.
6. Educational Testing Service (ETS) Word Beginnings and Endings, two parts, 3 minutes each, 0.71.
7. Visual Memory (delayed recall), 1 minute, 0.62.
These particular tests were selected on the basis of previous research (Wilson et al., 1975) in which they were found to load on factors that were theoretically interesting and identical for two of the ethnic populations (Caucasian and Japanese) that were sampled in this experiment. Examples of each of the seven tests and instructions for administration are presented in Appendix A.

**Equipment.** Stimuli were presented and biographical data and reaction time data were gathered using an Apple II plus microcomputer, with 48K memory. The display was a black and white video terminal with 12 inch diagonal screen. The response device for biographical information and all non-timed responses was the Apple keyboard itself. The response device for timed reactions was a three button panel connected to the Apple computer by way of an external I/O port. The timing of responses was controlled by a John Bell 6522 Versatile Interface Adapter (VIA) programmed by Sigurdson (Note, 1, 1982). The VIA was manufactured by John Bell Engineering, Inc. of California.

**Stimuli.** Stimuli in this experiment were of two types, geometric figures or CVC trigrams. The geometric stimuli were made up of squares with a diamond in the center. The stimuli differed from each other only in the size of the squares. Two sets of geometric stimuli made up of seven stimuli in each set were used. These two sets differed in the range of sizes and the ratio between adjacent stimuli. In the wide range set of stimuli the areas ranged from .42 square centimeters for the smallest stimulus to 27.6 square centimeters for the largest stimulus. The ratio of each stimulus to the next largest one was approximately 1 to 2. For the narrow set of stimuli the areas were 1.34 square centimeters for the smallest stimulus and 14.61 square centimeters for the largest stimulus. The size ratio of adjacent stimuli in this range was approximately 1 to 1.5. Inside each square was a small diamond of approximately .42 square centimeters in area. This
diamond did not change in size. It was the same for all stimuli in both sets. The diamond served as a size reference for the subjects. A set of seven CVC trigrams was chosen at random from a list of trigrams having an association value of 10 percent or less (Archer, 1960). The resultant list was: YAV, ZEJ, QOH, XUS, NIJ, GYX, and PYB. The stimuli are displayed in Appendix B.

**Procedure**

Upon arrival at the laboratory, subjects were assigned at random to one of eight experimental groups. Each subject was then given a brief overview of the experiment and an orientation to the microcomputer. Biographical information was then obtained from the subject. In response to queries by the computer, subjects indicated their age, their major in college, the ethnicity of their parents, the languages that they spoke in addition to English, and the languages they read in addition to English. The biographical information was followed by instructions for the first phase of the experiment.

The first phase of the experiment was a paired associate learning task in which subjects were asked to learn a name, a CVC trigram, for each of seven geometric figures. Subjects in four of the experimental groups matched trigrams with the wide range stimuli and subjects in the other four experimental groups matched the trigrams with the narrow range stimuli. Each stimulus was paired with a CVC trigram and the pairs were presented one at a time in random order. Subjects were instructed to memorize the trigram associated with each figure. Following the presentation of all seven pairs of figures and trigrams, each figure was presented alone in random order. With each presentation, subjects were prompted for the name of the figure which they entered via the keyboard on the microcomputer. Memorization and test trials alternated until the subject reached the criterion of two successive error free test trials. Upon reaching criterion the learning trials were discontinued and only the test trials were presented until
subjects reached a level of 100 percent overlearning, or until an elapsed time of one hour had been reached. If subjects failed to reach criterion after an hour of testing, the experiment was aborted.

Following the paired associate procedure, base line reaction time was obtained on each of the subject's index, middle, and ring figures of either the subject's right or left hand, depending upon whether the subject claimed to be right-handed or left-handed. Simple reaction time to a visual stimulus was recorded 10 times for each finger. These simple reaction times were recorded for the purpose of removing finger differences from the choice reaction times which were obtained in the transposition experiment, to be described next.

Following the simple reaction time experiment, the subject was given instructions for the transposition procedure, the second phase of the experiment. These instructions included a few practice trials in which the subject had to correctly choose the smallest of three squares. At the end of the instructions the subject initiated the transposition procedure by pressing the return key on the microcomputer.

The transposition procedure had two parts. The first part was the training session. In this session the subject, regardless of experimental group, was presented with three geometric stimuli (squares) on each trial. These three stimuli were from the set of seven that the subject had seen in the previous paired associate learning task. The stimuli presented to subjects in four of the groups (the one-problem condition) were the second, third, and fourth stimuli from the set of seven. These three stimuli were presented simultaneously but the order on the screen was random. Subjects in the other four groups (the two-problem condition) were presented with stimuli one, two, and three alternating randomly with stimuli two, three, and four from the set of seven that they had seen on the paired associate learning task. Subjects were instructed to choose one of the
three stimuli on each trial by pushing one of the three buttons that corresponded to the positions of the stimuli on the screen. They were instructed to make their choices as rapidly as possible and as accurately as possible. In all cases the middle size square on the display was the correct square.

The instructions informed the subject that he would receive ten points for each correct answer. The cumulative total of points was displayed continuously throughout the experiment. The correct choice was followed immediately by the word "right" cascading from the upper left part of the screen to the lower midportion of the screen, and 10 points were added to the display. An incorrect response was followed by the statement "Incorrect" appearing on the screen. This part of the experiment continued until the subject had responded correctly on five successive trials and at least 25 trials had been presented. Upon reaching criterion the subject was instructed to take a deep breath, stretch, or relax for a minute and then to begin whenever he was ready.

At the beginning of the second part of the experiment, subjects were told that they would be tested on how well they had learned the problem in the previous part. Half of the subjects were informed that instead of seeing squares on the screen they would see the names of the squares that they had learned in the paired associate learning task, but they were instructed to respond to the names just as if the squares themselves were present. Thus, in the test part of the experiment half of the subjects were presented with geometric stimuli (the figures condition) and the other half were presented with CVC trigrams (the names condition). On each trial three stimuli were presented. Five combinations of stimuli were selected from the original set of seven stimuli that the subjects had learned in the paired associate learning task.

Subjects in four of the groups were presented with stimuli three, four, five; stimuli four, five, six; stimuli five, six, seven; stimuli three, five, seven; and
stimuli one, four, seven. The order of presentation was random, except for the first five trials in which the triads were presented in order of increasing distance from the training stimuli. Each triad had an equal probability of appearing on any given trial up to a total of five presentations of each triad. On any given trial the arrangement of the three stimuli on the screen was random. The stimuli on the test part were the same stimuli that the subjects had seen on the paired associate learning task. That is, two groups of subjects who had learned names to wide range stimuli in the paired associate learning task were presented with wide range stimuli in the transposition task, and two groups of subjects who had learned names for narrow range stimuli in the paired associate learning task were presented with narrow range stimuli in the transposition task.

Subjects in the other four groups were presented with CVC trigrams, three on each trial. These subjects saw the following combinations of trigrams: QOH, XUS, NIJ; XUS, NIJ, GYX; NIJ, GYX, PYB: QOH, NIJ, PYB: and YAY, XUS, PYB. As with the geometric stimuli, the order of presentation of the display was random. Each triadic combination was presented six times for a total of 30 test trials. The subjects responded on the test trials as on the training trials by pressing a button that corresponded to the position on the screen of the correct square or the name of the correct square.

The question of reinforcement in the test trials is an unresolved question in the transposition literature. If no reinforcement is given in the test trials, then extinction sets in and the probability of choosing the middle size response as the learned relationship decreases with each succeeding test trial. On the other hand, if all test trials are rewarded then the response that is made on the first test trial is likely to be strengthened on each successive test trial. That is, if the subject makes a transposition response on the first test trial, he is likely to continue to make transposition responses; and and if the subject makes an absolute response-
on the first test trial, he is more likely to continue making absolute responses. If only the correct responses are reinforced, then the test trials become another set of learning trials. Clearly the third alternative reinforcing only the correct trials is unsatisfactory. As for the other two, the problem is of more theoretical interest than empirical interest. Reese (1968) argues that there does not seem to be much difference in results whether the experimenter chooses to reinforce all trials or whether the experimenter chooses to reinforce none of the test trials. However, one solution that has been proposed by Reese (1968) and Zeiler (1967) has been to increase resistance to extinction by using an intermittent schedule of reinforcement in the training part and reinforce none of the trials in the test part.

Following their suggestion an intermittent schedule of reinforcement was applied during the training part of the transposition experiment and no reinforcement was given during the test part of the transposition experiment. In the training part of the experiment the subjects were reinforced on a continuous schedule for the first 15 trials. On the 16th trial the schedule switched to an intermittent schedule of reinforcement with a 0.84 probability of reinforcement. On each subsequent trial the probability of reinforcement was decreased by 0.01 until on the 25th trial the probability of reinforcement was 0.75. The probability was decremented at the same rate for each triad beyond 25 if subjects took longer to reach criterion. No reinforcement was given during the test part of the experiment. On non-reinforced trials subjects merely saw a statement that said "End of trial" followed by the trial number. No points were displayed on these trials.

At the conclusion of the transposition experiment subjects were given the battery of cognitive tests. Each test was administered one at a time and each test was timed. The whole battery took approximately 30 to 35 minutes. Following the cognitive tests subjects were interviewed about the experiment.
They were questioned as to what they thought the experiment was about and they were given an explanation regarding the experiment and the hypotheses that were being investigated. During the interview they were also asked what they had guessed was the correct answer. The interview generally lasted 10 to 20 minutes. Of particular interest during the interview was evidence of different strategies and thought processes engaged in while solving the transposition problem.

**Design and Analysis**

The sampling design in this experiment is a 2 x 2 x 2 factorial design. The three factors in the design were (a) number of training problems (one or two), (b) range of training stimuli (wide or narrow), and (c) format of the test stimuli (figures or names).

There are two dependent variables. One dependent variable is the percent of transposition on the test trials, that is, the percentage of correct responses or middle size choices made by each subject on the test trials. The second dependent variable is the mean choice reaction time, that is, the mean time it takes the subject to choose the correct answer.

All responses were equated on simple reaction times before calculating the mean choice reaction time per subject. A robust mean of the ten simple reaction times for each finger was calculated and the appropriate mean, depending upon which button was pressed, was subtracted from the reaction time for each trial. The robust means were calculated according to the Hampel procedure because the Hampel is relatively unaffected by a skewed distribution (Andrews et al., 1972).

Two distance variables make up a design on the dependent variables. The first distance variable is the distance of the test stimuli from the training stimuli in terms of steps. In this experiment subjects were exposed to test stimuli at all three steps from the training stimuli. The second distance variable is based on the ordinal position of stimuli within each triad. Three of the triads were
composed of stimuli that are adjacent to each other on the size dimension. One of the triads is made up of stimuli occupying positions separated by one other position, and one triad is made up of stimuli separated by two positions. For this distance factor the dependent measure for distance 0 is the average reaction time of the correct responses out of 18 possible choices. For distance one, the dependent measure is the average reaction time of correct responses out of 6 possible correct responses, and for distance two, it is the average reaction time of correct responses out of 6 possible correct responses. The term "step" will be used in reporting results to include both distance from training and ordinal position distance. Steps one, two and three refer to distance from training at an ordinal position distance of zero. Step four refers to an ordinal position distance of one and step five refers to an ordinal position distance of two. Steps four and five do not mean distance from training.

These distance factors are clearly repeated factors since each subject is exposed to all levels of each factor. These repeated levels may be considered as three inter-correlated dependent variables, thus removing the distance factor from the sampling design. The actual analysis then is a 2 x 2 x 2 multivariate analysis of variance (MANOVA).

Three composite variables were created from the three distance variables (Y1, Y2, Y3). The first composite variable, Y1', is a linear combination of the three dependent variables. The other two composite dependent variables test the difference between steps. The second composite, Y2', tests for a linear trend in the data, and the third composite, Y3', tests for a quadratic trend in the data. The calculation of these three composite variables is based on a table of orthogonal polynomials (Bock, 1975, p. 585). The three dependent variables are thus orthogonal. Table 1 presents the orthogonal polynomials used in calculating these dependent variables.
Table 1. Table of weights for constructing orthogonal polynomials of dependent variables.

<table>
<thead>
<tr>
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<th>1</th>
<th>1</th>
</tr>
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<tbody>
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<td>1</td>
</tr>
<tr>
<td>Linear</td>
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<td>0</td>
<td>-1</td>
</tr>
<tr>
<td>Quadratic</td>
<td>1</td>
<td>-2</td>
<td>1</td>
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</tbody>
</table>
The item choice and the reaction time factors were treated as two sets of dependent variables. Each set was analyzed in a separate MANOVA. Only subjects who transposed according to the criterion of transposition were included in these analyses.

Two criteria of transposition were used and they agreed in all but four cases. The first criterion was the subject's response to the question "What did you guess was the correct answer?" If the subjects mentioned something such as middle size or intermediate size, it was determined that they had learned the relationship. If, on the other hand, the subjects responded with a name of a particular square, such as NIJ or XUS, it was decided that they had responded absolutely and had learned a particular stimulus. The other criterion was total percentage of transposition. Subjects who chose the middle size on 50 percent or less of all trials were determined to have responded absolutely. Subjects who chose the middle size on more than 50 percent of all trials were said to have transposed. Four subjects indicated that the middle size was correct but their percentages of correct responses were no higher than expected by chance, so they were coded as non-transposers. Forty-seven subjects were found to transpose. Figure 1 presents the data matrix for this experiment including the n's for each cell.

Subjects were divided into the two groups, transposers and non-transposers according to the two criteria mentioned above; the cognitive test battery was factor analyzed separately for each group. Factors were extracted using a maximum likelihood factor analysis with the criterion for extraction being eigenvalues greater than 1.0. The factors were rotated to a unique solution using a varimax rotation.
### Figure 1.

Data Matrix for a 2 X 2 X 2 MANOVA with repeated levels of distance. Number of predominant transposers are indicated in each row. Columns are repeated levels.
VIII. RESULTS

Transposition

Failure to reach the criterion of learning in the figure association phase of the experiment resulted in the experiment being aborted for 11 subjects. Failure to reach the criterion of learning in the training part of the transposition experiment resulted in the experiment being aborted for three subjects. Data on two subjects were lost as a result of equipment failure. Complete data are available for 94 subjects.

The percentage of transposition was calculated for each step in the test phase. Means for each group are presented in Table 2. The square roots of the percentages were transformed to radians by an arcsine transformation. A multivariate analysis of variance was performed on the transformed percentages. The results for a linear combination of dependent variables are presented in Table 3. The main effect of test format was significant \( (F_{1,86} = 11.61) \). The percentage of transposition was higher in the figure condition than in the name condition. No other main effects or interactions were significant. The null hypothesis of parallel means on test format was tested and was not rejected (Hotelling's \( T^2 \) = 1.369, \( F_{(4,83)} = 0.33 \)). The results are presented graphically in Figure 2.

Males and females differed significantly in the percentage of transposition at the first and third steps but not at the other three steps. The means and standard errors at each step by sex are presented in Table 4. Subjects were classified as predominant transposers and predominant non-transposers on the basis of two criteria described above. There were 47 subjects in each group. The proportions of male and female subjects who predominantly transposed were .59 and .48, respectively. These proportions are not significantly different from .50 \( (X^2_{df=2} = 3.4) \).
<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th>Step 2</th>
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Table 2. Mean percent transposition and standard errors for each group at each step. Cells are formed by range of stimuli (narrow or wide), test format (figures or names), and number of problems in training (one or two).
<table>
<thead>
<tr>
<th></th>
<th>Sums of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
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<td>7.1420</td>
<td>11.69</td>
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<td>Number of problems</td>
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<td>0.0037</td>
<td>0.01</td>
<td>0.938</td>
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<td>1.3454</td>
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<td>0.141</td>
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<tr>
<td>Range X number of problems</td>
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<td>0.0750</td>
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<td>0.727</td>
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<td>Test format X number of problems</td>
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<td>1</td>
<td>0.1168</td>
<td>0.19</td>
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<td>0.728</td>
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<td>Total</td>
<td>515.0314</td>
<td>94</td>
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</table>

Table 3. Analysis of Variance of unweighted composite of percent transposition after arcsine transformation for all subjects.
Figure 2. Mean percentage of transposition at each step in the figure and name conditions. Brackets indicate plus or minus one standard error.
Table 4. Mean percent transposition and standard errors for males and females at each step. The values of $t$, $d$, and associated probabilities are listed below.

<table>
<thead>
<tr>
<th></th>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
<th>Step 4</th>
<th>Step 5</th>
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<td>$SE$</td>
<td>$\bar{X}$</td>
<td>$SE$</td>
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<tr>
<td><strong>Male</strong></td>
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<td>78.20</td>
<td>3.34</td>
<td>57.93</td>
<td>4.78</td>
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<tr>
<td><strong>Female</strong></td>
<td>62</td>
<td>58.52</td>
<td>3.01</td>
<td>51.86</td>
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<tr>
<td>$t$</td>
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<td>.025</td>
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<td>NS</td>
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<tr>
<td>$d$</td>
<td>.924</td>
<td>.249</td>
<td>.480</td>
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</tbody>
</table>
An additional statistic is presented in Table 4. The effect-size or $d$ was calculated as $(M_1 - M_2)/\bar{SD}$ where $M_1$ is the mean for males, $M_2$ is the mean for females and $\bar{SD}$ is the average of the standard deviations for the two groups. In other words, $d$ is the ratio of the difference between group means to the standard deviation of a group (the standard deviations of the two groups are assumed to be equal). The average standard deviation was used in the present study because it is the best estimate of the standard deviation for either group when both standard deviations are assumed to be equal. The values of $d$ ranged from -.028 to .924. The minus sign should be interpreted as a reversal in the direction of the effect. The mean value of $d$ was .408. This may be interpreted to mean that the percentage of relational responses given by males was less than half a standard deviation greater than females. With an effect size of .408 and sample sizes of 32 and 62, the power to detect a difference that is statistically significantly at .05 is between .35 and .60 (Cohen, 1969).

Mean percentage of transposition at each step for predominant transposers and predominant non-transposers are presented in Figure 3. It can be seen that there is no distance effect for transposers. The level of transposition is nearly the same at all three steps. For non-transposers, however, the amount of transposition drops off sharply with increasing distance from the training stimuli. The other effect of ordinal position distance is also apparent in Figure 3. The amount of transposition increases with increasing separation between stimuli.

Table 5 presents the results of a multivariate analysis of variance with a linear combination of percentages of transposition on the first three steps from training as the dependent variable. Only data from predominant transposers were included. The mean percentages were transformed into radians prior to analysis. The main effect of test format was significant. No other main effects or interactions were significant.
Figure 3. Mean percentage of transposition at each step for predominant transposers and predominant non-transposers.
<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grand means</td>
<td>167.584</td>
<td>167.584</td>
<td>824.47</td>
<td>0.000</td>
</tr>
<tr>
<td>Range</td>
<td>0.0117</td>
<td>0.0117</td>
<td>0.06</td>
<td>0.812</td>
</tr>
<tr>
<td>Test format</td>
<td>1.7721</td>
<td>1.7721</td>
<td>8.72</td>
<td>0.005</td>
</tr>
<tr>
<td>Number of problems</td>
<td>0.3801</td>
<td>0.3801</td>
<td>1.87</td>
<td>0.179</td>
</tr>
<tr>
<td>Range X test format</td>
<td>0.3757</td>
<td>0.3757</td>
<td>1.85</td>
<td>0.182</td>
</tr>
<tr>
<td>Range X number of problems</td>
<td>0.0521</td>
<td>0.0521</td>
<td>0.26</td>
<td>0.616</td>
</tr>
<tr>
<td>Test format X number of problems</td>
<td>0.5099</td>
<td>0.5099</td>
<td>2.51</td>
<td>0.121</td>
</tr>
<tr>
<td>Range X test format X number of problems</td>
<td>0.0018</td>
<td>0.0018</td>
<td>0.01</td>
<td>0.9265</td>
</tr>
<tr>
<td>Error</td>
<td>7.9272</td>
<td>39</td>
<td>0.2033</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>178.6146</td>
<td>47</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Analysis of Variance of a linear combination of dependent variables at one to three steps distance from training. Dependent measure is percent transposition following arcsine transformation.
Since the main effect of number of problems in training was determined a priori to be of theoretical interest, the means were collapsed across range and presented by test format and number of problems in Table 6. The same means are presented graphically in Figure 4a and Figure 4b. From these figures, it can be seen that the hypothesized interaction of distance from training and number of problems in training is not present. There does, however, appear to be a small but non-significant interaction between number of problems and test format. There is greater transposition following two problems in training than following one problem in training for subjects presented with figures on the test. The difference is significant at Step 1 and Step 2. In order to protect against Type I error, the alpha level for each comparison was set at $\alpha = 1 - (1 - .05)^2 = .0085$. When tested against this criterion, the difference between one problem and two problems at Step 3 is not significant. The number of problems in training has no effect for subjects presented with names in the test.

**Reaction Time**

A baseline measure of reaction time for each finger was calculated from the data obtained in the simple reaction time test. Choice reaction times were adjusted for finger differences by subtracting the appropriate baseline time from each response in the transposition experiment.

The mean choice reaction time after baseline adjustment was calculated for each ordinal position distance for all predominant transposers. Reaction times on trials in which the middle size square was not chosen were not included. Means and standard errors for each group at each distance are presented in Table 7.

Inspection of Table 7 suggested that the samples were drawn from populations with different variances. The assumption of homogeneity of variances was examined with Bartlett's test. A significant F ratio was obtained at each
<table>
<thead>
<tr>
<th></th>
<th>Step 1</th>
<th></th>
<th></th>
<th></th>
<th>Step 2</th>
<th></th>
<th></th>
<th></th>
<th>Step 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>x</td>
<td>SE</td>
<td></td>
<td>x</td>
<td>SE</td>
<td></td>
<td>x</td>
<td>SE</td>
</tr>
<tr>
<td>Figure</td>
<td>One</td>
<td>17</td>
<td>86.18</td>
<td>1.88</td>
<td>81.90</td>
<td>2.57</td>
<td>79.38</td>
<td>3.88</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two</td>
<td>12</td>
<td>98.39</td>
<td>1.62</td>
<td>96.24</td>
<td>1.72</td>
<td>91.77</td>
<td>2.95</td>
<td></td>
</tr>
</tbody>
</table>

|       | t      | 4.653 | 4.226 | 2.385   |
|       | p      | 0.0025| 0.0025| .025    |
|       | d      | 1.827 | 1.733 | 0.945   |

| Names | One    | 8     | 67.98 | 4.38    | 69.79 | 2.44 | 81.45 | 6.53  |
|       | Two    | 10    | 73.08 | 8.87    | 71.98 | 4.13 | 70.27 | 4.44  |

|       | t      | 0.477 | 0.427 | -1.461  |
|       | p      | NS    | NS    | NS      |
|       | d      | 0.252 | 0.219 | -0.688  |

Table 6. Mean percent transposition and standard errors for predominant transposers in two levels of number of problems and test format conditions collapsed across range on three steps distance.
Figure 4. Mean percentage of transposition at each of three steps distance for one or two problems in training groups.
Table 7. Cell means and standard errors for choice reaction times at each of three ordinal position distances. Tests for homogeneity of variance are listed below each distance. Cells are formed by range of stimuli (wide or narrow), test format (figures or names), and number of problems in training (one or two).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>X</th>
<th>SE</th>
<th>X</th>
<th>SE</th>
<th>X</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Narrow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Figures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One</td>
<td>9</td>
<td>842.814</td>
<td>155.383</td>
<td>605.411</td>
<td>84.918</td>
<td>548.911</td>
<td>57.375</td>
</tr>
<tr>
<td>Two</td>
<td>6</td>
<td>1006.677</td>
<td>197.143</td>
<td>632.050</td>
<td>105.968</td>
<td>636.950</td>
<td>91.761</td>
</tr>
<tr>
<td>Names</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One</td>
<td>3</td>
<td>3508.381</td>
<td>572.532</td>
<td>2778.299</td>
<td>478.264</td>
<td>1966.733</td>
<td>329.829</td>
</tr>
<tr>
<td>Two</td>
<td>6</td>
<td>2341.732</td>
<td>458.673</td>
<td>2226.999</td>
<td>234.681</td>
<td>1954.016</td>
<td>195.404</td>
</tr>
<tr>
<td><strong>Wide</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Figures</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One</td>
<td>8</td>
<td>775.086</td>
<td>124.168</td>
<td>498.912</td>
<td>74.509</td>
<td>424.600</td>
<td>72.990</td>
</tr>
<tr>
<td>Two</td>
<td>7</td>
<td>628.899</td>
<td>60.766</td>
<td>433.900</td>
<td>32.390</td>
<td>468.057</td>
<td>54.685</td>
</tr>
<tr>
<td>Names</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One</td>
<td>4</td>
<td>3098.381</td>
<td>442.586</td>
<td>2641.148</td>
<td>243.249</td>
<td>2446.624</td>
<td>502.356</td>
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<td>2555.163</td>
<td>434.639</td>
<td>2287.123</td>
<td>251.325</td>
<td>1946.599</td>
<td>182.452</td>
</tr>
</tbody>
</table>

**Bartlett's Test**
- Approximate F: 23.714, p = .002
- Approximate F: 3.142, p = .001
- Approximate F: 14.509, p = .001

- Approximate F: 32.390, p = .001
- Approximate F: 424.600, p = .001

- Approximate F: 12.990, p = .001
- Approximate F: 502.356, p = .001

Table 1. Cell means and standard errors for choice reaction times at each of three ordinal position distances. Tests for homogeneity of variance are listed below each distance. Cells are formed by range of stimuli (wide or narrow), test format (figures or names), and number of problems in training (one or two).
distance. Consequently, the reaction time data were transformed logarithmically. Means and standard errors in log units are presented in Table 8.

The effects of number of problems, test format, size range of stimuli and ordinal position distance of stimuli were examined in a multivariate analysis of variance. The results are presented in Tables 9, 10, and 11. From Table 9 it can be seen that the main effect of test format for a linear combination of variables is significant ($F_{1,38} = 204.19$). The time required for making a choice among three names of squares is much longer than the time required for making a choice among the three squares themselves. The hypothesis of parallel means was tested and rejected ($T^2 = 6.397$, $F_{2,37} = 3.11$, $p = .0562$).

Significant linear and quadratic trend effects were found for ordinal position distance as indicated in Tables 10 and 11. There was a significant interaction between test format and the quadratic trend as can be seen in Table 11. There was no interaction between test format and the linear trend as can be seen in Table 10. There were no other significant interactions involving distance.

There were no significant effects of range. However, since differences due to range had been hypothesized a priori, the data were collapsed across number of problems and summarized by distance, range and test format. The means and standard errors are presented in Table 12. Each of the six comparisons were tested at an alpha level of .0085. None of the comparisons were significant when tested against this criterion. The results are presented graphically in Figure 5.

From Figure 5a it can be seen that there is a quadratic trend for the figure condition in both wide range and narrow range groups. The discrimination appears to be easier for stimuli that are not adjacent on the size dimension. An effect of range is also apparent in Figure 5a although it is not large enough to be statistically significant.
<table>
<thead>
<tr>
<th>N</th>
<th>$\bar{x}$</th>
<th>SE</th>
<th>$\bar{x}$</th>
<th>SE</th>
<th>$\bar{x}$</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Figures</td>
<td>One 9</td>
<td>2.880</td>
<td>0.067</td>
<td>2.750</td>
<td>0.059</td>
<td>2.720</td>
</tr>
<tr>
<td></td>
<td>Two 6</td>
<td>2.962</td>
<td>0.078</td>
<td>2.767</td>
<td>0.073</td>
<td>2.780</td>
</tr>
<tr>
<td>Names</td>
<td>One 3</td>
<td>3.534</td>
<td>0.068</td>
<td>3.430</td>
<td>0.081</td>
<td>3.282</td>
</tr>
<tr>
<td></td>
<td>Two 6</td>
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<td>0.088</td>
<td>3.335</td>
<td>0.048</td>
<td>3.233</td>
</tr>
<tr>
<td>Wide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Figures</td>
<td>One 8</td>
<td>2.853</td>
<td>0.067</td>
<td>2.665</td>
<td>0.064</td>
<td>2.587</td>
</tr>
<tr>
<td></td>
<td>Two 7</td>
<td>2.787</td>
<td>0.038</td>
<td>2.631</td>
<td>0.027</td>
<td>2.652</td>
</tr>
<tr>
<td>Names</td>
<td>One 4</td>
<td>3.477</td>
<td>0.064</td>
<td>3.416</td>
<td>0.041</td>
<td>3.361</td>
</tr>
<tr>
<td></td>
<td>Two 4</td>
<td>3.387</td>
<td>0.078</td>
<td>3.351</td>
<td>0.051</td>
<td>3.284</td>
</tr>
<tr>
<td>Bartlett's Test</td>
<td>4.340</td>
<td>8.262</td>
<td>3.919</td>
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<tr>
<td>Approximate F</td>
<td>0.565</td>
<td>1.077</td>
<td>0.510</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>.785</td>
<td>.376</td>
<td>.828</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8. Cell means and standard errors for choice reaction times at each of three ordinal position distances after logarithmic transformation. Cells are formed by range of stimuli (wide or narrow), test format (figures or names), and number of problems in training (one or two).
<table>
<thead>
<tr>
<th></th>
<th>Sums of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grand mean</td>
<td>1142.31</td>
<td>1</td>
<td>1142.31</td>
<td>19680.9</td>
<td>0.001</td>
</tr>
<tr>
<td>Range</td>
<td>0.09168</td>
<td>1</td>
<td>0.0917</td>
<td>1.58</td>
<td>0.216</td>
</tr>
<tr>
<td>Test format</td>
<td>11.8513</td>
<td>1</td>
<td>11.8513</td>
<td>204.19</td>
<td>0.001</td>
</tr>
<tr>
<td>Number of problems</td>
<td>0.0258</td>
<td>1</td>
<td>0.0258</td>
<td>0.44</td>
<td>0.509</td>
</tr>
<tr>
<td>Range X test format</td>
<td>0.1067</td>
<td>1</td>
<td>0.1067</td>
<td>1.84</td>
<td>0.183</td>
</tr>
<tr>
<td>Range X number of problems</td>
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<td>1</td>
<td>0.0072</td>
<td>0.12</td>
<td>0.726</td>
</tr>
<tr>
<td>Test format X number of problems</td>
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<td>1</td>
<td>0.0760</td>
<td>1.31</td>
<td>0.260</td>
</tr>
<tr>
<td>Range X test format X number of problems</td>
<td>0.0087</td>
<td>1</td>
<td>0.0087</td>
<td>0.15</td>
<td>0.700</td>
</tr>
<tr>
<td>Error</td>
<td>2.2056</td>
<td>38</td>
<td>0.0580</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1156.6572</td>
<td>46</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9. Analysis of variance of unweighted composite of reaction times after log 10 transformation.
<table>
<thead>
<tr>
<th></th>
<th>Sums of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grand mean</td>
<td>0.5712</td>
<td>1</td>
<td>0.5712</td>
<td>93.48</td>
<td>0.001</td>
</tr>
<tr>
<td>Range</td>
<td>0.0032</td>
<td>1</td>
<td>0.0032</td>
<td>0.53</td>
<td>0.472</td>
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<tr>
<td>Test format</td>
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<td>0.0064</td>
<td>1.05</td>
<td>0.312</td>
</tr>
<tr>
<td>Number of problems</td>
<td>0.0187</td>
<td>1</td>
<td>0.0187</td>
<td>3.06</td>
<td>0.088</td>
</tr>
<tr>
<td>Range X test format</td>
<td>0.0153</td>
<td>1</td>
<td>0.0153</td>
<td>2.51</td>
<td>0.121</td>
</tr>
<tr>
<td>Range X number of problems</td>
<td>0.0006</td>
<td>1</td>
<td>0.0006</td>
<td>0.10</td>
<td>0.759</td>
</tr>
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<td>Test format X number of problems</td>
<td>0.0002</td>
<td>1</td>
<td>0.0002</td>
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<td>0.844</td>
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<td>Total</td>
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<td>46</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10. Analysis of variance of linear component of reaction times after log 10 transformation.
<table>
<thead>
<tr>
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<th>Sums of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grand means</td>
<td>1011.77</td>
<td>1</td>
<td>1011.77</td>
<td>20041.84</td>
<td>0.001</td>
</tr>
<tr>
<td>Range</td>
<td>0.0813</td>
<td>1</td>
<td>0.0813</td>
<td>1.61</td>
<td>0.212</td>
</tr>
<tr>
<td>Test format</td>
<td>11.0057</td>
<td>1</td>
<td>11.0057</td>
<td>218.01</td>
<td>0.001</td>
</tr>
<tr>
<td>Number of problems</td>
<td>0.0291</td>
<td>1</td>
<td>0.0291</td>
<td>0.58</td>
<td>0.452</td>
</tr>
<tr>
<td>Range X test format</td>
<td>0.0920</td>
<td>1</td>
<td>0.0920</td>
<td>1.82</td>
<td>0.185</td>
</tr>
<tr>
<td>Range X number of problems</td>
<td>0.0045</td>
<td>1</td>
<td>0.0045</td>
<td>0.09</td>
<td>0.766</td>
</tr>
<tr>
<td>Test format X number of problems</td>
<td>0.0583</td>
<td>1</td>
<td>0.0583</td>
<td>1.16</td>
<td>0.289</td>
</tr>
<tr>
<td>Range X test format X number of</td>
<td>0.0085</td>
<td>1</td>
<td>0.0085</td>
<td>0.17</td>
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<td>problems</td>
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</tr>
<tr>
<td>Error</td>
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<td>0.0505</td>
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</tr>
<tr>
<td>Total</td>
<td>1024.9677</td>
<td>46</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Table 11. Analysis of variance of quadratic component of reaction times after log 10 transformation.
Table 12. Mean choice reaction times to make a correct decision at each ordinal position distance by range and test format for predominant transposers only.
Figure 5. Mean choice reaction times at each distance level for wide and narrow range stimuli in the figure condition (4a) and the name condition (4b).
As Figure 5b illustrates, the level of difficulty in making the discrimination appears about equal for both wide range and narrow range stimuli in the name condition.

Cognitive Tests

Means and standard errors on each of the cognitive tests for predominant transposers and predominant non-transposers are presented in Table 13. There were no significant differences between the two groups on any of the tests.

Correlations among the tests are presented in Table 14 for predominant transposers and predominant non-transposers.

A maximum likelihood factor analysis yielded two factors for the predominant non-transposer group. The two factors together accounted for 42.59% of the total variance. The factor loadings following a varimax rotation are presented in Table 15.

The tests with the highest loadings on Factor I are Vocabulary, Things, Mental Rotations, and Word Beginning and Endings, all of which have loadings greater than .500. A fifth test, Figure Memory, loads higher on Factor I than Factor II although the loading is less than .500. This is very clearly a verbal factor since all the verbal tests load highly on it. But the high loadings of Mental Rotations and Figure Memory indicate that this factor also encompasses abstract operations. Only one test, Visual Memory, has a loading greater than .500 on Factor II. One other test, Delayed Visual Memory, loads higher on Factor II than on Factor I although the loading is less than .500. Thus, this factor encompasses only concrete visual memory.

A maximum likelihood factor analysis also yielded two factors for the predominant transposer group. The two factors together account for 41.10% of the total variance. The factor loadings following a varimax rotation are presented in Table 16.
Table 13. Means and standard errors on each test for transposers and non-transposers. Forty-seven subjects in each group.

<table>
<thead>
<tr>
<th>Test</th>
<th>Transposers</th>
<th>Non-transposers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\bar{x}$</td>
<td>SE</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>14.6</td>
<td>0.432</td>
</tr>
<tr>
<td>Vocabulary</td>
<td>39.3</td>
<td>1.462</td>
</tr>
<tr>
<td>Figure Memory</td>
<td>11.4</td>
<td>0.525</td>
</tr>
<tr>
<td>Things</td>
<td>34.6</td>
<td>1.929</td>
</tr>
<tr>
<td>Mental Rotations</td>
<td>24.1</td>
<td>1.165</td>
</tr>
<tr>
<td>Word Beginnings and Endings</td>
<td>19.6</td>
<td>0.959</td>
</tr>
<tr>
<td>Delayed Visual Memory</td>
<td>10.7</td>
<td>0.530</td>
</tr>
<tr>
<td>Test</td>
<td>VM</td>
<td>VOC</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>0.060</td>
<td>0.300</td>
</tr>
<tr>
<td>Vocabulary</td>
<td>-0.079</td>
<td>-0.104</td>
</tr>
<tr>
<td>Figure Memory</td>
<td>0.159</td>
<td>0.269</td>
</tr>
<tr>
<td>Things</td>
<td>-0.079</td>
<td>0.461</td>
</tr>
<tr>
<td>Mental Rotations</td>
<td>-0.100</td>
<td>0.360</td>
</tr>
<tr>
<td>Word Beginnings and Endings</td>
<td>0.184</td>
<td>0.402</td>
</tr>
<tr>
<td>Delayed Visual Memory</td>
<td>0.425</td>
<td>0.057</td>
</tr>
</tbody>
</table>

Table 14. Correlations among cognitive tests for predominant non-transposers below the diagonal and for predominant transposers above the diagonal.
<table>
<thead>
<tr>
<th></th>
<th>Factor I</th>
<th>Factor II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Memory</td>
<td>-0.091</td>
<td>0.996</td>
</tr>
<tr>
<td>Vocabulary</td>
<td>0.694</td>
<td>-0.016</td>
</tr>
<tr>
<td>Figure Memory</td>
<td>0.391</td>
<td>0.196</td>
</tr>
<tr>
<td>Things</td>
<td>0.621</td>
<td>-0.022</td>
</tr>
<tr>
<td>Mental Rotations</td>
<td>0.578</td>
<td>-0.048</td>
</tr>
<tr>
<td>Word Beginnings and Endings</td>
<td>0.576</td>
<td>0.237</td>
</tr>
<tr>
<td>Delayed Visual Memory</td>
<td>0.095</td>
<td>0.435</td>
</tr>
</tbody>
</table>

Table 15. Rotated factor loadings on two cognitive factors for predominant non-transposers.

<table>
<thead>
<tr>
<th></th>
<th>Factor I</th>
<th>Factor II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Memory</td>
<td>0.095</td>
<td>0.695</td>
</tr>
<tr>
<td>Vocabulary</td>
<td>0.725</td>
<td>-0.058</td>
</tr>
<tr>
<td>Figure Memory</td>
<td>0.058</td>
<td>0.495</td>
</tr>
<tr>
<td>Things</td>
<td>0.513</td>
<td>0.027</td>
</tr>
<tr>
<td>Mental Rotations</td>
<td>0.137</td>
<td>0.297</td>
</tr>
<tr>
<td>Word Beginnings and Endings</td>
<td>0.844</td>
<td>0.454</td>
</tr>
<tr>
<td>Delayed Visual Memory</td>
<td>-0.101</td>
<td>0.555</td>
</tr>
</tbody>
</table>

Table 16. Rotated factor loadings on two cognitive factors for predominant transposers.
All three verbal tests, Vocabulary, Things, and Word Beginnings and Endings, have high loadings on Factor I. All of the loadings are greater than .500. No other tests have high loadings on this factor. For predominant transposers, therefore, Factor I is limited to verbal processes. Two tests, Visual Memory and Delayed Visual Memory, had loadings greater than .500 on Factor II. Figure Memory and Word Beginnings and Endings also loaded highly on Factor II with loading of .495 and .454, respectively. Mental rotations loaded higher on Factor II than on Factor I (.297 and .137, respectively). Although the loading of mental rotations on Factor II is small, it is nevertheless significant (alpha = .05, t = 2.036, df = 46). Therefore, mental rotations is included in the interpretation of Factor II. For predominant transposers, Factor II encompasses both concrete and abstract visual operations.

For both predominant transposers and predominant non-transposers, the proportion of total variance accounted for by the two factors underlying the tests was about equal as can be seen from Table 17.

That these seven tests yield two factors that are similar for both groups is not surprising since the tests were purposefully drawn from only the verbal and visual domain. In order to determine how similar, a salient variable index (s) was calculated. The s index is recommended by Cattell et al. (1969) and Levine (1977). However, s is most valid when there is a lot of "hyperplane stuff"; that is, when, for any factor, a large number of variables fall into the hyperplane. The value of s increases and factors may appear more similar than they really are when there are only a few variables in the hyperplane.

Cattell et al. score any variable with a loading between -.10 and .10 as a hyperplane variable. Variables with any other loadings are considered salient. Applying this criterion to the loadings in Tables 15 and 16, there would be very few hyperplane variables but there would be some variables with salient but non-
<table>
<thead>
<tr>
<th></th>
<th>Factor I</th>
<th>Factor II</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transposers</td>
<td>0.220</td>
<td>0.191</td>
<td>0.411</td>
</tr>
<tr>
<td>Non-transposers</td>
<td>0.243</td>
<td>0.183</td>
<td>0.426</td>
</tr>
</tbody>
</table>

Table 17. Variance on cognitive tests accounted for by two factors for each group.
significant loadings. In order to maximize the hyperplane stuff and make s more valid, a different criterion was adopted: a variable was considered to fall into the hyperplane if it had a non-significant loading. Loadings between -.296 and .296 were nonsignificant. The s index was then calculated according to the formula supplied by Cattell et al. For the verbal factor (I) the value of s was .75; for the visual factor (II) the value of s was .57. Both values are high indicating, as expected, that the factor structures for transposers and non-transposers are similar. But the similarity is far from perfect, especially for the visual factor (II). There is no way to determine whether or not the observed values of s are larger than would be expected by chance because both the number of variables and the percent of variables in the hyperplane are lower than the minimum values for entering the probability tables constructed by Cattell et al. (1969).

**Criterion of Learning**

Two hypotheses about speed of learning were tested: First, that there was no difference between transposers and non-transposers in the number of trials required to reach criterion on the training phase; and, second, that number of problems in training did not affect the number of trials required to reach criterion. The criterion of learning was four consecutive correct trials.

The results of an analysis of variance are presented in Table 18. Only the main effect of number of problems in training was significant ($F_{1,90} = 5.70$, $p = .0191$). Cell statistics and comparisons of mean differences between one and two problems in training are presented in Table 19. The alpha level per comparison was set at .025 ($c = 1 - \sqrt{1 - .05}$). The values of $t$ and $d$ indicate that the effect of two problems in training was to significantly increase the number of trials required by non-transposers to reach criterion.
<table>
<thead>
<tr>
<th>Source</th>
<th>Sums of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>0.08739</td>
<td>1</td>
<td>0.08739</td>
<td>0.00</td>
<td>0.979</td>
</tr>
<tr>
<td>Number of problems</td>
<td>727.27162</td>
<td>1</td>
<td>727.27162</td>
<td>5.70</td>
<td>0.019</td>
</tr>
<tr>
<td>Group x number of problems</td>
<td>326.31977</td>
<td>1</td>
<td>326.31977</td>
<td>2.56</td>
<td>0.113</td>
</tr>
<tr>
<td>Error</td>
<td>11493.06703</td>
<td>90</td>
<td>127.70074</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12546.746</td>
<td>93</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 18. Analysis of Variance of number of trials to reach criterion for transposers and non-transposers with training on one or two problems.
Table 19. Cell means, standard errors and sample sizes on number of trials to reach criterion of learning for transposers and non-transposers.

<table>
<thead>
<tr>
<th></th>
<th>Non-Transposers</th>
<th>Transposers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.E.</td>
</tr>
<tr>
<td>One problem</td>
<td>7.5</td>
<td>1.145</td>
</tr>
<tr>
<td>Two problems</td>
<td>16.8</td>
<td>3.36</td>
</tr>
<tr>
<td>t</td>
<td>2.815</td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>.01</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>.933</td>
<td></td>
</tr>
</tbody>
</table>
IX. DISCUSSION

One important result of this experiment is that exactly 50 percent of the subjects who completed the experiment learned the relationship and 50 percent learned the absolute stimulus configuration. This raises the first question. Why did not more subjects transpose? Extrapolating from developmental studies which show increasing transposition as a function of age, a reasonable expectation is that mature subjects should make few or no absolute responses. In fact, however, there is very little agreement about the nature of transposition in adults (Zeiler, 1964). Some studies have concluded that adults attend more to absolute stimulus properties than to relationships while others have concluded just the opposite. In any case, Zeiler points out that procedure and design factors in most studies of adults preclude any definite conclusions. In order to proceed, therefore, the assumption that adults should transpose will be accepted and possible explanations for the failure to transpose will be examined.

First, there were procedural variables and parameters that distinguish this experiment from other transposition experiments. One important variable is the factor of test format. Subjects who were tested with the names of the stimuli rather than with figures as they had been trained were, in effect, being tested on their ability to make a double transposition. In other words, subjects who responded relationally transferred their response (a) from one stimulus to another, and (b) from a visual modality to a verbal modality. The transfer from one modality to another appears to have been difficult for some subjects as indicated by the significantly lower percentage of relational responding in the names condition.

A relevant parameter of this experiment was the paired associate learning task before the transposition procedure. Learning a name for each square probably served to direct attention to the distinguishing features of each stimulus
and, thus, assist the learning of absolute stimulus configurations. Stimuli were also distinguishable from each other by the relationship between the square, which changed in size, and the diamond in the center, which did not change.

One explanation for the occurrence of transposition was put forth by Washburn (1926) who suggested that subjects transpose because they fail to notice the change in stimuli from the training phase to the test phase. The effect of making stimuli distinguishable is to increase the likelihood that the change in stimuli will be noticed. It can be argued that the change in modality from visual to verbal is one which cannot escape notice. However, the subjects were forewarned in the instructions that stimuli could be presented in either verbal or visual form. It was hoped that the subject's internal representation of the stimuli would be the same regardless of modality. Therefore, it is possible that subjects did not notice a change in the informational content of the stimuli even though the format of presentation had changed.

In any case, the data provide some evidence that contradict Washburn's hypothesis. The change in stimuli ought to be more noticeable on those trials in which the ordinal position distance increases as in the triads at steps 4 and 5. Thus, according to Washburn's hypothesis, there should be a decrease in transposition on those trials. In fact, the percentage of transposition increases for both predominant transposers and predominant non-transposers as can be seen from Figure 2 and 3 and Table 2. Therefore, the low percentage of transposition among half of the subjects is not explained by an awareness of change in the stimuli.

Differences in representational structure may explain the greater tendency toward absolute responding in some subjects and relational responding in others. The cognitive organization of both predominant transposers and predominant non-transposers involved a verbal factor and a visual factor. However, there were differences in the interpretation of the factors for each group.
The first factor for non-transposers seems to involve greater cognitive complexity than the second. An interpretation of the first factor is that most processes of abstraction are carried out in the verbal mode. This interpretation is supported by the high loadings of mental rotation and figure memory tests on this factor in addition to the high loadings of the verbal tests. In contrast, only concrete operations of memory are carried out in the visual mode.

Based on the factor structure, a reasonable description of non-transposers is as follows: The primary mode of thinking for these subjects is verbal. Most mental operations, including reasoning and abstraction are carried out verbally. The visual modality on the other hand is highly involved only in concrete visual memory. For these subjects the operation of memory is very much as Plato described it; that is "...whenever we wish to remember something we see or hear or conceive in our own minds, we hold this wax under the perceptions or ideas and imprint them on it as we might stamp the impression of a seal ring" (Plato, Theaetetus, 191d). These subjects may experience very vivid visual imagery, and at the same time, they may experience very little control over their imagery.

This interpretation gets support from a post hoc analysis of the rate of acquisition of the response in the training phase and from subject's own descriptions of their thinking processes obtained in informal discussions after the experiment. The ease with which non-transposers learned the response in the one-problem condition versus the difficulty experienced in the two-problem condition suggests that the stimulus properties were acquired in a manner analogous to an imprint of a seal in wax.

Consider that on initial exposure to the stimuli in the training phase the chances of guessing the correct stimulus and receiving reinforcement are one out of three. The average number of trials to make the first correct guess is only two and, if learning is complete after the first correct trial, the average number of
trials needed to reach a criterion of four consecutive correct responses is only five. In the one problem condition, non-transposers required an average of only seven and a half trials to reach criterion, very close to the minimum expected number when allowing for error. Therefore, it can be concluded that, with the first experience of reinforcement, the absolute stimulus characteristics are stamped into the memory of non-transposers.

If this is so, then subjects exposed to two-problems in training can be expected to face considerable interference in learning the second problem as a result of having a vivid memory trace of the correct stimulus in the first problem. Indeed this was the case, as indicated by the large number of trials required by non-transposers to reach criterion in the two-problem condition.

A vivid memory trace of the absolute stimulus qualities caused similar interference in the test phase of the transposition experiment. Non-transposers frequently expressed confusion because the stimulus they had learned in training was absent from many of the trials.

Subject's own reports provide additional confirmation of their ability to retain information as vivid visual memory traces. One subject, a non-transposer, reported that she prepares for exams by imprinting eight to ten pages of notes in memory and then "reading" them off during the exam. Another subject, also a non-transposer, reported a similar practice when performing music.

The two factors for transposers appear to be about equal in complexity. An interpretation of the cognitive structure of transposers is that processes of reasoning and abstraction are carried out in both modes. The verbal mode involves word knowledge and fluency. The visual mode involves visual memory, for both concrete and abstract items, and spatial ability. Furthermore, the Word Beginning and Endings test involves a verbal component and, to a lesser extent, a visual component. The loading of this test on the visual factor suggests that these
subjects use visualization of words in solving the problem. Most likely this visualization is used in normal spelling operations.

The visual factor of these subjects includes both of the components previously identified as being a part of visual imagery, vividness, operationally defined as memory, and control, operationally defined as spatial ability. Although there were no mean differences between transposers and non-transposers on the memory tests, the richer imagery of the transposers appears to have some consequences for the development of a memory trace. The post hoc examination of the acquisition of the response indicates no differences in rate of learning when presented with one problem or two problems in training. Put another way, the two problem condition did not interfere with the learning of the response for transposers as it did for non-transposers. It must be remembered that transposers learned a relational response and non-transposers learned an absolute response so that direct comparisons are not possible. Nevertheless, the analysis suggests that, for subjects who learned the relational response, the wax imprint is not an appropriate metaphor of learning and memory. This may be due to the richer imagery which attenuates the vividness of the internal representation or which increases the salience of other parts of the representation.

Sex is an important consideration in discussions of cognitive abilities. The results of the present experiment may shed some light on previous research findings. The important findings to consider are first, the report that females have greater vividness of imagery than males (Galton, 1883; White, Sheehan, & Ashton, 1977); second, the report that, in adolescence and maturity, females surpass males in verbal ability (Jensen, 1980); and third, the report that males surpass females in spatial ability (McGee, 1978). Maccoby and Jacklin (1974), after an extensive literature review, reported that it was "well established" that
girls have greater verbal ability than boys, and boys have better visual-spatial ability than girls.

These sex related findings suggest some linkage between the three abilities. In the first place, it suggests that verbal processes and imagery vividness are somehow related since high ability in both tend to be found in the same population. In the second place, it suggests that spatial problems are handled in different ways by different populations. Females in the aggregate tend to have superior verbal abilities and greater vividness of imagery but inferior spatial ability while the opposite is true for males. The differences between males and females in these abilities may reflect differences in the preferred mode of information processing. Perhaps females invest more intellectual functions in the verbal mode than in the visual mode leaving the visual mode specialized for visual memory. Spatial processing might be more intimately tied to verbal tasks as Ernest (1977) suggests and memory traces might appear more vivid.

In the present experiment, the cognitive constructs of non-transposers resemble those hypothesized for females: more intellectual functions, including spatial ability, are invested in the verbal mode; and only visual memory remains in the visual mode. The lack of sex differences in transposition may be due to unique characteristics of the population sampled. That is, most of the subjects were liberal arts students for whom successfully performing verbal tasks is an important ability regardless of sex. Or it may be due to vagaries of sampling.

The preferred explanation, however, is that the lack of significance is due to sample size. Hyde (1981) reviewed the studies cited by Maccoby and Jacklin and applied meta-analysis techniques to them. Of the 27 studies of verbal ability, 20 had sample sizes of 100 or more. For visual-spatial ability, nine of twelve studies had sample sizes of 100 or more. Large sample sizes can yield significant results with small effect; conversely, small sample sizes may result in a failure to find
significant differences with moderate or large effects. Therefore, effect size is an important consideration. And it appears that the failure to find a significant gender effect in transposition was due to the small sample size coupled with the small to moderate effect size. Nevertheless, the effect is within the range of the size of the gender effect on cognitive tasks in the population as a whole as will be shown.

Hyde (1981) calculated the effect size of the studies cited by Maccoby and Jacklin (1974). She found that the median size of the gender effect for verbal ability was .24. For visual-spatial ability the median size of the gender effect was .45. These are comparable to the average size of the gender effect for transposition which was .41. It can be concluded that the gender effect for relational learning is nearly equal to the gender effect for visual-spatial abilities and that the source of the effect for both relational learning and visual-spatial abilities lies in the internal representational structure. The effect is so small, however, that it would seem to have few theoretical consequences and little or no practical consequences.

Non-transposers were characterized as having invested the verbal mode with most intellectual operations. Transposers, on the other hand, apparently invest the visual mode with more, although not all, intellectual operations. This suggests that transposers and non-transposers differ along the cognitive dimension of verbalizer-visualizer.

Verbalizer-visualizer is an attractive hypothesis because it seems to have a long history in cognitive research (Griffitts, 1927; Roe, 1951); it has important implications for understanding the evolution of intelligence (Jerison, 1977); it appears to have a physical anchor in hemispheric lateralization (Kinsbourne, 1972; Kocel et al., 1972); and, it has figured prominently in recent literature on mental
imagery (A. Richardson, 1977b). But, it does not explain the cognitive or behavioral differences between transposers and non-transposers.

If non-transposers are verbal, where on the scale are transposers? They are more visual than non-transposers, but clearly they do not occupy an extreme position on the dimension as it is usually conceived. Rather they seem to occupy a middle position. But, there are no extreme visualizers, due in part, to the fact that there are only two groups. In the absence of an extreme visualizer group, it might be appropriate to divide the scale in half and assign non-transposers to the verbal half and transposers to the visual half, but this runs the risk of oversimplifying a complex dimension.

Subject responses during the interview following the experiment do not support a relationship between the verbalizer-visualizer dimension and the occurrence of transposition. In response to the question "Do you think in words or pictures?", subjects in approximately equal numbers indicated words, pictures, or both, regardless of whether they were found to have predominantly transposed or not. Subjects responses, of course, are not very discriminating and about half said they did not know. Nevertheless, non-transposers who report very vivid memory images do not wear the verbalizer label well. These subjects would probably answer in the affirmative to questions such as "My thinking often consists of mental pictures or images" and "My powers of imagination are higher than average." Such questions and others were used by A. Richardson (1977b) to classify subjects as verbalizers or visualizers.

Finally, the failure of the cognitive test means to discriminate between transposers and non-transposers is discouraging for the verbalizer-visualizer hypothesis. If transposers are visualizers, their visualization ability, as indicated by scores on the visual tests, ought to be superior to that of non-transposers. But, it is not. Likewise the verbal ability of non-transposers indicated by scores on the
verbal tests ought to be superior to that of transposers. But it is not. Observed mean differences on tests in the visual and verbal domains are a necessary criteria for classifying transposers and non-transposers on the verbalizer-visualizer dimension. In the absence of mean differences the verbalizer-visualizer dimension, as an explanatory theory, can be discarded.

But that does not deny the relevance of verbal and visual modes of representation to the outcome of this experiment. It does suggest, however, that a theory that emphasizes the fundamental unity of mind rather than its specializations will offer a better explanation.

**Dual Coding Theory**

Paivio (1971) proposed a theory which views images and verbal processes as alternative coding systems or modes of representation. Imagery is a representational system for nonverbal information characterized as being concrete and analogic. It is distinct from the representational system for verbal information characterized as being abstract and logical. Although these are separate and distinct modes, they are never the less interrelated. The theory, in more detail, follows (Paivio, 1978):

The theory assumes that cognitive behavior is mediated by two independent but richly interconnected symbolic systems, which are specialized for encoding, organizing, transforming, storing, and retrieving information. One (the image system) is specialized for dealing with perceptual information concerning nonverbal objects and events. The other (the verbal system) is specialized for dealing with linguistic information. The systems differ in the nature of the representational units, the way the units are organized into higher
order structures, and the way the structures can be reorganized or transformed. (p. 379)

The image and verbal systems have also been contrasted as being synchronically organized versus sequentially organized (Paivio, 1975a). Synchronous organization means that multiple items of information can be combined rapidly into integrated visual units in memory. No constituent information is lost in the image process. Words, on the other hand, are sequentially combined or concatenated into linear structures for storage in memory. The verbal system is subject to sequential constraints that are not characteristic of the image system. The consequences for thought when information is stored synchronically are different than when information is stored sequentially.

One such constraint is in the potential for partial information loss. Consider, for example, the concepts symbolized by the words "white" and "horse". These could be integrated into an image or they could be concatenated into a verbal string for storage in memory. Sequential information loss is like a transmission error or a problem of insufficient storage in which only part of the information is transmitted or stored. If storage space is insufficient one of the words might be stored but not the other. Or, if there is an error in transmission, one of the words might be retrieved but not the other. Whatever the actual mechanism might be, there is a greater likelihood of loss of one of the concepts ("white", for example) when the information is represented sequentially in a verbal mode than when it is represented synchronically in an image mode. There is ample evidence from paired-associate learning experiments to support this (Bugelski, 1970; Paivio, 1971; Bower, 1972; J. T. E. Richardson, 1980). Of course
both verbal and image representations are subject to trace decay in storage and information loss through other mechanisms.

Another constraint is upon the efficiency of storage. There should be little difference in ease of encoding simple concrete items as either words or images. Even a small set of items could be encoded as images or word strings. But with more items in the set information can be encoded in an imagery mode more rapidly and more efficiently (in terms of amount recalled) than in a verbal mode. This is the result of the synchronous organization. Things can be joined together in a variety of ways to form a meaningful image. But the sequential nature of the verbal mode does not allow a similar degree of freedom to construct higher order structures. Paivio (1975a) summarizes experimental evidence in support of this. The verbal mode, on the other hand, has an advantage in retrieving sequential items from memory. This makes the verbal mode especially suited for logical thinking (Paivio, 1975a).

Although the emphasis so far has been on the differences between imagery and verbal processes, they are clearly interconnected in cognition. Images may elicit verbal descriptions and concrete words may evoke images. According to Paivio "...activity in one system can initiate and guide activity in the other without necessarily determining the nature of that activity in a point-by-point position" (1975b, p. 277). This implies first that information presented in one or another format (pictures or words) may be encoded concurrently in both cognitive modes, and second, that the two representations may contain somewhat different content as a result of the different specialization of each mode.

Dual coding theory offers the best explanation of the behavior of subjects in the transposition experiment. The representational structure of transposers suggests that they are able to represent information in either mode with equal facility. More importantly, the reaction time data indicates that transposers
represented the relational information in both modes. The format of the test stimuli seems to have served a cueing function, directing subjects to one mode or the other from which to extract the information needed to make a decision. To put it another way, subjects employed an imagery mediator when the test stimuli were figures and a verbal mediator when the test stimuli were names.

This inference is based on the assumption that the relation between an image and a percept is that of second-order isomorphism. That is, that the response to a stimulus when it is not there should resemble the response to the actual stimulus if an image of the stimulus mediates the response. In this experiment, the response to the names does not resemble the response to the figures, as indicated by the significant effect of test format on the quadratic component of the reaction time data. The fact that there is no trend when names are presented and a quadratic trend when figures are presented indicates either that there is no second-order isomorphism between the image and the percept or that the mediator is different in the two conditions. A closer examination of the data supports the latter.

Reaction times should be slower when discrimination among stimuli is more difficult. It was expected that it would take longer to choose among narrow range stimuli than among wide range stimuli if the mediator was a visual image. In neither the figures condition nor the names condition was the difference between reaction time to wide and narrow range stimuli significant. However, in the figures condition, the difference is in the right direction (i.e., reaction time is faster for wide range stimuli) and the average effect is large. This is not true of the names condition in which the difference is in the opposite direction (i.e., reaction time is faster for narrow range stimuli), but the distributions overlap so much and the effect size is so small that it is very unlikely that they come from different populations.
The interpretation that the mediator in the names condition is verbal comes from the lack of difference in decision time between wide and narrow stimuli. This is based on an assumption that the verbal code contains no size information that would make discrimination with one set of stimuli more difficult than with another. That is, a verbal mediator that takes the form of a statement of the relationship (e.g., "It's the middle size") is blind with regard to the absolute size of the stimuli that are being discriminated. Thus, a verbal mediator ought to be identical for the two levels of size range of the stimuli and the consequent response should also be identical. Based on the similarity of reaction times in the two levels of range, a reasonable conclusion is that the responses in the names condition were mediated by a verbal process.

Additional support for this interpretation comes from the lack of a significant trend towards faster reaction times with increasing ordinal position distance. Just as a verbal mediator is not specialized for encoding absolute sizes of the stimuli, neither is it specialized for coding relative size differences among stimuli. That is, the increase in distance between elements of a stimulus configuration should have no effect upon the response when it is mediated by a verbal process. One exception to this is if the names of the stimuli are stored in memory along with ordinal information. An example is the following: YAV = smallest, ZEJ = small, QOH = medium/small, etc. Decision time could be reduced if a stimulus configuration contained either or both of the largest and smallest elements. In the present experiment the largest stimulus was one of the three at an ordinal position distance of one; and both largest and smallest were part of the configuration at an ordinal position distance of two. Thus, some decrease in decision time could be expected even with a verbal mediator. The decrease observed in this experiment, however, does not appear to be greater
than could be expected by chance so inferences about the content of the information encoded verbally cannot be made.

The data on percentage of transposition also contains evidence of two separate representational codes. Training on multiple problems is thought to increase the amount of transposition by making the relational information more salient. The results indicate that the two problem training did yield a greater percentage of transposition than one problem training for subjects who were tested on figures but not for subjects who were tested on names. Assuming, again, that the format of the test cued the representation from which information was obtained, these differences may be interpreted as evidence for two different codes.

The dual code theory specifies than an image stores information in a synchronic, analogic fashion. During training with only one problem, an analogue representation of the stimulus would be built up in memory against which the test stimuli would be matched. The analogue representation however would contain both relational information and absolute information so a match could be made on the basis of either type of information. During training with two problems, two analogue representations would be built up in memory simultaneously. Whether these remain separate but concurrent representations or whether they combine into a hybrid representation on the basis of common information cannot be determined. In either case, a comparison with the test stimuli will result in a match being made only on the relational information. Thus, the relational information is made more salient in the image following two problem training.

The verbal code stores information in a sequential, logical fashion. The correct stimulus could be named in memory or it could be described. Since the only unique characteristic of each stimulus was its size, a verbal description would have to be based on size information. The mode of presentation made
anything but relative size information difficult, however, so the most likely codes would be the name or the relation. During the test the same codes would be extracted and matched with the representation in memory. If the representation was the relation, transposition would result; if the representation was the name, an absolute response would result. The representation however would not be any different following two problems of training. The information that would be extracted would be either the two names or the relative size information. Depending upon the information that was stored subjects would be either predominant transposers or predominant non-transposers, but there would be no differences among transposers in content of memory following one or two problems in training.

A prediction derived from the dual code theory, therefore, is that multiple problems in training enhance the salience of the relational information in one memory representation but not in the other. This is the result of the organization of information in the two representational systems. The different percentages of transposition associated with number of problems in the figural condition, but not in the names condition, allow the inference that information is coded in two separate representational systems: one analogic and synchronic, and the other logical and sequential.

Common Code Theory

A plausible alternative to the dual code theory, the common or third code theory, has been put forth by several authors (Pylyshyn, 1973, 1981; Anderson & Bower, 1973; Anderson, 1978; Clark & Chase, 1972). These authors argue that visual information, including imagery, and verbal information are both encoded in the same format: an abstract network of propositions. The argument for propositional representations is based on three claims: First, the picture
metaphor of mental imagery is inadequate as a theoretical description of internal processes; second, a propositional representation is essential on independent grounds; and third, a propositional representation can handle all phenomena ascribed to both verbal and pictorial representation.

The picture metaphor of imagery is a convenient means of describing the phenomenological features that people report when they imagine an object. These reported features are similar to the properties of pictures. They have clarity, vividness, and spatial orientation. The implication is that a picture must be extracted from memory and then scanned to obtain meaningful information about objects and their relations. The objection of propositional theorists is that images do not behave in that way. Instead images come preinterpreted and organized. An individual is able to reproduce all or part of a scene depending upon the information required. And, if part of an image is forgotten, it is usually a meaningful part, unlike the arbitrary loss of information from a photograph with a torn corner.

In reply to this objection, some authors such as Bugelski (1977) and Kosslyn and Pomerantz (1977) claim that the picture metaphor is not taken seriously by proponents of imagery and that the attackers are slaying a straw man. Nevertheless, image theorists have found the picture metaphor to be both convenient and heuristic. Andersen (1978), an advocate of propositional representation, found nothing incoherent or contradictory in the use of pictures as a form of representation. He argued that there is no reason why perceptual output as well as imagery output should not be segmented and interpreted by the network of associations among the objects of imagination and perception. That there are intramodal associations is an important part of Paivio's (1978) dual code theory. Moreover, the results of this experiment suggest that the picture (or imprint) metaphor
offers an accurate description of the internal processes utilized by some subjects in certain, specified learning situations.

One of Pylyshyn's (1973) most important arguments is that a form of representation that is neither verbal nor imagistic is necessary to explain how people can describe pictures in words or create pictures to illustrate verbal material:

But the need to postulate a more abstract representation—one which resembles neither pictures nor words and is not accessible to subjective experience—is unavoidable. As long as we recognize that people can go from mental pictures to mental words or vice versa, we are forced to conclude that there must be a representation (which is more abstract and not available to conscious experience) which encompasses both. There must, in other words, be some common format or interlingua. (p. 5)

If Pylyshyn's theory were adopted it would be necessary to postulate an interlingua to account for the subject's abilities to respond correctly to names following training on figures.

But this argument has one logical flaw. It leads to an infinite regress since there would also be a need for an interlingua between either of the first two codes and the postulated third code. Kosslyn and Pomerantz (1977) agree that the transformational rules may be necessary to solve the translation problem, but they say that these rules need not represent specific knowledge as Pylyshyn suggests. Instead, they need only contain procedures for taking information in one format and reproducing it in another. Kosslyn and Pomerantz also argue that Paivio's dual code theory which proposes rich interconnections between codes is
sufficient to account for all perceptual and response capacities, thus giving it an advantage of parsimony over the third code theory.

Propositions, it is argued, can represent any well-specified set of information, be it information from an image, a sentence, or any other source. There is no denying the experience of imagery. What is at stake is whether imagery is sufficient as a primitive construct or whether it can be reduced further. One widely held opinion is that neither imagery nor verbal processes are sufficiently reduced and that both can be reduced to propositions. Computer simulations and post hoc analyses of some imagery experiments have been cited in support of the reducibility of imagery and verbal processes.

But, if propositions can encode all of the information that imagery and verbal processes can encode, how does one choose between the two theoretical positions? Although it was claimed that the dual-code theory best explains the data in this experiment, propositional theorists would assert that third code theory could explain it equally well. According to some, the problem may have no solution.

Kosslyn and Pomerantz (1977) reviewed empirical evidence purporting to support the common code theory. They considered two theoretical positions, the dual code theory, and a weaker version which accepts the necessity of propositions. They concluded that there was no reason to discard imagery as a theoretical construct nor could an appeal to a propositional format account for all imagery phenomena. Nevertheless, they decided that they were unable to discriminate between the weak and strong positions on the role of mental imagery.

Anderson (1978) adopted an agnostic position with regard to the form of representation. He decided that all evidence cited in support of a particular representation was actually evidence for a particular process operating upon the
representation. Moreover, he concluded that psychologists cannot decide between alternative representations on the basis of behavioral data:

It is not possible for behavioral data to decide uniquely issues of internal representation. The reason is that one cannot just test questions about a representation in the abstract. One must perform tests of the representation in combination with certain assumptions about the processes that use the representation. That is, one must test a representation-process pair. One can show that, given a set of assumptions about an image representation and a set of processes that operate upon it, one can construct an equivalent set of assumptions about a propositional representation and its processes. Or one can be given a propositional theory and construct an equivalent imagery theory. In fact, it is possible to establish a more general claim: given any representation-process pair it is possible to construct other pairs with different representations whose behavior is equivalent to it. These pairs make up for differences in representation by assuming compensating differences in the processes. (p. 263)

If Anderson is correct, then the differences in reaction time as a function of test format have to be considered as evidence for different processes rather than different representations. A plausible alternative to the dual code theory can be constructed by assuming that the middle size information is represented propositionally and the test format cues one of two possible retrieval processes. Rather than encoding the information twice and storing it independently as implied by the dual code theory, the information is encoded once and stored once as a proposition. The imagery process and the verbal process can be thought of as
two separate pathways for retrieving information from memory. Since the verbal pathway is the same for both levels of range, it would follow that there would be no reaction time difference between the two levels. And, indeed, there were none. However, the two levels of range could be thought to have an effect upon the efficiency of the imagery pathway, such that retrieval is easier when the pathway is wide and harder when it is narrow. Thus there should be an advantage for wide range over narrow range in the figures format. The conclusion, then, is that the reaction time data points to either two different representational formats or two different processes operating upon a common representation. But the data is inadequate to distinguish between the two.

The differences in percentage of transposition as a function of format and number of problems in training, however, make it possible to choose between theoretical positions. The effect of multiple problems in training is to increase the salience of the middle size stimulus because only the relational response is consistently reinforced; whereas, in single-problem training both the relational response and the absolute response are consistently and simultaneously reinforced. From the point of view of information processing theory, the multiple-problem effect is one of modifying the information that is stored. In dual-code theory, the information is also modified by the format into which it is encoded. In propositional theory, however, the common format is capable of handling all information.

Following the dual code theory, the single-problem training would result in both absolute and relational information stored in an image format and either absolute or relational information stored in a verbal format. The multiple-problem training would result in relational information stored in an image format and either absolute or relational information stored in a verbal format. This logic was discussed above.
Following propositional theory, the single-problem training would result in both absolute and relational information stored in memory. The multiple-problem training would result in only relational information being stored in memory. If the processes operating upon memory are independent of the representation, then relational information would be more likely to be retrieved following multiple-problem training than following single problem training regardless of the format of the retrieval process. This is because the salience of the relational properties of the stimuli is an attribute of the information that is stored, not of the process that retrieved the information. Both verbal and imagery processes are capable of retrieving relational or absolute information. So, there should be no difference in percentage of transposition as a function of test format and number of problems in training if the representation is a proposition.

But, the number of problems in training did make a difference in amount of transposition as a function of the format of the test. This could only happen if information were stored concurrently in two distinct modes with different patterns of organization as in the dual code theory.

The data on percentage of transposition support the following two assertions. First, Anderson's epistemological agnosticism should not be adopted by cognitive psychologists. Instances can be found where dual code theory and propositional theory predict different experimental outcomes. Second, the results confirm the predictions made by dual-code theory. The data does not support the theory that information is represented as a proposition with two different processes operating on it. Rather the data support the theory that information is represented in two independent formats concurrently.
The Abstract Image Problem

The evidence that information is encoded and stored in two separate modes of representation comes from the data on transposers. But, what about non-transposers? Can dual-coding theory accommodate both transposers and non-transposers?

Non-transposers have been characterized as investing the verbal mode with most of the intellectual functions. Therefore, it would be very tempting to assert that non-transposers encode information in only one mode, the verbal mode, in contrast to transposers who encode information in two modes. But this is assuredly not the case. Non-transposers report images of a very vivid type. The difference between transposers and non-transposers appear to be primarily in the concrete nature of the non-transposers' imagery.

A theoretical explanation of the differences in cognition between the two groups requires an understanding of the relationships between the two representational systems within dual-coding theory. The theory assumes that they are functionally independent but interconnected. Because they are independent, cognitive activity can take place in one or the other modality alone, or they can both be concurrently active. At the same time, the system must be richly interconnected since we can name things, draw pictures in response to names and so on. The interconnections cannot be complete, however, because there are many things that we can't describe easily and there are many linguistic concepts that have no perceptual counterpart.

Paivio (1978) makes a logical analysis of the functional relations between the codes based on the idea of processing levels. He identifies three. The first is the representational level where the stimulus activates a corresponding symbolic representation or trace in long-term memory; words activate verbal representations and nonverbal objects or pictures activate imaginal representations. The
second is the referential level where the symbolic representations in one system activate corresponding symbolic representations in the other systems; imagined objects elicit names or descriptions and names evoke images. The third is the associative level which refers to associative connections among different verbal representations, as in word associations, and analogous associations between images.

Transposers and non-transposers could conceivably differ at any one of the three levels although for several reasons the most likely level of difference is the third or associative level. The first level describes operations that can be said to be primitive and probably universal. Few people would deny the experience of visual memory images. Nor could anyone function normally without linguistic memory. In this experiment there was no reason to suppose that transposers and non-transposers differed in either visual memory or linguistic memory unless the differences were very subtle. Since no mean differences were found on the visual memory and vocabulary tests, it can be assumed that the two groups did not differ at the representational level. Neither can they be said to differ at the second or referential level. The paired associate learning task required subjects to produce the name of a stimulus upon its presentation. Presumably, in this task, the stimulus evokes its corresponding image which elicits its name, a process occurring at the referential level. All subjects were required to reach the same level of criterion on this task; failure to reach criterion resulted in termination of the experiment. So, differences between transposers and non-transposers at the referential level do not seem likely.

The third level, the associative level, is where the transposers and non-transposers may be distinguished. However, this is an inference that does not derive from data but from eliminating the other levels as the locus of the difference.
According to Paivio (1978), the processes that occur at the associative level resemble word association in the verbal mode and an analogous function in the imagery mode. But whatever the imagery analogue to word association might be, it is unspecified. Another associative function suggested by Paivio but not elaborated upon is a categorical function as in the association between "cat" and "animal" and "dog" and "animal". This function could also be considered one of abstraction or generalization. "Cat", "dog", and "animal" are linguistic concepts. Corresponding images can be formed of cats and dogs; but can images be formed that correspond to "animal"? That is, can an abstract or generalized image be formed? Paivio seems to be uncertain about this as do others (for example, Kosslyn, 1980).

At any rate the problem is not a new one and some have answered affirmatively while others have answered negatively. The issue has often been known as the triangle problem because John Locke (1690) formulated it as follows:

For when we nicely reflect upon them, we shall find that general ideas are fictions and contrivances of the mind, that carry difficulty with them, and do not so easily offer themselves as we are apt to imagine. For example, does it not require some pains and skill to form the general idea of a triangle, (which is yet none of the most abstract, comprehensive, and difficult) for it must be neither oblique nor rectangle, neither equilateral, equicrural, nor scaleron; but all of these and none of these at once. In effect, it is something imperfect, that cannot exist; an idea wherein some parts of several different and inconsistent ideas are put together. (Book IV, Chapter 7:9)
Locke's imprecise language has caused some difficulties in interpreting this passage. For one, he uses "idea" in his writings in ways that do not always mean "image". But assuming that image is what he means, there remains a problem with the nature of the image. Is it a truly abstract representation that is "all of these and none of these at once"? Locke admits that such a representation is difficult because it has no perceptual counterpart, but some have declared flatly that such a representation is impossible.

The most influential spokesman for the opposite point of view was George Berkeley (1710) who caricatured Locke's position:

If any man has the faculty of framing in his mind such an idea of a triangle as is here described, it is in vain to pretend to dispute him out of it, nor would I go about it. All I desire is, that the reader would fully and certainly inform himself whether he has such an idea or no...What is more easy than for anyone to look a little into his own thoughts, and there try whether he has, or can attain to have, an idea that shall correspond with the description that is here given of the general idea of a triangle, which is, neither oblique, nor rectangle, equilateral, equicrural, nor scalaron, but all and none of these at once? (Introduction, 13)

Berkeley subscribes to the position that Locke's image is an abstract image having the quality of triangleness. However, another interpretation is that of a composite image or a series of images of triangles, either whole or in part, that share common features for he describes "an idea wherein some parts of several different and inconsistent ideas are put together." In such an image the common elements might be highlighted and the elements peculiar to each triangle ignored.
In this manner an image of the common elements of several images could yield abstractions or generalizations.

However one might interpret Locke's abstract image, it is still unavailable to Berkeley:

> Whether others have this wonderful faculty of abstracting their ideas, they best can tell: for myself I find indeed I have a faculty of imagining, or representing to myself the ideas of those particular things I have perceived and of variously compounding and dividing them. I can imagine a man with two heads or the upper parts of a man joined to the body of a horse. I can consider the hand, the eye, the nose, each leg by itself abstracted or separated from the rest of the body. But then whatever hand or eye I imagine, it must have some particular shape and colour. Likewise the idea of man that I frame to myself, must be either of a white, or a black, or a tawney, a straight, or a crooked, a tall, or a low, or a middle-sized man. I cannot by any effort of thought conceive the abstract idea above described. (Introduction, 10)

Berkeley's position is exactly opposite Locke's. It is the position that visual mental images are capable of encoding only concrete information. In Berkeley's mind there could be an image of a dog and an image of a cat but not an image of an animal in the general sense.

One more quote, this time from Titchener, will serve to illustrate how sharply drawn is the issue. Titchener accepts Locke's position that images can be constructed to represent abstractions.
My own picture of the triangle, the image that means triangle to me, is usually a fairly definite outline of the little triangular figure that stands for the word "triangle" in the geometries. But I can quite well get Locke's picture, the triangle that is no triangle and all triangles at one and the same time. It is a flashy thing, come and gone from moment to moment; it hints two or three red angles, with the red lines deepening into black, seen on a dark green ground. It is not there long enough for me to say whether the angles joining to form the complete figure, or even whether all three of the necessary angles are given. Nevertheless, it means triangle; it is Locke's general idea of triangle; it is Hamilton's palpable absurdity made real. (1909, pp 17-18)

It is apparent that some feel that abstract images can be constructed and others feel that they cannot. There is no question but that visual images are universal. The question is whether they are only concrete in content or also abstract. The other question concerning the form of an abstract image probably can never be answered because our language is inadequate to describe such events. Titchener seems to have been more successful than Locke but even Titchener's rich description fell short at the end.

Individuals who cannot construct abstract images can be expected to perform most abstract operations in the verbal mode. For these individuals the visual mode is very likely specialized for visual memory. Individuals who can construct abstract images are able to perform abstract operations in both modes. This is the same interpretation that was given to the factor structures of non-transposers and transposers, respectively. The conclusion derived from this interpretation is that the locus of the individual differences that yield either relational responses or absolute responses is at the associative level of the
imagery mode. That is, non-transposers cannot or do not construct images to represent abstract information. Transposers in contrast do represent abstract information in the imagery mode as well as in the verbal mode.

Summary

Two distinct populations of subjects were found to have been sampled in this experiment. The two populations differed in the type of response that was learned. Subjects from one population learned an absolute response in a transposition experiment while subjects from the other population learned a relational response.

The general hypothesis that relational learning is mediated by a mental image was found to be untenable. Instead, the results indicate that two representational systems mediated the learning. Information about a particular stimulus configuration was encoded in memory in both verbal and imagery modes. Subjects accessed the information in the modality that was cued by the format of the test stimuli; when figures were presented, subjects accessed the imagery-encoded information; when names were presented, subjects accessed the verbally-encoded information.

According to the dual code theory, each representational system places different constraints upon the encoding of the information. These constraints were found to have different consequences for behavior so that the representational systems were distinguishable. Moreover, the resultant differences in behavior suggested that an explanation based on imagery and verbal representational systems was to be preferred to an explanation based on a propositional representational system.

The other general hypothesis that individual differences in learning stimulus relations were related to individual differences in the structure of internal
representations was confirmed. Different patterns of intercorrelations among cognitive tests were distinguishable for transposers and non-transposers. The major difference can be interpreted in terms of the associative operations that can be carried out in the two representational modes. It is hypothesized that non-transposers performed most, if not all associative operations in the verbal mode, whereas transposers performed associative operations in both modes. This interpretation has far-reaching consequences because it is directly relevant to a knotty problem that has confounded and continues to confound our understanding of how we form ideas. Specifically, it is the question of whether or not we can have abstract images. The answer appears to be that some people can and some people cannot.
X. CONCLUSION

During learning information is encoded in at least two formats or representational systems—a mental image and a verbal structure. The organization of information in storage is different for each of the two structures both within an individual and between individuals. The consequence of the differences in organization is that different learning outcomes may result even under uniform antecedent conditions. The importance of this cannot be overstated. It is asserted that internal states do have a functional role in behavior in contradiction to the pronouncements of psychologists of a previous era. Explanations of behavior that rely on analyses of antecedent conditions and reinforcement contingencies while ignoring memory structures and internal representations will be unsuccessful.

Nothing could be clearer than the case of transposition research. An accumulation of studies which have neglected internal constructs have revealed little about the nature of transfer or generalization. But what, in fact, is being generalized in the transposition experiments? Certainly not the stimuli. Rather, it is the idea or representations of the stimuli that are generalized. Consequently, to understand the process of generalization, it is necessary to consider the development and organization of the internal representations of the stimuli.

To return to the original question in this experiment, we can ask: "What mediates the learning of stimulus relations?" The conclusion from the data is that both a visual mental image and a verbal process mediate the learning. But because of the nature of the stimuli and the nature of the presentation, the visual mental image is the more important of the two in transposition. For without the ability to construct abstract visual images, generalization of visual stimuli does
not occur. To be more precise, the generalization of the idea of a visual stimulus is accomplished through the formation of an abstract visual image.
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APPENDIX B. Stimuli and Order of Presentation

Stimuli used in the training phase in the one problem condition. Positions of the stimuli alternated randomly. These stimuli are from the narrow range set.

Problem 1.

Stimuli used in the training phase in the two problem condition. Both the problem and the positions within each problem alternated randomly.

Problem 2.
Figural stimuli used in the test phase. Positions of the stimuli alternated randomly. Trigrams below each figure indicate the corresponding stimulus sets in the names condition.

Step 1. Ordinal position distance 0.

QOH  XUS  NIJ

Step 2. Ordinal position distance 0.

XUS  NIJ  GYX

Step 3. Ordinal position distance 0.

NIJ  GYX  PYB

QOH

NIJ

PYB

Step 5. Ordinal position distance 2.

YAV

XUS

PYB
Stimuli used in the transposition experiment shown in actual size. Top row displays the wide range stimuli and bottom row displays the narrow range stimuli. Names are listed beneath each stimulus.
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